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The Threat to Our Food Supply

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The Evolution of **HOUSE CATS**
page 68

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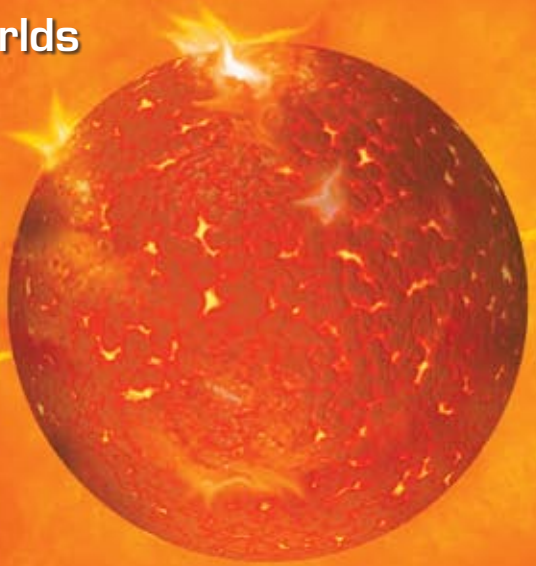
Unlikely Suns, Improbable Planets

Astronomers find new worlds around surprisingly small stars



Silent Mutations

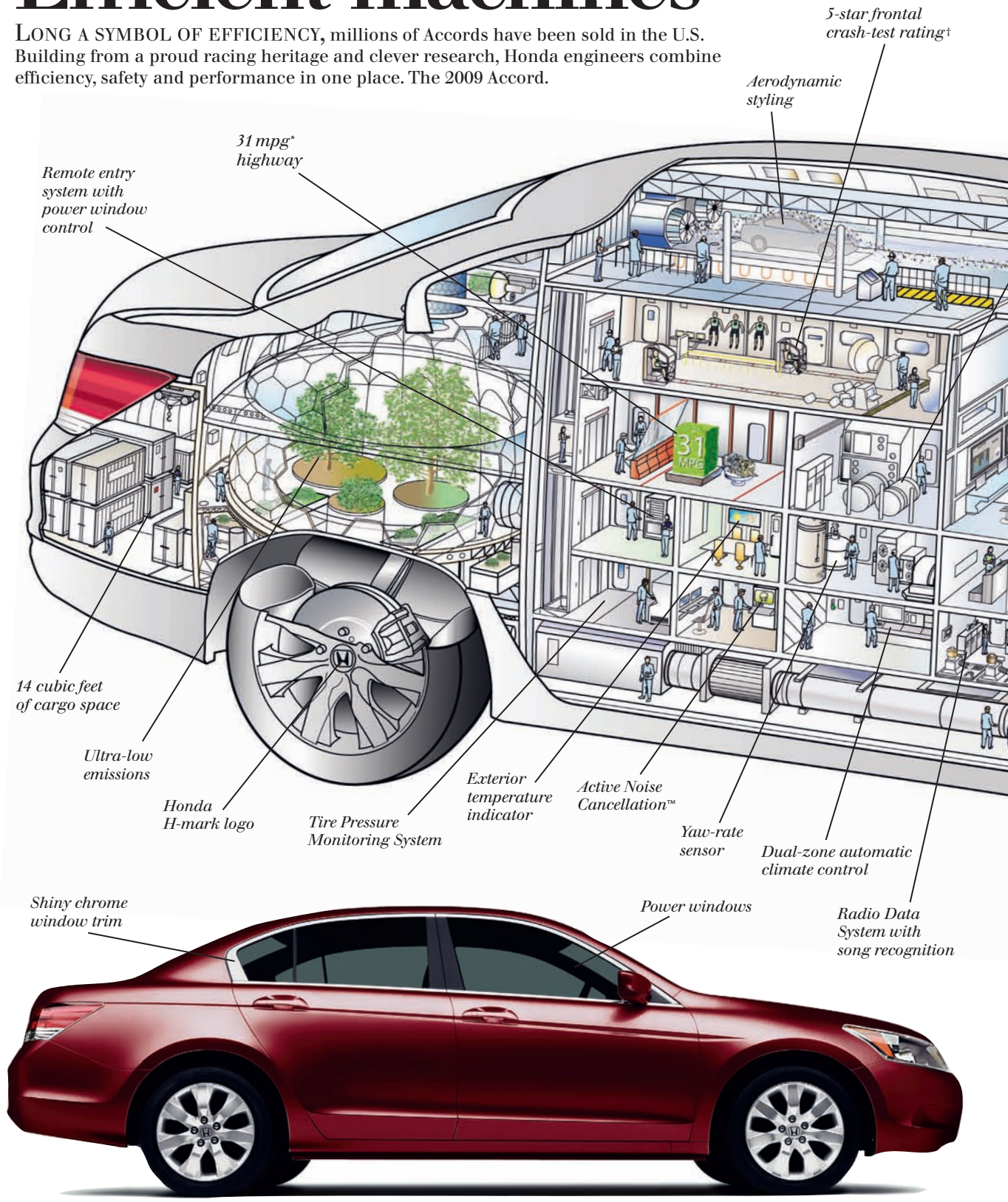
Seemingly Trivial DNA Changes Can Hurt Health

Racetrack Memory

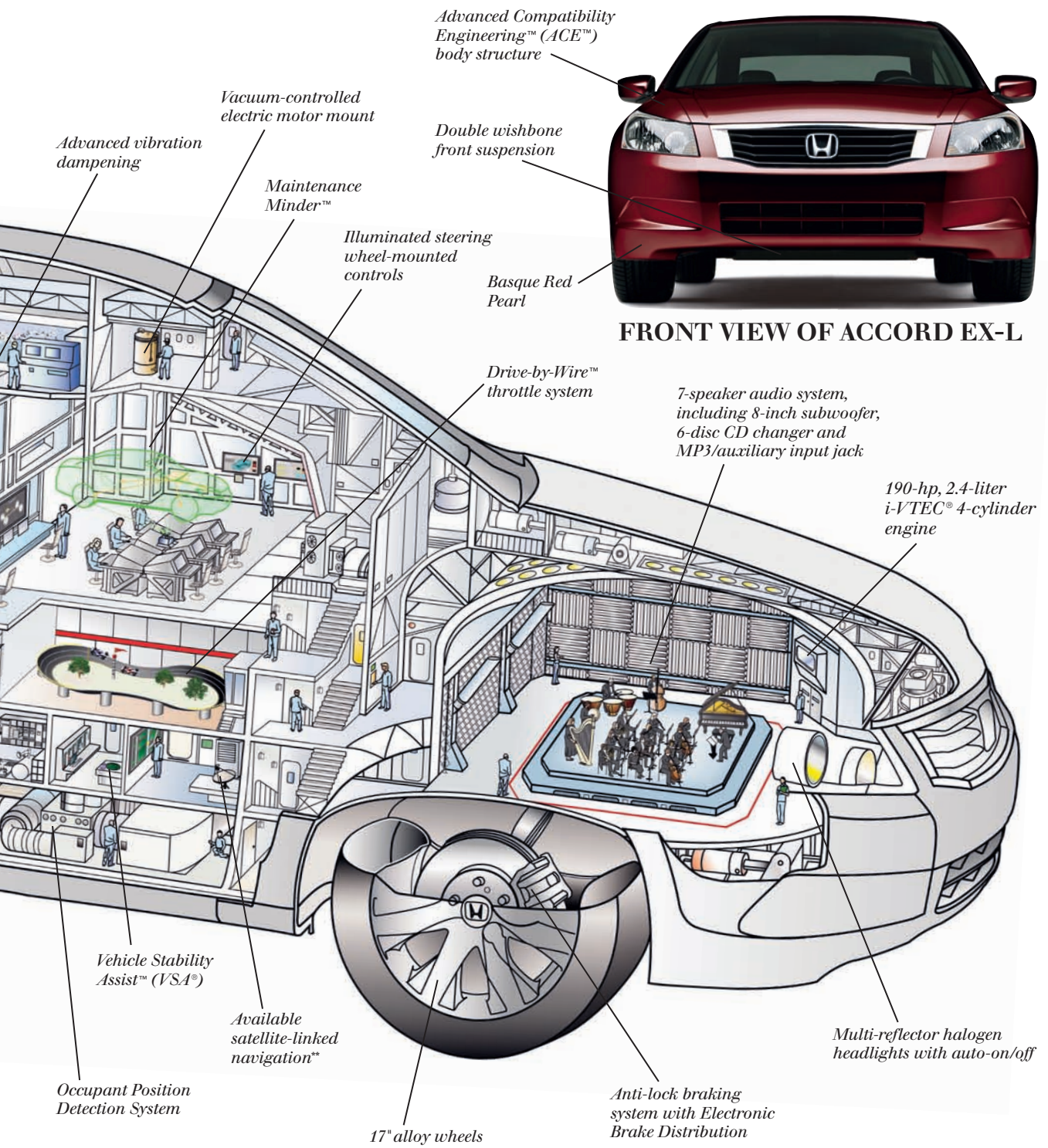
Zooming Magnetic Bits for 3-D Data Storage

Efficient machines

LONG A SYMBOL OF EFFICIENCY, millions of Accords have been sold in the U.S. Building from a proud racing heritage and clever research, Honda engineers combine efficiency, safety and performance in one place. The 2009 Accord.



SIDE VIEW OF ACCORD EX-L



FRONT VIEW OF ACCORD EX-L

It's all we know, all in one place. The 31-mpg* Accord.

*EPA-estimated hwy mpg based on 4-cylinder, 5-speed manual transmission. Use for comparison purposes only. Actual mileage will vary. EX-L Sedan model shown. †Based on 5-star frontal crash ratings. Government star ratings are part of the National Highway Traffic Safety Administration's (NHTSA's) New Car Assessment Program (www.safercar.gov). **The Honda Satellite-Linked Navigation System™ is available on EX-L models in the U.S., except Alaska. See your Honda dealer for details.* honda.com 1-800-33-Honda

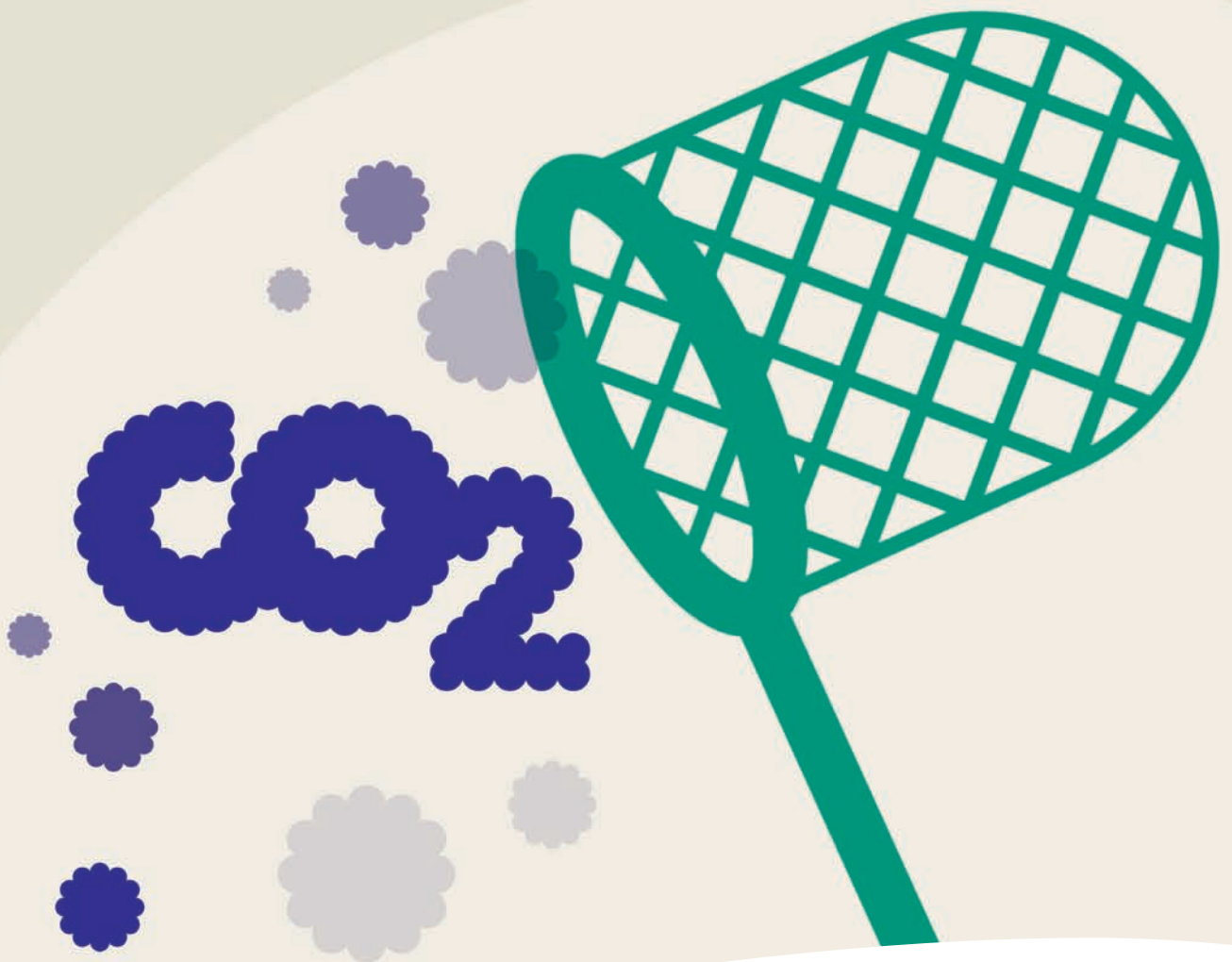
IN THE NEW ENERGY FUTURE WE'LL NEED TO THINK THE IMPOSSIBLE IS POSSIBLE.

The world needs to tackle CO_2 emissions. Carbon Capture and Storage (CCS) technology aims to capture CO_2 and store it safely underground.

At Shell, we're working on several different projects around the world, including CO_2SINK in Ketzin, Germany, a demonstration facility that is operated in collaboration with the European Union.

Perfecting CCS won't be easy, but we believe it is needed to tackle CO_2 emissions.

To find out how Shell is helping prepare for the new energy future visit **www.shell.com/us/realenergy**



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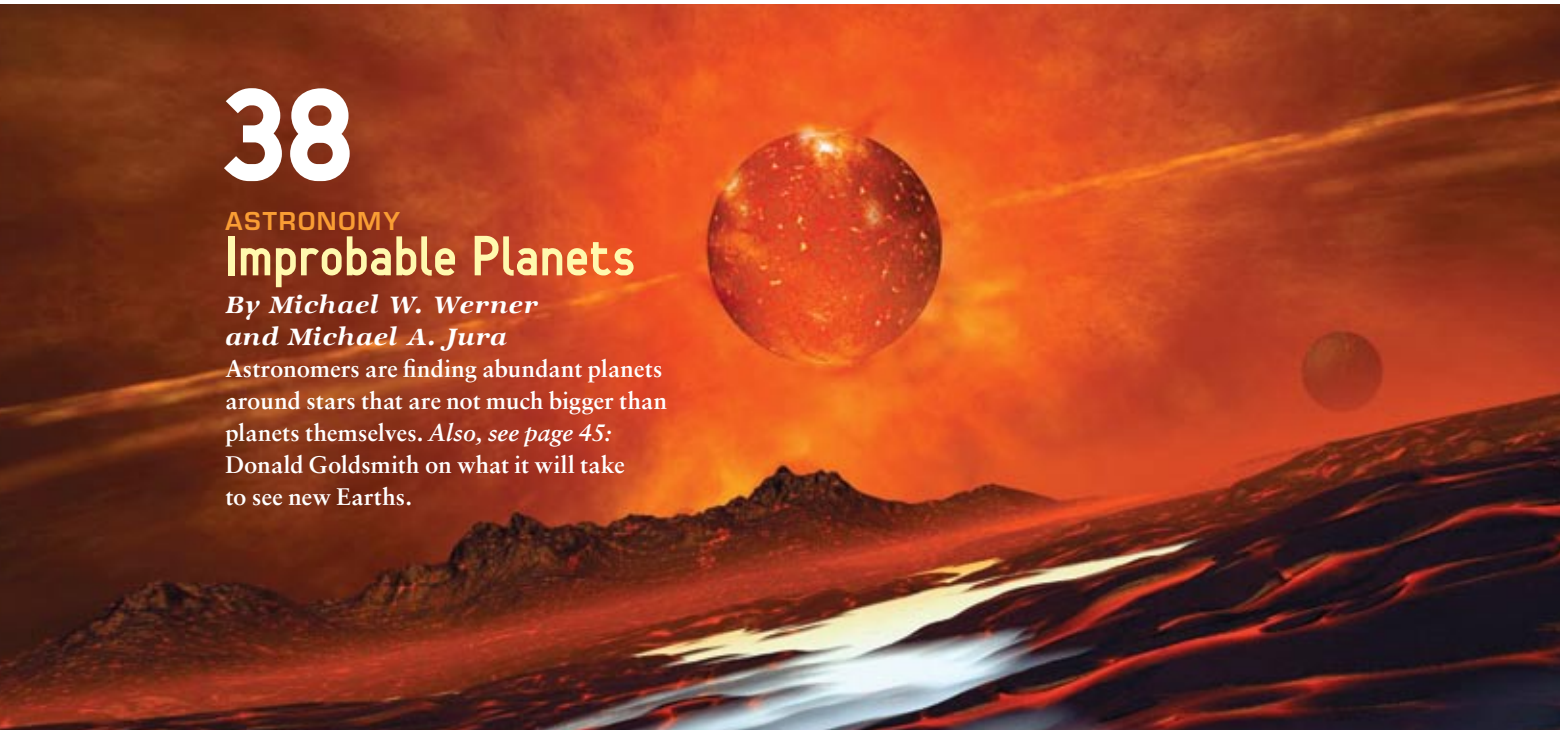
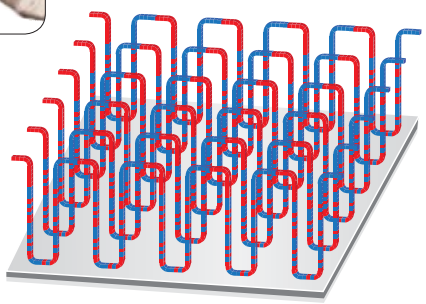


ON THE COVER

A brown dwarf star glows dully in the sky of one of its orbiting planets, as imagined by artist Phil Saunders of Space Channel Ltd. Astronomers long dismissed the idea of planetary systems around such small stars as unlikely.

CAT ON COVER: GK AND VIKKI HART *Getty Images*

MORE FEATURES



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From human growth hormone to collagen stimulators, we examine the tactics employed to enhance beauty and stave off the ravages of aging.

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Slide Show

Five Ways Science Is Trying to Keep Your Food Safe

In the wake of salmonella outbreaks, scientists are developing technologies that could protect against future threats.

60-Second Science Blog

PCs Idling Overnight Waste Billions in Energy Costs

Because nearly half of U.S. workers leave their computers running overnight, offices rack up an extra $2.8 billion annually in wasteful electricity bills, according to one tally.

News

The First Meteorites Recovered from a Tracked Asteroid

Fragments in the Sudanese desert complete an "asteroid trifecta"—discovery in space, prediction of the impact site and recovery of fragments.

60-Second Science Podcast

Caffeine Cuts Workout Pain

New research suggests that caffeine, by keeping you from feeling the burn, can help you get more bang for your workout buck.

Slide Show

The Hidden Face of Nefertiti

The famous carved bust of the ancient Egyptian queen has held many secrets. Now researchers are applying computed tomography to bring them to light.

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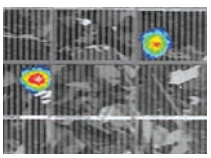
Helping to make better photovoltaic cells—to extract more power from the sun...

In the lower image above, a highly sensitive Hamamatsu CCD camera captures the electro-luminescence emitted from a polycrystalline photovoltaic module.

Reducing defects, boosting performance

Makers of photovoltaic (PV) cells, the units that make up solar panels, were looking for ways to help them perform better—more *efficiently*...

So, Hamamatsu began developing whole new systems to more precisely identify problems and assess PV performance.



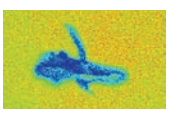
Highly-sensitive infrared detectors spot failure points in this silicon PV module.

One type of system uses very sensitive CCD cameras to capture electro-luminescence from PV cells or modules—to generate two-dimensional maps of their performance efficiency.

Other Hamamatsu systems identify failure sites by capturing low-level light emissions from PV cells and superimposing those emission images with microscopic images. Which precisely reveals defects, cracks, leaks and more.

Hamamatsu is opening the new frontiers of Light

Still other systems employ high-sensitivity infrared detectors to analyze the temperature profiles of solar cells—to spot wiring shorts and other failure points that are indicated by temperature.



Micro inspection of electro-luminescence revealed this micro-scopic foreign material.

The goal: a new generation of higher-performance, higher-efficiency, longer-life solar panels, to better serve the need for green power around the globe.

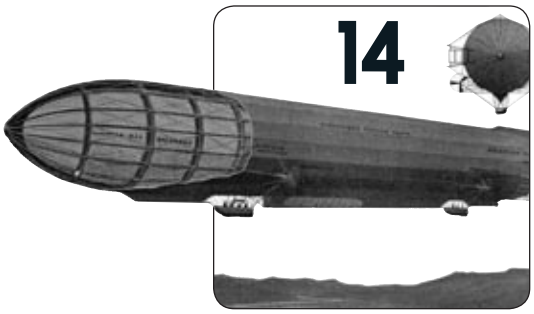
Solar power: it's one more industry in which Hamamatsu is applying its knowledge of light to help make our world a better place to live.

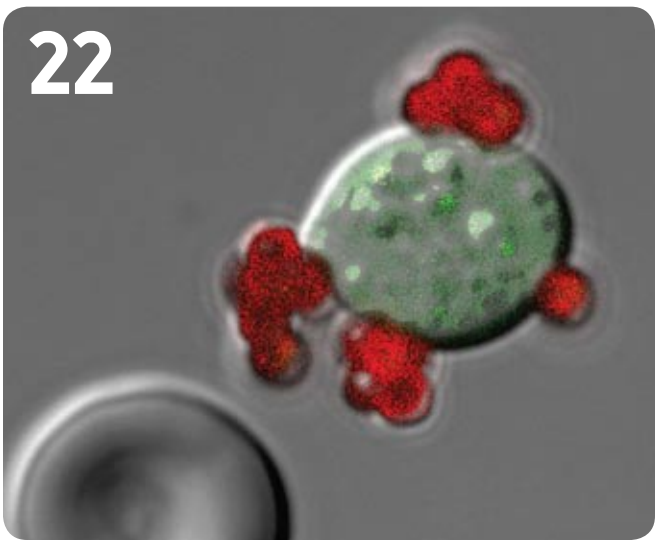
http://jp.hamamatsu.com/en/rd/publication/

HAMAMATSU

Photon is Our Business

DEPARTMENTS





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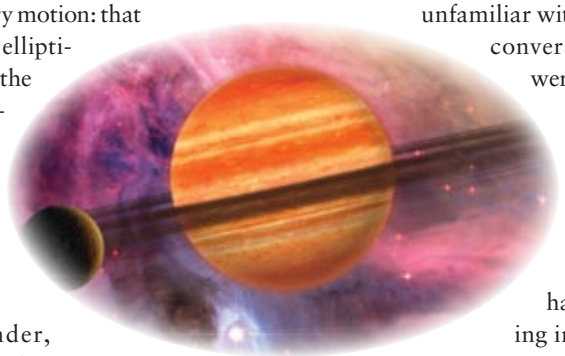
Inspirational Orbits

Astronomers are finding new planets; humanitarians are improving this one

The year 1609 was noteworthy for two astronomical milestones. That was when Galileo built his first telescopes and began his meticulous study of the skies. Within months he discovered the four major satellites of Jupiter, saw that Venus (like our moon) has illuminated phases and confirmed earlier observations of sunspots—all evidence that undermined the Aristotelian model of an unchanging, Earth-centered cosmos.

During that same year, Johannes Kepler published *Astronomia Nova,* which contained his detailed calculation of the orbit of Mars. It also established the first two laws of planetary motion: that planets follow elliptical orbits, with the sun at one focus, and that planets sweep through equal areas of their orbits in a given interval.



NEW WORLDS await around the stars least likely to be suns.

Small wonder, then, that when the United Nations General Assembly declared an International Year of Astronomy to promote the wider appreciation of the science, it selected 2009, the quadricentennial of those standout accomplishments (among many) by Galileo and Kepler that informally founded modern astronomy.

Currently astronomers can look beyond the familiar planets and moons to entirely new systems of worlds around other stars. As I write this, the tally stands at 344 known extrasolar planets. Only a handful of these bodies were found by telescopic means that Galileo or Kepler would have recognized, but each one owes its discovery to their work.

A recent and surprising trend is the apparent abundance of planets turning up close to very small stars—suns that may not be much larger than the planets circling them. Astronomers Michael W. Werner and Michael A. Jura have more in their article starting on page 38, including why the existence of these unlikely planetary systems might imply that the universe is chockfull of planets.

This year also marks the 50th anniversary of the famous "Two Cultures" lecture by C. P. Snow, the English physicist and novelist. Snow's speech, and his later books that elaborated on it, argued that communication and respect between the sciences and humanities had broken down. Literary intellectuals, he said, were often nonplussed at their own ignorance of basic science and yet would be aghast at a scientist unfamiliar with Shakespeare; conversely, scientists were more likely to have some schooling in the arts. This asymmetrical hostility hurt society, Snow maintained, because it impeded the embrace of what science and technology could do to eliminate poverty and inequality.

Even today critics disagree about whether Snow's thesis is better seen as controversial or clichéd. If the "two cultures" is a problem, however, some leaders—not just in science but also industry, government and nongovernmental organizations—are overcoming it spectacularly. They are doing what they can to ensure that the fruits of scientific knowledge are constructively applied to improve well-being and prosperity. This month, with our SCIENTIFIC AMERICAN 10 honor roll, we are proud to recognize a few of them. ■

JOHN RENNIE
editor in chief

FLYNN LARSEN (*Rennie*); RON MILLER (*planets and stars*)

Among Our Contributors

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STUART S. P. PARKIN
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DAVID A. VACCARI
directs the department of civil, environmental and ocean engineering at the Stevens Institute of Technology and has worked with NASA on systems for manned space missions.

MICHAEL W. WERNER
is project scientist for NASA's Spitzer Space Telescope and chief scientist for astronomy and physics at the NASA/Caltech Jet Propulsion Laboratory.

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Naked Singularities ▪ Serious Games ▪ Beef Production

FEBRUARY 2009

"Game designers are increasingly aware of games' power to influence neural pathway formation."
—*Noah Falstein* GREENBRAE, CALIF.

End without Horizons?

In "Naked Singularities," Pankaj S. Joshi argues that models for stellar collapse can produce naked singularities, or singularities without the event horizon that surrounds a black hole. According to quantum theory, black holes emit thermal radiation and evaporate because of the separation of particle-antiparticle pairs near their event horizon. Will a naked singularity ever disappear?

Daniel Chamudot
Riverdale, N.Y.

If an event horizon has an extreme but finite spacetime curvature and gravity, and in a singularity these are infinite, how can there be any path between a low-gravity and curvature region and a singularity without passing through a horizon?

Lloyd Anderson
Villa Park, Ill.

JOSHI REPLIES: *Regarding Chamudot's question, the event horizon is a crucial factor in the evaporation of a black hole through quantum effects, but in a naked singularity case, it is still possible for the event horizon to disappear or evaporate through quantum or classical processes. The effects of quantum gravity, for example, could generate a huge negative pressure, causing the star to emit most of its mass in late collapse stages. Further, classical processes such as powerful shock formations caused by inhomogeneities in matter densities near the naked singularity could cause it to explode.*

With respect to Anderson's letter, it is not just the local density or curvature values that determine the behavior of light paths in general relativity. Aspects such as the causal structure of spacetime and the global properties of light cones are crucial factors. These factors arise mainly as a result of the nonlinearity of Einsteinian equations, and detailed studies of collapse models imply that gravity can be arbitrarily large and dense in a stellar collapse but still not inescapable. Large density or curvature values do not necessarily mean an event horizon is present.

In Newtonian gravity, density is the sole parameter that determines the behavior of a gravitational field. But in general relativity, there are 10 gravitational metric potentials, and these elements can and do give rise to many novel features for gravity and its interactions in the universe.

Gaming the Neural System

In "Childhood Recovered" [News Scan], Gary Stix notes that adult amblyopia patients have achieved substantial improvements after video game–like exercises. He states that "Grand Theft Auto IV or Medal of Honor may retrain the brain in ways its developers never imagined."

I found this assertion personally ironic: I was the initial designer and executive producer on the Normandy Beach game that later became the first Medal of Honor and am now working primarily in games that have a function beyond entertainment. Designers are increasingly aware of games' power to influence neural pathway formation and have designed programs to build cognitive reserve through brain training, to treat attention-deficit hyperactivity disorder and to help patients with Parkinson's disease. We may not have thought of those

applications years ago, but we are learning to rewire our brains to do so now!

Noah Falstein
Greenbrae, Calif.

Cows and Carbon

"The Greenhouse Hamburger," by Nathan Fiala, argues that beef production is a major cause of global warming. But the data and articles Fiala cites assume that the total amount of beef produced is all grown in concentrated animal feeding operations (CAFOs). In my beef operation, cows never eat or see a pound of harvested grain. They spend their lives (average of 10 years) eating grass from native pastureland. I am not the exception; all my neighbors raise their cattle the same way.

William Fogarty
Oakdale, Calif.

AVERAGE AMERICAN'S annual beef diet emits as much greenhouse gas as a car driven more than 1,800 miles.

ANDY POTTS

FIALA REPLIES: *My numbers assume that all cow production occurs in CAFOs for two reasons. First, CAFOs produce most of the beef consumed in the U.S. The total percentage of CAFO cows is unclear, but in testimony given to the House Judiciary Committee in 2000, the U.S. National Farmers Union's then president Leland Swenson claimed that four companies produce 81 percent of cows in the country. Companies of such size can only be using the CAFO system, which creates large quantities of beef cheaply. More environmentally friendly production systems will never yield enough food for Americans to eat the current amount of beef, almost 100 pounds a year per person.*

Second, to meet the demand for increased consumption worldwide, CAFOs are the fastest-growing production method in developing countries, and they most likely are the future of beef production for everyone around the globe.

Also, focusing on CAFOs in many ways actually underestimates cows' impact. Multiplication of my CAFO figures shows that assuming all animals are grown in CAFOs produces aggregate carbon dioxide (CO_2) numbers that are at least one half to one third as large as those from the Food and Agriculture Organization, which found that livestock contribute about 18 percent of world greenhouse emissions.

Pastoral systems can sometimes be responsible for producing more CO_2 than CAFOs, mainly because many communities, mostly in Latin America, require deforestation for pastoral land. And CAFO cows live only about one year before slaughter. In the July 1999 Ecological Economics, Susan Subak did find that a good pastoral system generates just more than half the CO_2 of a feedlot, but she assumed that the pastoral animals live for just less than three years. If the animals are allowed to live more than three times as long, the difference narrows considerably.

My work is not intended to convert people to vegetarianism, only to help them understand how consumption choices can have major effects on the environment. Given the incredible quantities of meat Americans and others eat, even a small decrease in beef consumption (to, say, three or four times a week) can have a big impact.

Car Crash

In discussing the woes of the U.S. auto industry in "Transforming the Auto Industry" [Sustainable Developments], Jeffrey Sachs misses the essential failing that has led to decline of its long-term market share and sales volume: mediocre cars.

Having worked in the industry in the 1970s and having followed it since then, I observed at least 15 years go by before U.S. auto executives acknowledged their products' quality deficiencies. They have been playing catch-up since then. American vehicles have been improving, but they still lag. For the U.S. auto industry to truly succeed, management needs a paradigm shift that will result in the best vehicles in their class by any measurement.

Rick Robins
Grass Valley, Calif.

Letters to the Editor

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Refresh your science spirit with the vitality of intelligent conversation, the balance of conceptual and practical, and the energy of striving towards new horizons. Join Scientific American on Bright Horizons 6 cruise conference on Holland America's Eurodam, December 5–12, 2009. Expert knowledge, lush Caribbean islands, recreation and reflection await you.

Update your cosmology knowledge with Dr. Lawrence Krauss, as he analyzes which cosmology ideas and theories are holding up over time, which have changed, and which suggest the future form of the universe. Tune in to astronaut Dr. Guy Bluford and learn first hand about Space Shuttle and International Space Station missions. Rendezvous with Dr. Jim Bell and make a deep impact on your knowledge of Near Earth Asteroids and planetary geology. Think green and dig in to a hot topic with Dr. David Blackwell, geothermal energy maven. Sit with immunologist Dr. Noah Isakov and get the latest thinking in allergy, immunobiology, and the origins of cancer.

Take home keys to understanding pressing topics in green energy, medicine, and space science. Savor the moment with a friend on an uncrowded Grand Turk beach or a Virgin Islands rainforest hike. Get all the details at InSightCruises.com/SciAm-6, or call Neil at (650) 787-5665 and effortlessly arrange to stimulate your brain with Scientific American Travel!

Bright Horizons #2 [December 2008] is proof of what value was added by your planning for our pleasure. Organization is not our greatest talent. We have been on three previous cruises, but the package you provided is by far the best. Bright Horizons #2 was a delightfully totally new experience. We were never bored! As a retired Professor of Astrophysics, I was thrilled to be able to learn of the latest results in Cosmology. All the lectures were great and your choice of speakers and subjects is to be praised. At this time we cannot commit to another major excursion, but we can assure you that InSightCruises.com has moved to the head of our list.

Thank you!!!
Larry & Kathlyn Auer

PLUS . . . join Lawrence Krauss, Ph.D. author, *The Physics of Star Trek*, for an informal Q&A.

ASTROPHYSICS & COSMOLOGY

Einstein's Biggest Blunder — A Cosmic Mystery Story

Speaker: **Lawrence Krauss, Ph.D.**

Recent discoveries have implications for our understanding both of the future of our universe and life within it and for our understanding of fundamental physics. Join Dr. Krauss as he covers the fate of the Milky Way, what lies beyond the event horizon, and cosmic phenomena of the next 100 billion years.

The Undiscovered Country

We humans have undoubtedly questioned the origins of the cosmos for as long as we've walked the Earth but we've made spectacular progress in recent years. This progress forces us to discard much of what cosmology textbooks told us up until quite recently. Get the latest on competing ideas, their implications, and how they can be experimentally tested.

An Atom From Boston

Standing somewhere between natural history and biography, Dr. Krauss lays out the life history of an single atom from the beginning of the universe to the end. Life is a journey, and this atom's journey runs from nuclear physics to chemistry to cosmology, with passages through geology and biology along the way. Whether you are an atom afficianado, or more a "universe in a grain of sand" type, sit with Dr. Krauss for a refreshing look at an atom.

IMMUNOLOGY

The Many Facets of the Allergic Responses

Speaker: **Noah Isakov, Ph.D.**

Many faceted if not many splendored, allergic phenomena have increased in prevalence over the past several decades. Join Dr. Isakov for the latest thought on:

- Allergens, asthma and other types of immune-mediated responses
- Effector mechanisms in allergic responses
- Approaches for prevention and treatment of allergy

Immune Mediated Responses: A Double-Edged Sword

While scientific speculation about the immune system dates back to the Plague of Athens in 430BCE, the discipline of immunobiology defined itself in the 19th and 20th centuries. Refresh your picture of the immune system with Dr. Isakov, starting with discussions of:

- Introduction to immunobiology
- Basic concepts of the immune system
- Failure of host defense mechanisms

Monoclonal Antibodies and Cancer Immunotherapy

Take a look under the hood of contemporary immunotherapy. From molecular biology to medicine, monoclonal antibodies are a valuable part of the scientist's toolkit. From his view deep in the trenches of immunobiology, Dr. Isakov will offer:

- An overview of antibody molecules
- A guide to the production of monoclonal antibodies with specificity against a predetermined pathogen
- The scoop on monoclonal antibody use in research, diagnosis, and therapy

Understanding the Roots of Cancer

Dr. Isakov will orient you to the evolving views of the genesis of cancer. Internal and external factors, oncogenes, tumor suppressor genes, cell transformation, immunosurveillance, immunoediting, and immunotherapy are all part of the mix. Learn:

- What causes normal cells to become cancerous
- How cancer cells from a primary tumor form metastases in remote organs
- Immune-mediated approaches for the treatment of cancer diseases

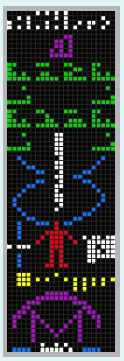
ARECIBO OBSERVATORY: A BEHIND-THE-SCENES TOUR

Explore the contributions and potential of radio astronomy at the celebrated Arecibo Observatory. Get an unparalleled behind-the-scenes tour of the iconic facility, and absorb an in-depth look at the unique contributions derived from Arecibo research and development.

Join us as we wind through the rainforest-blanketed karst terrain of Northern Puerto Rico. We'll get a sense of the massive physical scope of the Arecibo radio telescope. We'll boldly go where ordinary visitors are not permitted. NAIC scientists will update us about the radio astronomy, planetary radar discoveries, and climatology research at the observatory. From the monitoring of near-earth objects to cosmology, astrophysics, and global warming research, you'll gain insight into the vital activities at Arecibo.

Optional eight-hour tour includes transportation, entrance fees, and a private luncheon at the Arecibo Observatory ($175).

Transmission of the Arecibo message to star cluster M13 in 1974 marked the remodeling of the telescope we'll be visiting. The 73 row by 23 column message depicts numbers, aspects of DNA, graphic depictions of humans, the solar system, and the Arecibo telescope.



Photograph Courtesy of the NAIC–Arecibo Observatory, a facility of the NSF

I thoroughly enjoyed the Bright Horizons #2 cruise and must confess that the content of the cruise and the speakers far exceeded my expectations. Of the 26 excellent lectures, and I didn't miss a single one, I found each one equally as challenging and informative as the next. You and Randal did a magnificent job of attending to every detail and I only heard compliments of the highest order from every guest. I hope to join you on a future event cruise, so please keep me on your email list.

Perry Walton

Cruise prices vary from $799 for an Inside to $2,999 for a Full Suite, per person. (Cruise pricing is subject to change.) For those attending the conference, there is a $1,375 fee. Taxes and gratuities are approximately $150.

GEOLOGY

Geology and Plate Tectonics of Europe

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

Take a guided tour of the European area of the vast Eurasian tectonic plate. From topology to geology to tectonics, you'll get a picture of the forces that created Europe, and continue to shape it today.

Basins, plains, volcanoes, and mountain ranges have stories to tell. Survey the terrain with Dr. Blackwell.

Future of Energy — Geothermal as a Major Player

Any time zettajoules (10 superscript 21) enter the conversation about alternative energies, you know the potential for the resource is great. Dr. Blackwell will lay out the factors in play in a look at the practical future of geothermal energy. Raw and practical potential, inventory of accessible enery, environmental impact, and competitive position are some of the facets in the discussion. Geothermal economics are on the agenda, too: Short and long term investment and implications, direct and indirect costs, and domestic and imported sources.

Plate Tectonics

Glide into an updated understanding of plate tectonics. Join Dr. Blackwell for a discussion of the development of the theory, its key principles, and its consequences. You'll learn about physical properties of the dynamic lithosphere, athenosphere, and mantle layers versus chemical layers of the earth, driving forces of plate movement, and the relationship of plate boundaries to geological events such as earthquakes and the creation of topographic features like mountains, volcanoes, and oceanic trenches.

Intro to Geothermal Energy

Get in on the ground floor of geothermal energy. Dr. Blackwell will cover the natural foundations of this alternative energy resource. You'll deepen your understanding of the origin of the earth's heat, the role of plate boundaries, spreading centers and hot spots, mechanisms of tapping geothermal, and the risks and benefits, advantages, and disadvantages of tapping this resource.

We have just returned from the Bright Horizons #2 cruise and want to commend you and your staff for putting together an absolutely first rate combination of cruise line, destinations, program and speakers. We were particularly impressed with Max Tegmark, both as a lecturer and as a person. Please convey our gratitude to all the speakers.

Thanks again for a perfect cruise.
Let us know what else you are planning.

Dick and Elizabeth Santoro

THE SPACE PROGRAM

The Future of the Space Program

Speaker: **Guion S. Bluford, Jr., Ph.D.**

Travel back to the future with an indepth discussion on the future of the NASA Space Program. Dr. Bluford will address the issues and opportunities ahead as space exploration matures. You'll get the big picture of the Constellation Program (with its Aries, Orion, and Altair components) which will return humans to the moon and later take them to Mars. Come away with the insights and views on what lies ahead from Dr. Bluford, astronaut and aeronautical engineer.

The International Space Station

Join Dr. Bluford for a comprehensive survey of the International Space Station (ISS) Program. He will orient us to the history and complexities of this permanent human presence in space. From project inception to launch to ongoing development and daily living, pick up a new understanding of the logistics, function, and significance of the ISS.

An Evening with Shuttle Astronaut Dr. Bluford

How has aeronautics affected society and vice versa? Having worked in space, what open questions does Dr. Bluford have about space exploration, and space? What are the core characteristics and qualities shared by astronauts i.e., what is "the right stuff"? Dr. Bluford will present food for thought arising from his experience in space (688 hours), in jet cockpits (5,200 hours), and in the field of aeronautical engineering. We'll have an out-of-this-world round of astronaut Q&A, too!

The Space Shuttle Program

Countdown to contemporary treasure — a first-hand account of life in space. Dr. Guion Bluford, a veteran of four Space Transportation System (STS) missions (STS 8, STS 61-A, STS 39, and STS 53) will present a look at the Space Shuttle Program, from its inception to the wrap up of its service in 2010. Learn about training for shuttle duty, noteworthy aspects of daily routine in space on the Discovery and Challenger, and gain a behind the scenes look at the science and technology projects executed by Shuttle astronauts.

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PLANETARY SCIENCE & SOLAR SYSTEMS

Postcards from Mars

Speaker: **Jim Bell, Ph.D.**

The NASA Mars Exploration Rovers Spirit and Opportunity landed on the Red Planet in January 2004, and have been driving, photographing, and analyzing their landing sites for the past five years. Prof. Bell has been the lead scientist in charge of the rovers' Panoramic Camera imaging system since the rovers were "born" nearly a decade ago. Come along for an amazing journey of geologic exploration and learn about the ways that both rovers have been utilized to discover convincing evidence that Mars was once warmer, wetter, and much more Earthlike than it is today.

Studying the Solar System in 3-D

Don your red-blue glasses and join planetary imaging expert Prof. Jim Bell on a voyage of 3-D discovery of the solar system. Stereo pictures of Mars, the Moon, Saturn, asteroids, comets, and other places taken by astronauts and robotic space probes provide new details about the geology and history of our planetary neighbors. Learn about the ways that 3-D images are taken, and the ways that they are used by scientists and engineers involved in space exploration. Viewing the solar system in 3-D is the next best thing to being there!

Impact!

The solar system is teeming with millions of asteroids and comets, and occasionally they crash into the planets with catastrophic consequences. Planetary scientist Jim Bell leads a discussion about the science fact and science fiction of the role of such impacts in shaping the geology and biology of our home world. Earth has been hit in the past, with severe consequences for life on our planet. Will Earth be hit again in the future? Almost certainly. Unlike any previous species in history, however, we have the chance to understand the threat ahead of time and, perhaps, to prevent a planetary-scale catastrophe.

Searching for Life in the Solar System and Beyond

Are we alone? The search for habitable environments and for life on other worlds is a major driving force for the exploration of the solar system. Join Prof. Bell as we explore the short list of worlds around us that may once have been (and perhaps still are, in places) habitable: Mars, Jupiter's moon Europa, Saturn's moons Titan and Enceladus, and perhaps other places as well. During the last decade scientists have also discovered an amazing diversity of life on our own planet, thriving in what were once considered hostile conditions. And during the same time, astronomers have discovered hundreds of planets orbiting other Sun-like stars, and some of them may be habitable as well. It's an incredible time to search for life in the solar system and beyond!

Space Food ▪ Zeppelin II ▪ Safe Passage

Compiled by Daniel C. Schlenoff

JUNE 1959

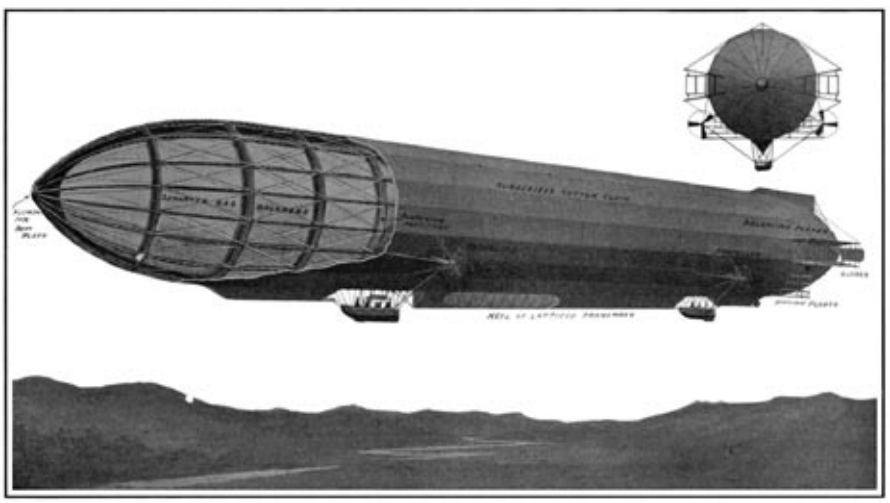
SELF-REPRODUCTION—"The construction of a machine capable of building itself might be judged to be impossible and to belong to the category of perpetual-motion engines. Together with Roger Penrose, I have approached the problem in a radical manner, without the encumbrance of prefabricated units such as wheels and photoelectric cells. Our idea was to design and, if possible, to construct simple units or bricks with such properties that a self-reproducing machine could be built out of them. —L. S. Penrose"

SPACE MENU—"The problems of eating and drinking under weightless conditions in space, long a topic of speculation among science-fiction writers, are now under investigation in a flying laboratory. Preliminary results indicate that space travelers will drink from plastic squeeze bottles and that space cooks will specialize in semiliquid preparations resembling baby food. According to a report in the *Journal of Aviation Medicine*, almost all the volunteers found that drinking from an open container was a frustrating and exceedingly messy process. Under weightless conditions even a slowly lifted glass of water was apt to project an amoeba-like mass of fluid onto the face. Drinking from a straw was hardly more satisfactory. Bubbles of air remained suspended in the weightless water, and the subjects ingested more air than water."

JUNE 1909

WRITERS NEEDED—"Moving pictures are exhibited in about ten thousand theaters and halls in the United States. With the rapid spread of this new amusement has also come a marked change in the public taste. Spectators were once quite content with a view of factory employees going to and from their work, the arrival and departure of railway trains, and similar scenes. Nowadays, a more or less coherent story must be unfolded, for which reason the makers of moving pictures have been compelled to write plays (or at least to conceive them) and to have them acted before the camera."

WAY UP HIGH IN THE SKY—"The illustration which appears below will give the reader an excellent idea of the general construction of the latest Zeppelin airship 'Zeppelin II' [also designated LZ 5], which recently made a record flight of about 900 miles. The airship consists of a trussed aluminium frame having tapered ends, containing 17 separate gas bags filled with hydrogen. The lifting power of the airship is about 16 tons. Plans are on foot for the establishment of a regular airship line between several of the large German cities."



LIGHTER-THAN-AIR FLIGHT: The Zeppelin II, 1909

SNAIL LAW—"The French Minister of Agriculture, after a careful examination of the subject, has established 'the legal status of the snail' by defining snails as animals injurious to vegetation, and therefore legally subject to capture and destruction at all times and seasons. This decision has created dismay among the numerous persons who earn a livelihood by collecting snails for market. Snails are in high favor with French epicures, and immense numbers of these mollusks are eaten in Paris. In the winter of 1900 the consumption of snails in the French capital amounted to some 800 tons."

JUNE 1859

SAFE AND FORGOTTEN—"The benefits arising from constructing vessels with water-tight compartments were fully displayed in the case of the iron screw-steamship, *Edinburgh*, which plies between New York City and Glasgow. On the 6th of June, when 186 miles east of St. Johns, Newfoundland [350 miles north of where the RMS *Titanic* sank 53 years later], she struck an iceberg while in a dense fog, and her forward plates were stoved in by the collision. Being divided into water-tight compartments, two of these at once filled up, but the others floated the vessel for thirty hours, during which period she ran back to St. Johns. Had this vessel not been built in compartments she would have sunk to the bottom in half an hour after she struck."

SCIENTIFIC AMERICAN, VOL. C, NO. 26, JUNE 26, 1909

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Edited by Philip Yam

Revving Up Fuel Cells

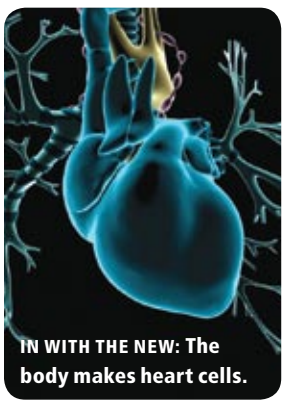
Progress toward hydrogen-powered cars depends on less expensive but greater capacity fuel-cell systems [see "On the Road to Fuel-Cell Cars"; SciAm, March 2005]. Researchers have taken big steps on both the cost and storage challenges. A team from Quebec came up with a recipe that uses iron instead of expensive platinum to catalyze the electricity-making reaction of hydrogen and oxygen. The key was carbon structures containing microscopic pores, which were filled with iron to provide plenty of active sites for chemical reactions. The iron-based substance, described in the April 3 *Science*, produced catalytic activity within 10 percent of the best platinum versions and 35 times better than previous, nonprecious metal catalysts.

POWER SHIFT: New materials may render hydrogen-fueled car engines more feasible.

Pores are also driving the search for materials that can store hydrogen for delivery to fuel cells. A team from the University of Michigan at Ann Arbor says it has made a material that has a record-high surface area for holding gases. This hydrogen sponge consists of zinc oxide clusters linked by an organic material; one gram has the surface area of 5,000 square meters, nearly the size of a football field. Details of the substance, dubbed UMCM-2, appear in the April 1 *Journal of the American Chemical Society*.

New Heart Cells from the Atomic Age

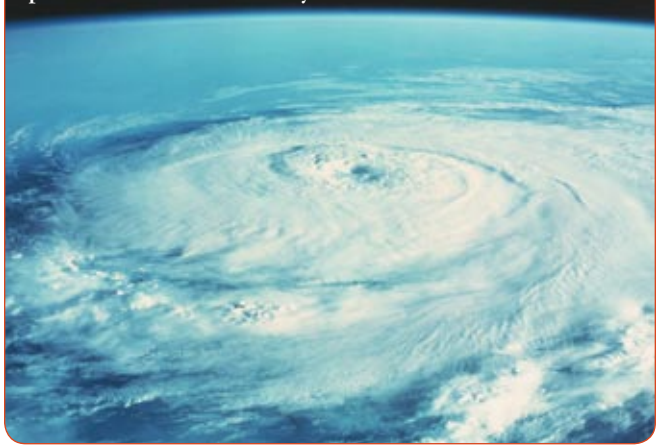
Aboveground nuclear testing in the 1950s spewed radioactive carbon 14 and other isotopes worldwide. Plants soaked up the compounds, animals ate the plants, and humans ate both, inadvertently creating an experimental opportunity for Jonas Frisén of the Karolinska Institute in Stockholm and his colleagues. They have used the decay of atomic age carbon 14 as a biological marker to determine how frequently the body replaces its cells [see "Cold War Clues"; SciAm, December 2005]. With the data, they have settled a long-standing question by showing that humans can indeed produce new heart cells, or cardiomyocytes. The annual turnover rate is 1 percent at age 25, decreasing to 0.45 percent by age 75; all told, about 40 percent of cardiomyocytes are replaced by age 70. The finding, in the April 3 *Science*, suggests that stimulating the turnover mechanism could repair damaged hearts.



IN WITH THE NEW: The body makes heart cells.

Lightning-Fast Warnings

Storms could become more intense as the world warms [see "Warmer Oceans, Stronger Hurricanes"; SciAm, July 2007]. Researchers studying 58 hurricanes found that an increase in lightning tended to precede the strongest winds by a day. For instance, monitors tracking Hurricane Dennis in 2005 recorded a surge in lightning flashes—from 600 a day to 1,500—nearly 24 hours before wind speeds doubled and peaked at 150 miles per hour. The correlation, reported online April 6 in *Nature Geoscience*, needs more data before lightning can be considered a definitive predictor of storm intensity.



Not So Lifesaving

For years researchers have questioned the value of a blood test for prostate cancer, called a PSA test [see "Does Screening for Prostate Cancer Make Sense?"; SciAm, September 1996]. After all, most prostate cancers progress slowly, sometimes never posing a problem, and treatment could cause impotence and incontinence. First results from large, ongoing U.S. and European studies, published in the March 26 *New England Journal of Medicine*, suggest that the PSA test does not save many lives. The U.S. trial found no reduction in death from prostate screening in men followed for about 11 years. The European study, which had different protocols, saw a 20 percent drop in death rates, which translated to seven fewer deaths per 10,000 men screened and tracked for nine years. Expect follow-up work to resolve some of the differences between the two studies.

GETTY IMAGES (*hydrogen fuel cell*); PHOTO RESEARCHERS, INC. (*heart*); GETTY IMAGES (*hurricane*)

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ENVIRONMENT

A Mechanism of Hot Air

A popular carbon-offset scheme may do little to cut emissions BY MADHUSREE MUKERJEE

A convenient way of cutting industrial gases that warm the planet was supposed to be the United Nation's clean development mechanism (CDM). As a provision of the Kyoto Protocol, the CDM enables industrial nations to reduce their greenhouse gas emissions in part by purchasing "carbon offsets" from poorer countries, where green projects are more affordable. The scheme, which issued its first credits in 2005, has already transferred the right to emit an extra 250 million tons of carbon dioxide (CO_2), and that could swell to 2.9 billion tons by 2012. Offsets will "play a more significant role" as emissions targets become tighter, asserts Yvo de Boer of the U.N. Framework Convention on Climate Change.

But criticism of the CDM has been mounting. Despite strenuous efforts by regulators, a significant fraction of the offset credits is fictitious "hot air" manufactured by accounting tricks, critics say. As a result, greenhouse gases are being emitted without compensating reductions elsewhere.

The accounting is rooted in a concept known as additionality. To earn credits, a project should owe its existence to the prospective earnings from carbon credits: the emissions reductions from the project should be additional to what would have happened in the absence of the CDM. Hence, the developers of a wind farm in India that replaces a coal-fired power plant could sell the difference in carbon emissions between the two projects as offsets—but not if the wind farm would have been built anyway.

Many CDM projects, however, do not appear to be offsetting carbon output at all. The Berkeley, Calif.–based organization International Rivers discovered that a third of the CDM's hydropower projects had been completed *before* they were accredited. Lambert Schneider of Germany's Institute for Applied Ecology judged two fifths of the world's CDM portfolio to be of similarly questionable additionality. Climatologist Michael Wara of Stanford University guesses the figure could be much higher, but, he says, "we have no way of knowing."

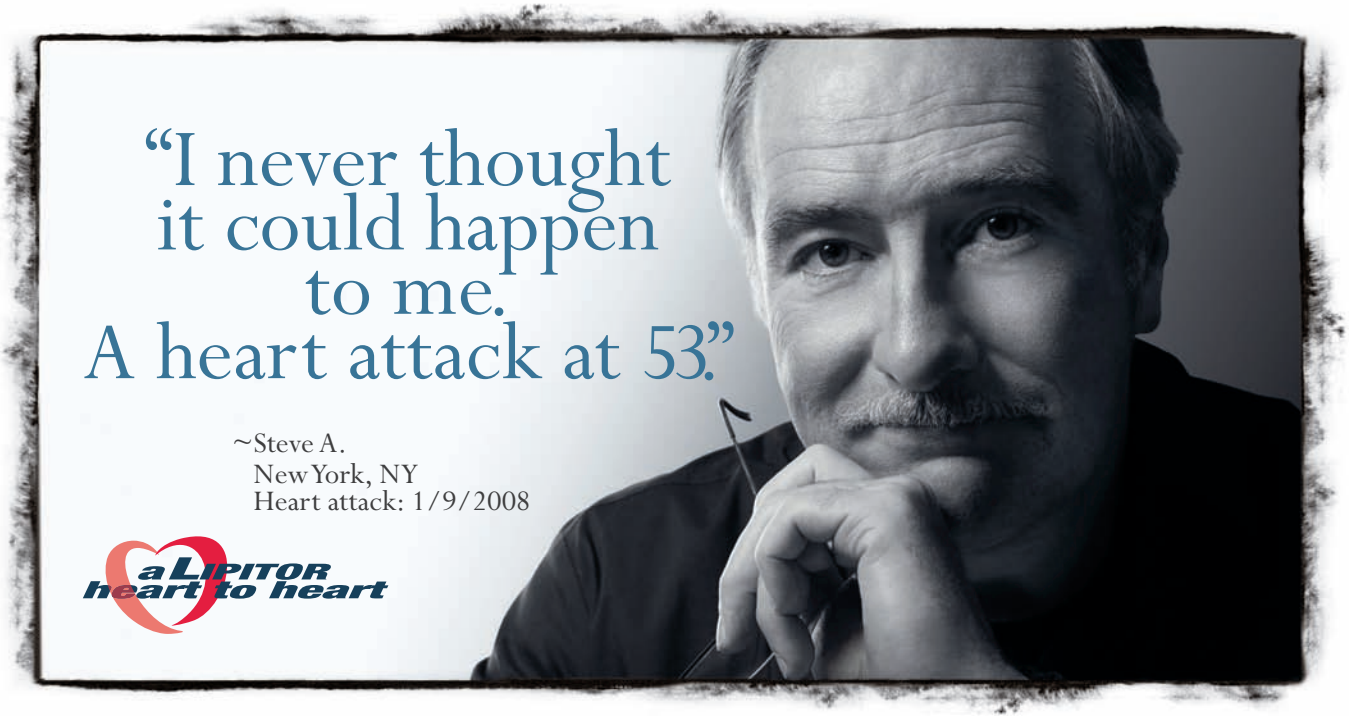
CARBON FLARE-UP: **Burning off waste gas in Nigerian oil fields—here near the city of Port Harcourt—spews pollutants and is illegal. But the practice persists in part because firms can take advantage of carbon offsets to earn credits for projects that reduce gas flaring.**

GEORGE OSODI/*AP Photo*

Determining which projects are "additional" can be tricky, explains researcher Larry Lohmann of the Corner House, an environmental think tank based in Dorset, England. "There's no such thing as a single world line, a single narrative of what would have happened without the project," he points out. "It's not a solvable problem."

A related worry is that of perverse incentives. Consultants assessing a carbon-offset project often compare it with the accepted practice in the developing country where it will be located. Such an approach gives that country an incentive to take the most polluting line to maximize the credits they earn for a CDM project. Selling this artificially inflated credit could thus ultimately enable more carbon to be emitted than if the offset had not been created at all.

Take the controversy over gas flaring in Nigeria, where oil firms burn off 40 percent of the natural gas found with oil. The state-owned Nigeria Agip Oil Company



"I had been feeling fine. But turns out my cholesterol and other risk factors* increased my chance of a heart attack. Now I trust my heart to Lipitor. Talk to your doctor about your risk and about Lipitor."

- **Adding Lipitor may help, when diet and exercise are not enough. Unlike some other cholesterol-lowering medications, Lipitor is FDA-approved to reduce the risk of heart attack and stroke in patients with several common risk factors, including family history, high blood pressure, low good cholesterol, age and smoking.**
- **Lipitor has been extensively studied with over 16 years of research. And Lipitor is backed by 400 ongoing or completed clinical studies.**

*Patient's risk factors include age, gender, smoking, and high blood pressure.

IMPORTANT INFORMATION: LIPITOR is a prescription drug. It is used in patients with multiple risk factors for heart disease such as family history, high blood pressure, age, low HDL ('good' cholesterol) or smoking to reduce the risk of heart attack, stroke and certain kinds of heart surgeries. When diet and exercise alone are not enough, LIPITOR is used along with a low-fat diet and exercise to lower cholesterol.

LIPITOR is not for everyone. It is not for those with liver problems. And it is not for women who are nursing, pregnant or may become pregnant. If you take LIPITOR, tell your doctor if you feel any new muscle pain or weakness. This could be a sign of rare but serious muscle side effects. Tell your doctor about all medications you take. This may help avoid serious drug interactions. Your doctor should do blood tests to check your liver function before and during treatment and may adjust your dose. The most common side effects are gas, constipation, stomach pain and heartburn. They tend to be mild and often go away.

LIPITOR is one of many cholesterol-lowering treatment options that you and your doctor can consider.

Please see additional important information on next page.

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IMPORTANT FACTS

LIPITOR atorvastatin calcium tablets (LIP-ih-tore)

LOWERING YOUR HIGH CHOLESTEROL

High cholesterol is more than just a number, it's a risk factor that should not be ignored. If your doctor said you have high cholesterol, you may be at an increased risk for heart attack. But the good news is, you can take steps to lower your cholesterol.

With the help of your doctor and a cholesterol-lowering medicine like LIPITOR, along with diet and exercise, you could be on your way to lowering your cholesterol.

Ready to start eating right and exercising more? Talk to your doctor and visit the American Heart Association at www.americanheart.org.

WHO IS LIPITOR FOR?

Who can take LIPITOR:

- People who cannot lower their cholesterol enough with diet and exercise
- Adults and children over 10

Who should NOT take LIPITOR:

- Women who are pregnant, may be pregnant, or may become pregnant. LIPITOR may harm your unborn baby. If you become pregnant, stop LIPITOR and call your doctor right away.
- Women who are breast-feeding. LIPITOR can pass into your breast milk and may harm your baby.
- People with liver problems
- People allergic to anything in LIPITOR

BEFORE YOU START LIPITOR

Tell your doctor:

- About all medications you take, including prescriptions, over-the-counter medications, vitamins, and herbal supplements
- If you have muscle aches or weakness
- If you drink more than 2 alcoholic drinks a day
- If you have diabetes or kidney problems
- If you have a thyroid problem

ABOUT LIPITOR

LIPITOR is a prescription medicine. Along with diet and exercise, it lowers "bad" cholesterol in your blood. It can also raise "good" cholesterol (HDL-C).

LIPITOR can lower the risk of heart attack or stroke in patients who have risk factors for heart disease such as:

- age, smoking, high blood pressure, low HDL-C, heart disease in the family, *or*
- diabetes with risk factor such as eye problems, kidney problems, smoking, or high blood pressure

POSSIBLE SIDE EFFECTS OF LIPITOR

Serious side effects in a small number of people:

- **Muscle problems** that can lead to kidney problems, including kidney failure. Your chance for muscle problems is higher if you take certain other medicines with LIPITOR.
- **Liver problems**. Your doctor may do blood tests to check your liver before you start LIPITOR and while you are taking it.

Symptoms of muscle or liver problems include:

- Unexplained muscle weakness or pain, especially if you have a fever or feel very tired
- Nausea, vomiting, or stomach pain
- Brown or dark-colored urine
- Feeling more tired than usual
- Your skin and the whites of your eyes turn yellow

If you have these symptoms, call your doctor right away.

The most common side effects of LIPITOR are:

- Headache
- Diarrhea, gas
- Rash
- Constipation
- Upset stomach and stomach pain
- Muscle and joint pain

Side effects are usually mild and may go away by themselves. Fewer than 3 people out of 100 stopped taking LIPITOR because of side effects.

HOW TO TAKE LIPITOR

Do:

- Take LIPITOR as prescribed by your doctor.
- Try to eat heart-healthy foods while you take LIPITOR.
- Take LIPITOR at any time of day, with or without food.
- If you miss a dose, take it as soon as you remember. But if it has been more than 12 hours since your missed dose, wait. Take the next dose at your regular time.

Don't:

- Do not change or stop your dose before talking to your doctor.
- Do not start new medicines before talking to your doctor.
- Do not give your LIPITOR to other people. It may harm them even if your problems are the same.
- Do not break the tablet.

NEED MORE INFORMATION?

- Ask your doctor or health care provider.
- Talk to your pharmacist.
- Go to **www.lipitor.com** or call **1-888-LIPITOR**.

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plans instead to generate electricity from the waste gas of its Kwale plant, displacing fossil fuels that might otherwise have been consumed. That strategy would create credits of 1.5 million tons of carbon dioxide a year for sale. (A credit for a ton of CO_2, called a certified emissions reduction, has been selling for about $15 in Europe.) The project is deemed additional because the prospect of selling offsets motivated the developers.

But activist Michael Karikpo of Oilwatch finds that classification to be "outrageous"—because routine flaring, which spews carcinogens such as benzene and triggers acid rain, is illegal in Nigeria. No company should profit from flouting the law, he adds: "It's like a criminal demanding money to stop committing crimes." Nevertheless, the incentive to declare a project as additional is powerful. Pan Ocean Oil Corporation, based in Nigeria, has applied for CDM approval for an effort to process and market waste gas from its Ovade-Ogharefe oil field. Should the government begin enforcing the law against flaring, it would render the project nonadditional and sacrifice considerable benefits.

The CDM's executive board has strengthened its review process to improve the tests for additionality and to reduce perverse incentives. For instance, the board no longer accepts new projects for burning off HFC-23, a greenhouse gas produced during the manufacture of refrigerant, because the windfall credits it generated had created an incentive to set up chemical factories for the sole purpose of burning HFC-23. (Because of HFC-23's heat-trapping potency, one ton of it fetches 12,000 CO_2 credits.)

Some observers think the CDM is too far gone to salvage. No amount of tinkering will repair such a "fundamental design flaw" as additionality, Wara contends. Last November the U.S. Government Accountability Office warned that carbon offsets "may not be a reliable long-term approach to climate change mitigation." In January the European Commission determined that the CDM should be phased out for at least the more advanced developing countries, which would instead be pressured to accept binding commitments to limit emissions. Another proposal would replace the CDM with a fund for developing countries to build green projects without generating credits—thereby eliminating the entire concept of additionality.

Doing away with the CDM and other offsets could be hard, though, because they are the easiest way for industrial nations to meet their emissions targets. The U.S. is considering a bill to reduce emissions by an ambitious 20 percent by 2020, but its provisions are so generous that apparently the country could meet its goal just by buying offsets. The fate of the CDM will be decided in climate talks to be held in December in Copenhagen.

Madhusree Mukerjee, a former editor at Scientific American, *is based near Frankfurt, Germany.*

Paying the Polluters

The World Bank is supposed to encourage sustainability, but much of its financing for carbon offsets ironically goes to polluters. For instance, the bank's private-sector lending arm is financing a coal-fired power plant in Gujarat, India, that will generate 25.7 million tons of carbon dioxide a year. The bank also hopes to garner brokerage fees from the sale of offsets worth three million tons of carbon a year, earned by energy-efficient processes at the same plant. Janet Redman of the Institute for Policy Studies in Washington, D.C., charges that four fifths of the bank's carbon finance portfolio is invested in offsets from polluting industries such as coal, chemicals, iron and steel. —***M.M.***

GEOPHYSICS

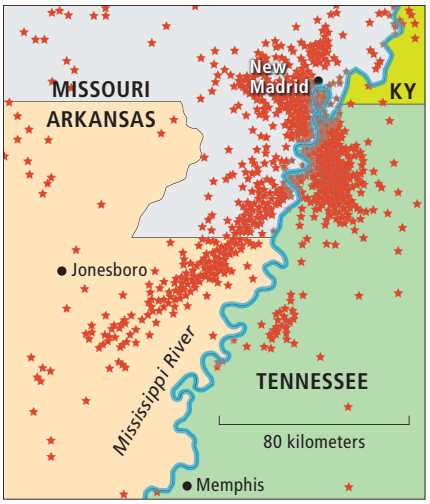
Rumble Off

A Midwest earthquake fault could be shutting down BY CHARLES Q. CHOI

The center of the U.S. saw earthquakes two centuries ago that were powerful enough to briefly reverse the flow of the Mississippi River. But unlike Californians, who must live with the specter of "the big one," Midwesterners may have already seen the last of them. New research suggests the crack in the earth behind the Mississippi Valley events may actually be shutting down. If so, geoscientists will need to rethink how earthquakes work.

Three of some of the largest earthquakes recorded in U.S. history struck over the course of two months from 1811 to 1812, the last of which destroyed the small town of New Madrid, Mo. Geologic evidence indicates that major earthquakes also shook this region around A.D. 1450, 900 and 490, implying a cycle of about every 500 years. This pattern fit in with the conventional view of faults—they build up stress and eventually relieve it violently, only to start anew.

Now millions of people dwell in the area of the New Madrid fault zone, which includes parts of Illinois, Indiana, Missouri, Tennessee, Arkansas, Kentucky and Mississippi. Conflicting evidence has emerged, however, regarding what risk they face. To assess how much energy a fault is building up, investigators look at the amount of motion in the ground there. Estimates in the past 20 years have varied from seven millimeters of movement a year to none whatsoever. As a consequence, the risk calculations have varied wildly, from a



GETTING LESS SHAKY? Positions of earthquakes since 1974 in the New Madrid seismic zone in the central Mississippi Valley were compiled by the U.S. Geological Survey. New data suggest that the fault system may be shutting down.

10 percent chance of a disastrous earthquake in the next 50 years to a chance of just 1 percent or less.

To settle the matter, geophysicist Eric Calais of Purdue University and seismologist Seth Stein of Northwestern University monitored the heart of the fault in southern Missouri and Tennessee with nine GPS antennas mounted on this ground for eight years. The devices can detect as little as 0.2 millimeter of movement—roughly the thickness of a fishing line—but they recorded no movement at all. Even if the earth moved at just below the detection limit of 0.2 millimeter, it would take a minimum of 10,000 years to accumulate enough energy for a magnitude 7 or greater quake to occur, the researchers conclude in the March 13 *Science*.

Hence, instead of recharging as the San Andreas fault is, New Madrid may be deactivating. The difference might be placement—whereas the San Andreas fault is found near the edge of tectonic plates, where a great deal of seismic violence occurs, the New Madrid fault is located in the heart of a continent, smack in the middle of a plate. "There's a whole new worldview that's emerging about how faults turn on and off within continents," Stein says.

Investigations of past records of big midcontinent earthquakes now hint they occur in clusters at one fault for a while and then migrate somewhere else, Stein explains, with the New Madrid fault "just being the one that's been active the most recently." How this migration occurs and where the energy comes from in midcontinental earthquakes still remains a big mystery. "Instead of focusing on one major, long-lived fault like the San Andreas, we need to think of how different faults interact," Stein says. Calais suggests that major earthquakes at one fault increase stress at others, making some of them more likely to "unclamp." Geophysicists Mian Liu of the University of Missouri–Columbia and Qingsong Li of the Lunar and Planetary Institute in Houston are currently modeling how such energy might transfer within plates from one fault to another.

Seismologist Susan Hough of the U.S. Geological Survey office in Pasadena, Calif., thought that Calais and Stein's findings were strong. But she points to research in 2000 that speculates that major earthquakes could still occur with little evidence of warping at the surface, "just like hidden time bombs." And, Stein observes, "research might look for other faults that are turning on." So even if New Madrid is shutting down, the Midwest might not be safe from earthquakes yet.

Charles Q. Choi is a frequent contributor based in New York City.

Where the Fault Lies within a Plate

Major faults occur at the point where two tectonic plates collide. But they can also exist within plates, as the New Madrid fault does in the middle of North America. Scientists are still unsure what powers these intraplate earthquakes; they may result from some combination of forces, such as the removal of glacial sheets after the last ice age or the drag from the fluid mantle underneath the plates. Earthquakes from such faults can be quite powerful and deadly. "Perhaps the most damaging earthquake in Australia's recent history was in Newcastle in 1989, when a quake measuring 5.6 killed 13 people and left a damage bill of billions of dollars. It was in the middle of the continent," recounts Seth Stein of Northwestern University. China and northern Europe may also be good places to investigate such activity. —*C.Q.C.*

HEALTH TECHNOLOGY

A Bead on Disease

Germ-grabbing magnetic beads that can be pulled from the blood BY KATE WILCOX

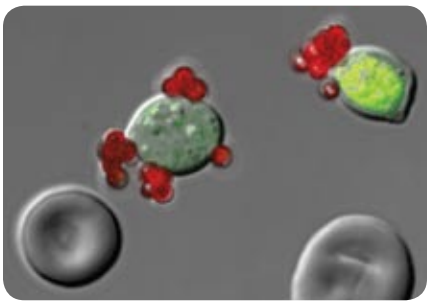
Using a magnetic field to literally pull diseases from the bloodstream sounds like a sci-fi dream. But scientists may have found a way to do just that, at least for sepsis, a potentially lethal blood infection that can lead to multiple-organ failure.

Biologist Donald E. Ingber of Harvard Medical School, his postdoctoral fellow Chong Wing Yung and their colleagues have devised a way to filter pathogens from the blood of septic patients using micron-size magnetic beads. In their model system, beads coated with an antibody that binds to sepsis-causing bacteria or fungi mix with blood drawn from a patient. After the antibody-coated magnets have bound with the pathogen, they are pulled via a magnetic field into a saline solution

that flows alongside the blood and sweeps them away. The filtered blood goes back into the patient. In tests using 10 to 20 milliliters of blood, the method removed 80 percent of the pathogens.

A key reason for the successful filtration was the size of the beads, which are about one-eighth the diameter of red blood cells. They are small enough that the flow of saline solution remains smooth; turbulence would end up mixing the solution with the blood and make separation of the germs and blood more difficult.

Ingber thinks a more advanced version of his system, which he described in the May 7 *Lab on a Chip,* could solve a headache for intensive care units that must determine whether a sepsis case stems from a bacterium or a fungus. Because fungal medications can be toxic, they are ordinarily withheld until a diagnosis confirms the pathogen type. Such a diagnosis takes time, however, which could jeopardize a rapidly declining patient. Ingber hopes to incorporate different kinds of sticky proteins on the beads to pull out several types of microbes at once, without having to make a diagnosis.



COURTESY OF CHONG WING YUNG, KIRSTEN JOHNSON AND DONALD E. INGBER *Harvard Medical School*

LATCHING ON: Tiny magnetic beads (*red*) are coated with antibodies, enabling them to attach themselves to fungus cells (*green*). Red blood cells are also shown.

He also thinks it is not necessary to remove all the germs. "What we're trying to do is establish a tipping point," Ingber says, referring to the amount of pathogens in the body. His theory is that lowering the number of bacteria or fungi will enable the antibiotics or fungicides to work more efficiently.

"It's a very elegant, very new theory," comments Tonse Raju, a neonatologist at Eunice Kennedy Shriver National Institute of Child Health and Human Development. "My hat's off to them for thinking differently." But, he notes, the theory has a major problem: namely, there is no proof yet that thinning the pathogen ranks will help medications work better. Besides, much of the damage from sepsis comes from the body's own inflammatory response, not the germs. Another problem, Raju points out, is that some bacteria and fungi can hide in pus pockets or in areas of low blood supply such as the peritoneal cavity and thus could avoid the blood cleansing.

Still, Ingber remains undaunted. He has begun preliminary testing on rabbits, because they are about the size of premature infants, who have very high rates of sepsis. Ingber acknowledges the practical roadblocks ahead but hopes that with further study magnetic stripping of disease will not be just science fiction.

GENETICS

Too Little, Too Much

A new sense for how variable numbers of genes cause disease BY MELINDA WENNER

Scientists published the first draft of the human genome nearly a decade ago, but the hunt for disease genes is far from over. Most researchers have focused on single changes in DNA base pairs (AT and CG) that cause fatal diseases, such as cystic fibrosis. Such mutations among the genome's three billion base pairs don't tell the whole story, however. Recently geneticists have taken a closer look at a genetic aberration previously considered rare: copy number variation (CNV). The genes may be perfectly normal, yet there is a shortage or surplus of DNA sequences that may play a role in diseases that defy straightforward genetic patterns, such as autism, schizophrenia and Crohn's disease, the causes of which have stumped researchers for decades.

American geneticist Calvin Bridges discovered copy number variation in 1936, when he noticed that flies that inherit a duplicate copy of a gene called *Bar* develop very small eyes. Two decades later a French researcher studying human chromosomes under a microscope identified CNV as the cause of Down syndrome: sufferers inherit an extra copy of chromosome 21. By all appearances, CNV was rare and always a direct cause of disease.

In 2004, however, things changed. Two groups of researchers published the first genome-wide CNV maps, which illustrated that variation in gene quantity is actually quite common: each group found about 12 copy number imbalances per person. "When these papers came out, they really turned everything on its head," says Stephen Scherer, a geneticist at the Hospital for Sick Children in Toronto and a co-author of one of the papers. "People always thought, as did we, that these large changes in DNA were always associated with disease."

Scherer and his colleagues, who included population geneticist Matthew Hurles of the Wellcome Trust Sanger Institute in Cambridge, England, followed up with a higher-resolution CNV study in 2006, which analyzed DNA from 270 individuals and identified an average of 47 copy number variations per person. And

in 2007 researchers sequenced the genome of genetic pioneer J. Craig Venter and found 62 copy number variations. Evidently, Hurles says, "it's not normal to be walking around with the perfect genome."

Scientists are still trying to decipher exactly how these variations—most of which are inherited—affect the body. Typically if a genome has three copies of a gene instead of the normal two (one from each parent), a cell will make proteins from all three, producing more than it probably needs. But such gene expression is "not always the case—there are exceptions," Scherer says. Sometimes cells make the correct amount anyway; other times CNVs affect DNA regions that regulate the expression of still other genes, making the problem more complicated.

Even so, scientists have been able to link CNVs to a handful of complex diseases. A September 2008 study in *Nature* confirmed earlier findings suggesting that 30 percent of people who have a deleted length of three million base pairs in a region of chromosome 22 suffer from psychiatric conditions such as autism and schizophrenia. A *Nature Genetics* study from August 2008 found a link between Crohn's disease and a 20,000 base-pair deletion in a region upstream of a gene called *IRGM,* which is involved in fighting invasive bacteria.

And in January 2009 another *Nature Genetics* paper found an association between high body mass index and a 45,000 base-pair deletion in a gene called *NEGR1,* which affects neuronal growth in the hypothalamus, a brain region that regulates hunger and metabolism. "We're coming up with so much data, and new kinds of data, that it's hard to keep up," remarks Edwin Cook, Jr., a psychiatrist at the University of Illinois at Chicago.

Copy number variation could help explain why complex diseases are often inherited but not always linked to the same genes: they may affect risk in a probabilistic manner, explains Steven McCarroll, a population geneticist at the Massachusetts Institute of Technology and a co-author of the Crohn's disease study. "The *IRGM* deletion may increase risk of Crohn's by only 40 percent, but it does so in millions of people," he says. Whether a person actually acquires the disease may depend on additional genetic or environmental factors.

As researchers hunt for more links between known CNVs and disease, Scherer and Hurles are scouting out new variants to add to the mix. Their 2006 map identified CNVs only down to 20,000 base pairs; now they are finishing a revised map that includes variants as short as 500 base pairs. The analysis suggests that about 1,000 copy number variations exist in each person, spanning at least 1 percent of the genome.

"We've come really far and really fast," Scherer says. But "over the next year, we're going to be finding more small CNVs and more common CNVs associated with disease—2009 is going to be a watershed year."

Melinda Wenner, based in New York City, described in the May issue how "quorum-sensing" bacteria could help beat antibiotic-resistant germs.

EQUINOX GRAPHICS *Photo Researchers, Inc.*

NUMBERS GAME IN CHROMOSOMES: Extra or missing stretches of DNA, which have been linked to various diseases, turn out to be more common than previously thought.

PHYSIOLOGY

Sled Dog Science

Cracking the metabolic secrets of distance-racing canines BY KRISTA WEST

With tongue and tail wagging wildly, Larry the lead dog crossed the finish line in March in sunny Nome, Alaska—after running 1,131 miles to win the Iditarod Trail Sled Dog Race for the third year in a row. To most mortals, Larry looks like a happy but nondescript, scrawny mutt. To sled dog mushers, he is a mini legend that simply needs no introduction. To scientists, Larry may hold the key to a physiological mystery.

Specifically, sled dogs seem to flip an internal switch that acutely changes how they burn fat calories, allowing them to keep going and going and going with no obvious pain. Figuring out how that mechanism works may have implications for human diabetics and those battling obesity.

Researchers first discovered the metabolic switch in 2005, when a team headed by Oklahoma State University's Michael Davis—who has been investigating the metabolic, gastrointestinal, respiratory and blood systems of sled dogs for 10 years—did a controlled study at a professional racing kennel in Alaska. Mushers ran the dogs in mock, 100-mile races for four to five days in a row. Every 100 miles the researchers took matchstick-size samples of leg muscle (about 60 milligrams apiece) from the dogs to test for protein levels, enzyme activity and glycogen, a starch-like compound that stores energy for quick release.

Glycogen turns out to be a crucial piece of the metabolic switch. During the first few days of racing, sled dogs draw energy from glycogen stored inside muscle cells. But instead of depleting glycogen stores and tiring the muscles, the animals suddenly switch to a glycogen-sparing metabolism. They start drawing energy from sources outside of the muscles.

Davis suggests that the muscle cells start extracting fat directly from the blood and somehow transport this fat across the cell membranes and into the cells, where it can be burned as fuel. During race times, fat builds up in a sled dog's blood, most likely because of the high-fat racing diet. Each 50-pound canine consumes about 12,000 calories daily (typically 60 percent fat and 40 percent carbohydrate and protein).

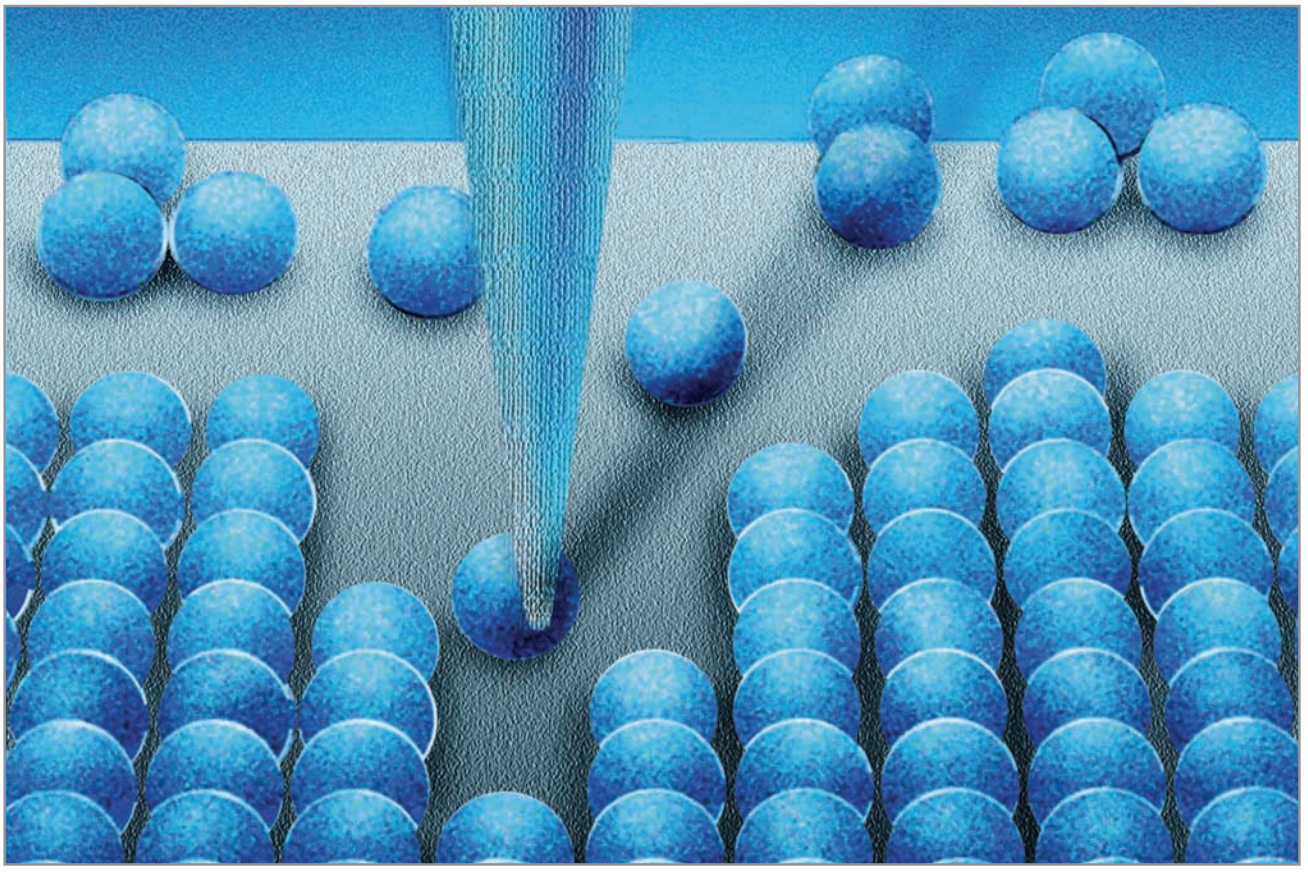
According to Raymond Geor, an exercise physiologist at Michigan State University, sled dog muscle cells are well equipped to use this fat because they have a higher mitochondrial density—more cellular power plants—than other animals. The mystery is how the blood-borne fat gets into cells in the first place. Increasing evidence suggests that fat is transported into the cells along similar pathways as glucose, Davis says, with the hormone insulin playing a critical role. Researchers are exploring the sled dog's sensitivity to insulin to better understand this pathway.

Breeding probably had much to do with the development of the metabolic switch. Larry is descended from a long line of racing dogs. "The bloodlines of my dogs date back 100 years," says Lance Mackey, Larry's owner and legendary racing musher, the only person to win the long-distance Iditarod and the Yukon Quest in the same year with the same dog team. "They are mixed breeds—mutts—but they've been bred to run."

Selective breeding, though, may not be the whole story. The dogs may have learned to switch metabolic strategies on demand through intense training. If so, then researchers might have an easier time applying what they learn about the canines to humans training for an endurance event or those seeking treatment for diabetes or obesity. Such patients might benefit, for instance, if researchers could pinpoint the mechanisms that boost the body's sensitivity to

WINNER'S CIRCLE: Lance Mackey celebrates the first of three Iditarod wins with his sled dog Larry (*left*), who holds fat-burning secrets.

AL GRILLO *AP Photo*



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insulin or that better utilize fat that builds up in muscle tissue.

This year Mackey won the Iditarod by one of the widest margins ever, finishing a comfortable eight hours ahead of his closest competitor. That Iditarod, however, will be the last one for Larry, after participating for eight of his nine living years. He will officially retire from racing at the end of this year for a well-deserved, if unneeded, rest.

Krista West lives in Fairbanks, Alaska, with a dog-chasing cat.

A Challenge to Canine Health

The rigors of the Iditarod sled dog race, in which a musher and a team of 12 to 16 dogs cover some 1,150 miles in 16 days, takes its toll on the health of its athletes. On average, three dogs die every year in the race; 2009 saw double that number. Some animal-rights groups have criticized the event as cruel. And in this age of juiced jocks, some observers also wonder if steroids are involved.

To monitor the dogs' health and watch for performance-enhancing drugs, volunteer veterinarians keep watch during runs. At the Iditarod, for example, a dedicated plane follows the canines and samples urine of dog teams for drugs without warning. Mushers must carry sick or injured dogs to the next checkpoint for treatment and continue the race without that canine. They must finish with at least six running dogs. —*K.W.*

PERCEPTION

A Real Stretch

Pulling your mouth around affects which words you hear BY ERICA WESTLY

Neuroscience textbooks typically portray the five senses as separate entities, but in the real world the senses frequently interact, as anyone who has tried to enjoy dinner with a stuffy nose can attest. Hearing and vision seem similarly connected, the most famous example being the "McGurk effect," where visual cues, such as moving lips, affect how people hear speech. And now new research shows that touch can influence speech perception, too.

David Ostry, a neuroscientist with coappointments at McGill University and the New Haven, Conn.–based speech center Haskins Laboratories, has been studying for years the relation between speech and the somatosensory system, the network of receptors in skin and muscle that report information on tactile stimuli to the brain. In his most recent study, published in the *Proceedings of the National Academy of Sciences USA*, he and two Haskins colleagues found that subjects heard words differently when their mouths were stretched into different positions. The results have implications for neuroscientists studying speech and hearing as well as for therapists looking for new ways to treat speech disorders.

WORDPLAY: Depending on how a mechanical device pulls and tugs areas around the mouth, the volunteer will hear and interpret speech sounds differently.

COURTESY OF HASKINS LABORATORIES

In the study, a specially designed robotic device stretched the mouths of volunteers slightly up, down or backward while they listened to a computer-generated continuum of speech verbalizations that sounded like "head" or "had," or something in between. When the subjects' mouths were stretched upward, closer to the position needed to say "head," they were more likely to hear the sounds as "head," especially with the more ambiguous output. If the subjects' mouths were stretched downward, as if to say "had," they were more likely to hear "had," even when the sounds being generated were closer to "head." Stretching subjects' mouths backward had no effect, implying a position-specific response. Moreover, the timing of the stretch had to match that of the sounds exactly to get an effect: the stretch altered speech perception only when it mimicked realistic vocalizations.

The concept of eliciting a cognitive response by manipulating the mouth is not entirely new. In 1988 psychologists found that they could improve subjects' moods by having them clench a pen between their teeth, thereby forcing them to smile, and researchers have been conducting similar experiments on physical manipulation and perception ever since. But most of those experiments focus on emotional responses, which require a longer timescale, whereas in Ostry's speech study the results were nearly instantaneous, notes Asif Ghazanfar, a sensory researcher at Princeton University. "What this study is showing is that these things are happening very quickly—on an order of tens of milliseconds," he says. "I think that's really important because it emphasizes that the brain is not something separate from our bodies. You can't point to events happening in one and not the other."

Ostry's study also has ties to a hypothesis from the 1960s called the motor theory of speech perception, which argues that the neural machinery associated with speech production is also involved with speech perception. Fernando Nottebohm, a neuroscientist at the Rockefeller University who uses songbirds as a model for human speech, believes Ostry's study represents one of the few examples of direct evidence supporting this hypothesis. Ostry, however, cautions that the somatosensory system could modulate speech perception in several ways without involving the motor system.

Previous studies using neuroimaging and magnetic stimulation have suggested that the brain regions involved with auditory, motor and sensory processing overlap at some level. Precisely how these areas work together to modulate speech perception remains unclear, however. Ostry and his colleagues hope to help answer this question with follow-up work that inverts the experiment: instead of hearing a continuum of sound, subjects will endure a continuum of stretches to see if auditory input can influence what they feel. Ostry suspects that touch and hearing will go both ways in this context, which would mean not only could you hear with your mouth, but you could also feel with your ears.

Erica Westly is a freelance science writer based in New York City.

Adding a Therapeutic Touch

Understanding how the skin around the mouth affects speech perception could lead to new methods to treat speech disorders. Traditionally the focus in speech therapy has been on the auditory component, says David Ostry of McGill University, but the mechanical and tactile aspects are crucial, too. "The somatosensory inputs play a role in both guiding speech production and speech learning, and now it's clear they play a role in auditory perception, too," Ostry explains, referring to his recent experiments. "It really identifies them as a potential conduit for therapeutic interventions." Speech therapies with tactile components could especially help patients who, because of hearing loss or other reasons, have trouble hearing their speech mistakes, he says. —*E.W.*

INFOTECH

Pulling Up Worms

The Conficker worm exposes computer flaws, fixes and fiends BY MICHAEL MOYER

Computer users could be forgiven if they kept their machines off on April 1. Since it first appeared last November, the malicious software known as the Conficker worm has established itself as one of the most powerful threats the Internet has seen in years, infecting an estimated 10 million computers worldwide. The malware slipped into machines running the Windows operating system and waited quietly for April Fools' Day (the timing did not go unnoticed), when it was scheduled to download and execute a new set of instructions. Although no one knew what was to come, the worm's sophistication provided a stark example of how the global malware industry is evolving into a model of corporate efficiency. At the same time, it raised calls for security researchers to steal a trick from their black hat counterparts.

A worm takes advantage of security holes in ubiquitous software—in this case, Microsoft Windows—to spread copies of itself. Conficker, though, was a strikingly advanced piece of code, capable of neutering a computer's antivirus software and receiving updates that would give it more complex abilities. Its sudden march across the Web reignited interest in one of the most controversial ideas in security protection: the release of a "good" worm. Such software would spread like a worm but help to secure the machines it infected. The approach had already been attempted once before. In late 2003 the Waledac worm burrowed into Windows machines by exploiting the same vulnerability as the then widespread Blaster worm. Yet unlike Blaster, which was programmed to launch an attack against a Microsoft Web site, Waledac updated the infected machines with security patches.

On the surface, Waledac appeared to be a success. Yet this worm, like every worm, spiked network traffic and clogged the Internet. It also rebooted machines without users' consent. (A common criticism of automatic security updates—and a key reason why many people decide to turn them off—is that updating a security patch requires restarting the computer, sometimes at inopportune moments.) More important, no matter how noble the purpose, a worm is an unauthorized intrusion.

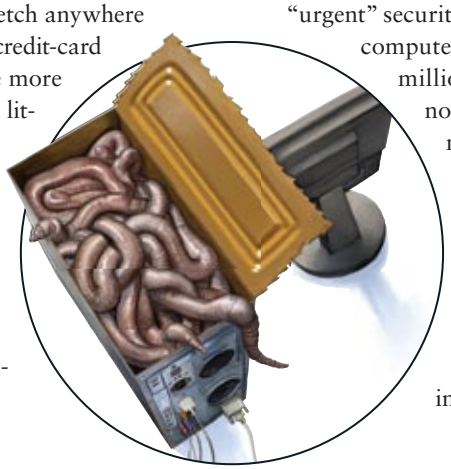
After Waledac, the discussion about good worms went away, at least in part because worms themselves went away. "Back in the early 2000s, there weren't strong business models for distributed malware," says Philip Porras, program director of the nonprofit security research firm SRI International. Hackers, he explains, "were using [worms] to make statements and to gain recognition." Worms would rope computers together into botnets—giant collections of zombie computers—which could then attempt to shut down legitimate Web sites. Exciting (if you're into that sort of thing), but not very profitable.

In the past five years malware has grown ever more explicitly financial. "Phishers" send out e-mails to trick people into revealing user names and passwords. Criminals have also begun uploading to legitimate store sites hard-to-detect surveillance code that covertly intercepts credit-card information. The stolen information then goes up for sale on the Internet's black market. An individual's user name and password to a banking site can fetch anywhere from $10 to $1,000; credit-card numbers, which are more ubiquitous, go for as little as six cents. The total value of the goods that appear on the black market in the course of a year now exceeds $7 billion, according to Internet security company Symantec.

The tightly managed criminal organizations behind such scams—often based in Russia and former Soviet republics—treat malware like a business. They buy advanced code on the Internet's black market, customize it, then sell or rent the resulting botnet to the highest bidders. They extend the worm's life span as long as possible by investing in updates—maintenance by another name. This assembly line–style approach to crime works: of all the viruses that Symantec has tracked over the past 20 years, 60 percent of them have been introduced in the past 12 months.

A week after the April 1 deadline, it became clear that the people responsible for Conficker had strong financial motivations. The worm downloaded a well-known spam generator. In addition, computers infected with the worm also began to display a highly annoying "Windows Security Alert" pop-up warning every few minutes. The alerts claimed that the computer was infected with a virus, which was true enough. Yet these scareware warnings also promised that the only way to clean one's machine was to download the $50 program advertised—credit-card payments only, please.

Ironically, routine updates could have prevented the worm's spread in the first place. In fact, Conficker emerged a full four weeks *after* Microsoft released the "urgent" security patch that protected computers against it. Clearly, millions of machines were not being updated. And millions still probably are not properly immunized—a disturbing thought, considering that, even after its April actions, Conficker resumed waiting for further instructions.



MATT COLLINS

NEURAL PLASTICITY

On the Other Hand

NIMBLE: Transplanted hands twist wires.

Double-hand transplantations could switch the handedness of patients. Two men who lost both hands in work injuries received transplants after three to four years of waiting. Despite such a long time—the brain typically reassigns areas linked with control of the amputated limb to other muscles—researchers at the French Center for Cognitive Neuroscience in Lyon found the patients' brain could connect to the new hands, which subsequently could perform complex tasks (in a demonstration, one patient repaired electrical wires). Although both men were right-handed, their left hand connected with their brain at least a year sooner than their right hand did, and they stayed left-handed. The reason for this switch, reported online April 6 by the *Proceedings of the National Academy of Sciences USA*, is unclear—perhaps the prior dominance of the right hand made the corresponding brain regions less flexible to reconnections or the surgeries were done slightly differently. —*Charles Q. Choi*

MEDICAL DEVICES

Point Taken

Every year hundreds of thousands of people develop medical complications such as nerve injury when hypodermic needles penetrate deeper than they should. A novel needle devised by researchers at Harvard Medical School and their colleagues automatically stops itself from going too far. The force from the first push of the device's plunger goes only to a blunt, flexible wire inside the hollow needle. As long as this filament remains unbent, a special clutch keeps the rest of the needle from advancing. On encountering resistance from tissue, the wire buckles and the clutch permits the entire needle to move forward. On reaching a target cavity, such as a blood vessel, the filament no longer faces resistance and so straightens out, preventing the needle from proceeding but uncovering the tip to allow medicine out. Described in the April 7 *Proceedings of the National Academy of Sciences USA*, the needle might reach clinics in three to five years.

—*Charles Q. Choi*

NEEDLED: Sometimes injections go too far into the body.

PALEOANTHROPOLOGY

Living Alike

The Geico "caveman" advertising campaign might be on to something. Evidence presented in April at the Paleoanthropology Society meeting in Chicago suggests that Neandertal behavior resembled that of early modern humans. Bruce Hardy of Kenyon College studied artifacts from Hohle Fels, a site in southwestern Germany. It contains tools made by Neandertals between 36,000 and 40,000 years ago as well as items manufactured by early modern humans between 33,000 and 36,000 years ago. Both groups lived under similar environmental conditions at this site, making their cultural remains ideal for comparison. Hardy examined the wear patterns and residue on the tools and found that although modern humans had a larger range of implements, both groups engaged in similar activities, such as using tree resin to bind stone points to wooden handles and crafting tools from bone and wood. He speculates that the Neandertals did not invent more tools because they could survive just fine with what they had. —*Kate Wong*

Data Points

A Flash of Fusion

On May 29 Lawrence Livermore National Laboratory dedicated the National Ignition Facility, the world's biggest laser system. It will direct laser beams from all directions onto a pencil-eraser-size pellet of frozen hydrogen (housed in a tube called a hohlraum), heating it to millions of degrees and inducing fusion. The laser beams must travel some distance to pick up energy from amplifiers and hit its tiny target; the lab likens the accuracy to a pitcher at AT&T Park in San Francisco throwing a strike at Dodger Stadium in Los Angeles. Designed to ensure that U.S. nuclear warheads work properly in lieu of actual testing, the facility will also provide a means to study the interior of stars and fusion as an energy source.

Number of laser beams that hit the target:	192
Number of "control points" to amplify and maintain the beams:	60,000
Laser travel distance:	1 kilometer
Time in which all beams must strike target, in trillionths of a second:	30
Energy delivered to target, in joules:	1.8 million
Initial cost estimate:	$1.1 billion
Actual final cost:	$3.5 billion
Initial construction time estimate:	6 years
Actual construction time:	12 years

SOURCES: Lawrence Livermore National Laboratory; "Beyond the Test Ban," by John Horgan [News Scan]; Scientific American, *December 1996*

COURTESY OF THE NATIONAL ACADEMY OF SCIENCES/*PNAS* (*hands*); JEFFREY HAMILTON *Getty Images* (*syringe*); ILLUSTRATION BY MATT COLLINS

In Brief

CALORIE-BURNING FAT

Once thought to disappear after infancy, the calorie-burning tissue known as brown fat may actually be keeping some adults slim. Newborns have brown fat to help generate body heat, but it seems to melt away as part of the aging process. A new study shows that some adults, especially those with a healthy body mass index, maintain reserves of the good fat that is metabolically active. The work, published in the April 9 *New England Journal of Medicine,* could potentially point to novel obesity-fighting compounds. —*Coco Ballantyne*

HAVE A NICE TRIP

Man's best friend could be one of man's biggest hazards. Pets cause nearly an estimated 87,000 falls that need emergency room treatment every year in the U.S., according to the March 27 *Morbidity and Mortality Weekly Report.* A quarter of the tumbles happened when owners were walking their dogs, and twice as many women as men were hurt. Most injuries occurred in children and those 35 to 54 years old, but people 75 or older suffered the most serious damage. —*Jordan Lite*

EGGS NOT OVER EASY

Infertility treatments operate under the assumption that women are born with all the eggs they will ever have. But researchers reporting online April 14 in *Nature Cell Biology* claim they have found precursor stem cells in newborn and adult mice that could be prodded into producing new eggs. The scientists grew these cells in a petri dish and implanted them in mice engineered to be infertile. Although some of the mice subsequently gave birth, more studies will be needed to confirm the results. —*Jordan Lite*

BEHAVIOR

Electromagnetic Chatter

Single-celled organisms may communicate via radiation. Daniel Fels of the Swiss Tropical Institute in Basel grew the microbe *Paramecium caudatum* in complete darkness in clear tubes, which prevented the cells from passing chemical messages to one another. Fels discovered the microorganisms could influence the feeding behavior and growth rates of neighbors in other tubes, suggesting that electromagnetic signals were involved. The microbes seemed to use at least two frequencies to communicate, one of which was in the ultraviolet (UV) range. For instance, small populations of paramecia grew significantly better when separated from larger ones by glass that blocks UV light than by quartz glass, which permits UV rays. The cellular structures behind these messages have not yet been identified, but in the April 1 *PLoS ONE,* Fels suggests that these signals could lead to novel noninvasive medical techniques.

—*Charles Q. Choi*

LIGHT TALKER: A paramecium can use two frequencies of light to communicate.

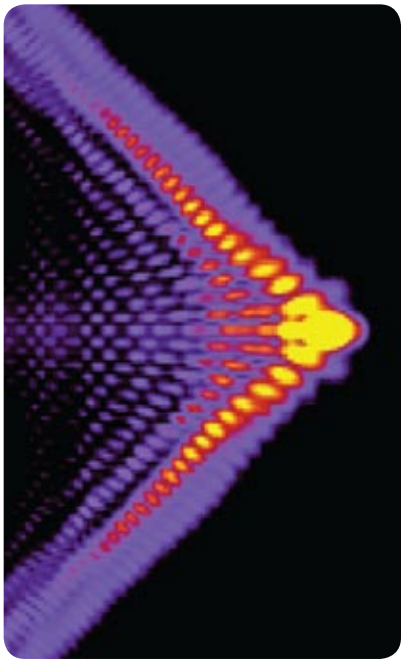
PHYSICS

Laser Beams That Curve

Two years ago physicists demonstrated that a laser beam traveling through the air can bend slightly if certain components are asymmetrical, forming what is called an Airy beam. Now researchers have shown that pulsed, high-intensity versions can leave curved trails of plasma. Shot out like a stack of pennies, each pulse, one centimeter wide and lasting 35 femtoseconds, passes through a glass plate that turns it into a triangular shape, in which an intense peak falls on one side of several weaker peaks. The brightest part heads in one direction, while the dimmer ones go the opposite way. (The momentum of the entire pulse remains straight, however.)

Being extremely intense, the bright spots ionize the air behind them and leave a curved plasma stream in their wake. The self-bending beam, described in the April 10 *Science,* does not curve by more than the beam's diameter, but that amount is enough to help physicists probe the structure of laser pulses.

—*Larry Greenemeier*



GETTING BENT: A simulation of an Airy pulse coming out of the page. The bright patch leaves a curved plasma trail.

HOWARD BERMAN Getty Images (dogs); M. I. WALKER Photo Researchers, Inc. (paramecium); COURTESY OF SCIENCE/AAAS (laser)

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Scientific American Perspectives

Reality Check for Stem Cells

The latest but far from final chapter on the controversial research at least starts well

BY THE EDITORS

Happy days are here again for the embryonic stem cell (ESC) research community, or at least they should be. The day after Barack Obama was inaugurated as president in January, the U.S. Food and Drug Administration greenlighted an application from Geron Corporation to pursue the first phase I clinical trial of an ESC-based therapy (in this case, for spinal cord injury).

President Obama, who ran on a pro-ESC research platform, cannot take credit for that regulatory first, which was largely a coincidence of timing. But he has already made good on his promise to lift the burdensome restrictions on federally funded ESC studies imposed by his predecessor in 2001. Laboratories receiving federal money are once again free to work on the cell lines of their choice (with some important restrictions).

So scientists at last mostly have what they have been asking for. And the public should now prepare to be disappointed.

Perhaps "disappointed" is an overstatement, but a realistic recalibration of expectations is surely in order. The problem with turning a scientific issue into a political football is that the passionate rough-and-tumble of the game can leave the science itself rather scuffed. When opponents of ESC research likened it to genocide and Nazi concentration camp experiments, its proponents countered by emphasizing how irreplaceable ESCs were and how miraculous the cures arising from them could be. Whether or not those claims wandered into rhetorical excess, at least a few false hopes and misimpressions have probably been left behind.

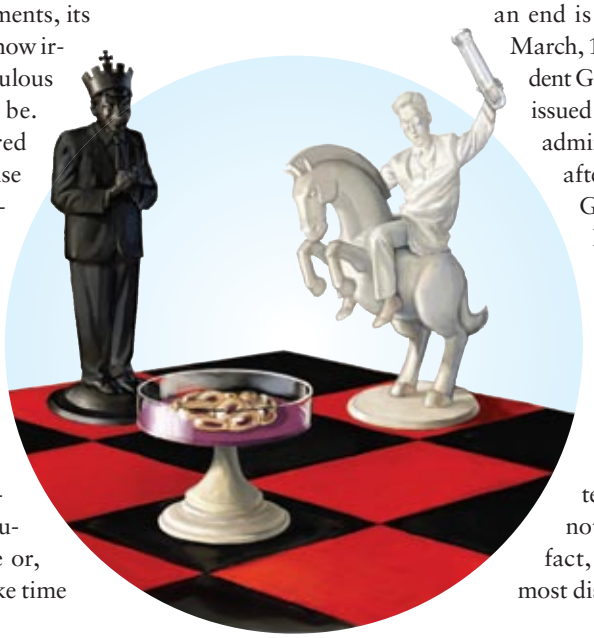
To address the most obvious one first: practicable ESC-based therapies are years away. The upcoming tests of Geron's paralysis treatment, for example, will look only at how safely it is tolerated by patients; tests of its effectiveness are further off. The therapeutic cells helped mice to partially recover from spinal injuries, but in humans they might fail to do the same or, worse, might induce tumors. It will take time to find out. New drugs often take five to nine years to progress from phase I testing to market.

Moreover, many if not most of those future therapies based on ESC research may not actually involve ESCs. Patients, after all, will not be able to supply embryonic cells directly from their own body. Therapeutic ESCs would either have to come from immunologically matched stockpiles (the equivalent of blood banks) or be cloned for each patient individually. Both solutions would involve technological and legal headaches. Using adult stem cells or others reprogrammed for versatility from a patient's own tissues may therefore prove much easier. (Adult stem cells are indeed already used to treat some blood-related and orthopedic disorders.)

Opponents of ESC research may howl that these facts only vindicate their long-standing position that it would be better simply to concentrate on adult stem cell therapies. But the hard-fought campaign against restricting ESC research was well worth it: ESCs will most likely be essential for developing sophisticated stem cell therapies of any kind because they offer the best clues to how the body naturally grows, repairs and regenerates demandingly intricate tissues.

Anyone who thinks that the public debate over ESCs is nearing an end is also in for a rude awakening. In March, 10 out of 18 members of former president George W. Bush's Council on Bioethics issued a press release criticizing the Obama administration's policy as unethical. Days after the president's executive order, the Georgia State Senate approved the Ethical Treatment of Human Embryos Act, which would bar the deliberate creation of embryos for ESCs. Expect more of the same.

Stem cell research continues to be a pawn in a larger political game being fought over abortion, women's reproductive autonomy, and the tension between individual rights and notions of public morality. And that fact, however inescapable, may be the most disappointing one of all. ■



MATT COLLINS

Sustainable Developments

Rethink the Global Money Supply

Less reliance on the U.S. dollar by international reserves would be widely beneficial

BY JEFFREY D. SACHS

The People's Bank of China jolted the financial world in March with a proposal for a new global monetary arrangement. The proposal initially attracted attention mostly for its signal of China's rising global economic power, but its content also has much to commend it.

A century ago almost all the world's currencies were linked to gold and most of the rest to silver. Currencies were readily interchangeable, gold anchored exchange rates and the physical supply of gold stabilized the money supply over the long term.

The gold standard collapsed in the wake of World War I. Wartime financing with unbacked paper currency led to widespread inflation. European nations tried to resume the gold standard in the 1920s, but the gold supply was insufficient and inelastic. A ferocious monetary squeeze and competition across countries for limited gold reserves followed and contributed to the Great Depression. After World War II, nations adopted the dollar-exchange standard. The U.S. dollar was backed by gold at $35 per ounce, while the rest of the world's currencies were backed by dollars. The global money stock could expand through dollar reserves.

President Richard Nixon delinked the dollar from gold in 1971 (to offset the U.S.'s expansionary monetary policies in the Vietnam era), and major currencies began to float against one another in value. But most global trade and financial transactions remained dollar-denominated, as did most foreign exchange reserves held by the world's central banks. The exchange rates of many currencies also remained tightly tied to the dollar.

This special role of the dollar in the international monetary system has contributed to the global scale of the current crisis, which is rooted in a combination of overly expansionary monetary policies by the Federal Reserve and lax financial regulations. Easy money fed an unprecedented surge in bank credits, first in the U.S. and then elsewhere, as international banks funded themselves in the U.S. money markets. As bank loans flowed into other economies, many foreign central banks intervened to maintain currency stability with the dollar. The surge in the U.S. money supply was thus matched by a surge in the money supplies of countries linked to the U.S. dollar. The result was a temporary worldwide credit bubble, followed by a wave of loan defaults, falling housing prices, banking losses and a dramatic tightening of bank lending.

China has now proposed that the world move to a more symmetrical monetary system, in which nations peg their currencies to a representative basket of others rather than to the dollar alone. The "special drawing rights" of the International Monetary Fund is such a basket of four currencies (the dollar, pound, yen and euro), although the Chinese rightly suggest that it should be rebased to reflect a broader range of them, including China's yuan. U.S. monetary policy would accordingly lose its excessive global influence over money supplies and credit conditions. On average, the dollar should depreciate against Asian currencies to encourage more U.S. net exports to Asia. The euro should probably strengthen against the dollar but weaken against Asian currencies.

The U.S. response to the Chinese proposal was revealing. Treasury Secretary Timothy Geithner initially described himself as open to exploring the idea; his candor quickly caused the dollar to weaken in value—which it needs to do for the good of the U.S. economy. That weakening, however, led Geithner to reverse himself within minutes by underscoring that the U.S. dollar would remain the world's reserve currency for the foreseeable future.

Geithner's first reaction was right. The Chinese proposal requires study but seems consistent with the long-term shift to a more balanced world economy in which the U.S. plays a monetary role more coequal with Europe and Asia. No change of global monetary system will happen abruptly, but the changes ahead are not under the sole control of the U.S. We will probably move over time to a world of greater monetary cooperation within Asia, a rising role for the Chinese yuan, and greater symmetry in overall world monetary and financial relations. ■

Jeffrey D. Sachs is director of the Earth Institute at Columbia University (www.earth.columbia.edu).

SCI AM An extended version of this essay is available at **www.ScientificAmerican.com/jun2009**

PHOTOGRAPH BY BRUCE GILBERT/EARTH INSTITUTE; ILLUSTRATION BY MATT COLLINS

unicef
united states fund

Every year, maternal and neonatal tetanus (MNT) claims the lives of almost 128,000 infants and 30,000 mothers.[1] MNT has been eliminated in most of the developed world – but it remains a deadly public health threat in 46 developing countries.

The U.S. Fund for UNICEF is partnering with other nonprofit organizations and leading healthcare companies to eliminate MNT. To learn more, visit www.unicefusa.org.

BD

Helping all people live healthy lives

Partnering to save lives

Preventing the occurence of maternal and neonatal tetanus (MNT) in developing countries requires uncomplicated solutions and strong partnerships.

BD is partnering with the U.S. Fund for UNICEF to protect newborn children and their mothers from MNT. BD has donated 135 million auto-disable injection devices and more than $3 million to the initiative.

The total commitment of $15 million makes BD one of the largest single corporate donors to the U.S. Fund for UNICEF's MNT campaign and is the largest single philanthropic activity in BD's 110 year history.

The BD Uniject™ device used in this campaign has unique features that make it ideal for safely administering the tetanus toxoid vaccine in the most remote regions of the world.

Named one of the *World's Most Admired Companies*®[2] as well as one of the *World's Most Ethical Companies,*[3] BD provides advanced medical technology to serve the global community's greatest needs.

BD – *Helping all people live healthy lives.*

[1] WHO/UNICEF, 2004 data
[2] *FORTUNE*, March 2009
[3] *Ethisphere® Magazine,* April 2009

Please visit www.bd.com

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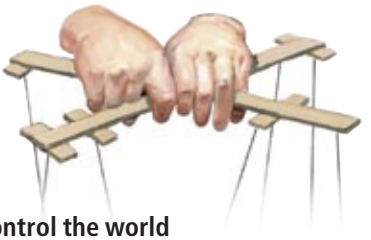
Skeptic

Agenticity



Why people believe that invisible agents control the world

BY MICHAEL SHERMER

Souls, spirits, ghosts, gods, demons, angels, aliens, intelligent designers, government conspirators, and all manner of invisible agents with power and intention are believed to haunt our world and control our lives. Why?

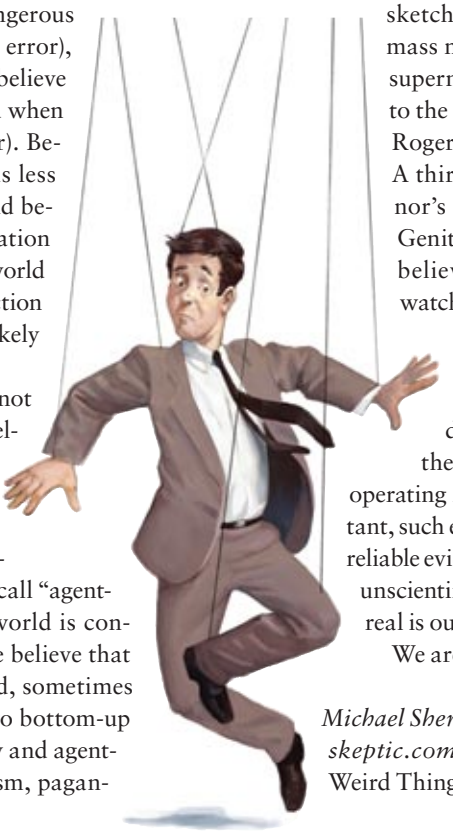
The answer has two parts, starting with the concept of "patternicity," which I defined in my December 2008 column as the human tendency to find meaningful patterns in meaningless noise. Consider the face on Mars, the Virgin Mary on a grilled cheese sandwich, satanic messages in rock music. Of course, some patterns are real. Finding predictive patterns in changing weather, fruiting trees, migrating prey animals and hungry predators was central to the survival of Paleolithic hominids.

The problem is that we did not evolve a baloney-detection device in our brains to discriminate between true and false patterns. So we make two types of errors: a type I error, or false positive, is believing a pattern is real when it is not; a type II error, or false negative, is not believing a pattern is real when it is. If you believe that the rustle in the grass is a dangerous predator when it is just the wind (a type I error), you are more likely to survive than if you believe that the rustle in the grass is just the wind when it is a dangerous predator (a type II error). Because the cost of making a type I error is less than the cost of making a type II error and because there is no time for careful deliberation between patternicities in the split-second world of predator-prey interactions, natural selection would have favored those animals most likely to assume that all patterns are real.

But we do something other animals do not do. As large-brained hominids with a developed cortex and a theory of mind—the capacity to be aware of such mental states as desires and intentions in both ourselves and others—we infer agency behind the patterns we observe in a practice I call "agenticity": the tendency to believe that the world is controlled by invisible intentional agents. We believe that these intentional agents control the world, sometimes invisibly from the top down (as opposed to bottom-up causal randomness). Together patternicity and agenticity form the cognitive basis of shamanism, paganism, animism, polytheism, monotheism, and all modes of Old and New Age spiritualisms.

Agenticity carries us far beyond the spirit world. The Intelligent Designer is said to be an invisible agent who created life from the top down. Aliens are often portrayed as powerful beings coming down from on high to warn us of our impending self-destruction. Conspiracy theories predictably include hidden agents at work behind the scenes, puppet masters pulling political and economic strings as we dance to the tune of the Bilderbergers, the Rothschilds, the Rockefellers or the Illuminati. Even the belief that government can impose top-down measures to rescue the economy is a form of agenticity, with President Barack Obama being touted as "the one" with almost messianic powers who will save us.

There is now substantial evidence from cognitive neuroscience that humans readily find patterns and impart agency to them, well documented in the new book *SuperSense* (HarperOne, 2009) by University of Bristol psychologist Bruce Hood. Examples: children believe that the sun can think and follows them around; because of such beliefs, they often add smiley faces on sketched suns. Adults typically refuse to wear a mass murderer's sweater, believing that "evil" is a supernatural force that imparts its negative agency to the wearer (and, alternatively, that donning Mr. Rogers's cardigan will make you a better person). A third of transplant patients believe that the donor's personality is transplanted with the organ. Genital-shaped foods (bananas, oysters) are often believed to enhance sexual potency. Subjects watching geometric shapes with eye spots interacting on a computer screen conclude that they represent agents with moral intentions.



"Many highly educated and intelligent individuals experience a powerful sense that there are patterns, forces, energies and entities operating in the world," Hood explains. "More important, such experiences are not substantiated by a body of reliable evidence, which is why they are *super*natural and unscientific. The inclination or sense that they may be real is our supersense."

We are natural-born supernaturalists. ■

Michael Shermer is publisher of Skeptic *(www.skeptic.com) and author of* Why People Believe Weird Things.

PHOTOGRAPH BY BRAD SWONETZ; ILLUSTRATION BY MATT COLLINS

Anti Gravity

An Immodest Proposal

Darwin was described as dogged, but are dog breeds specious?

BY STEVE MIRSKY

I have an idea. (No, it was not beginner's luck.) The idea came to me while listening to University of Chicago evolutionary geneticist Jerry A. Coyne give a talk on a cruise ship in early March. If you remember last month's column, you already know about the hardships of science lectures on the high seas, where "buffeted" refers not to the effects of winds and waves but to the feeling you get after one too many trips to the smorgasbord. But I digest. I mean, digress.

Creationists argue that speciation has never been seen. Here's part of a December 31, 2008, posting by Jonathan Wells on the Web site of the antithetically named Discovery Institute: "Darwinism depends on the splitting of one species into two, which then diverge and split and diverge and split, over and over again, to produce the branching-tree pattern required by Darwin's theory. And this sort of speciation has never been observed."

The claim makes me think of the trial where a man was charged with biting off another man's ear in a bar fight. (Incredibly, Mike Tyson was not involved.) An eyewitness to the fracas took the stand. The defense attorney asked, "Did you actually see with your own eyes my client bite off the ear in question?" The witness said, "No." The attorney pounced: "So how can you be so sure that the defendant actually bit off the ear?" To which the witness replied, "I saw him spit it out." We have the fossils, the intermediate forms, the comparative anatomy, the genomic homologies—we've seen what evolution spits out.

Back to the ship. Coyne's address was on the vast amounts of incontrovertible scientific evidence available for evolution. (To recapitulate the cruise experience, you can simply read Coyne's new book, *Why Evolution Is True*, while overeating.) As Darwin did before him, Coyne noted that the development of new breeds through artificial selection is a good model for the evolution of new species by natural selection. He then offered a comment about dog breeds, also found in his book: "If somehow the recognized breeds existed only as fossils, paleontologists would consider them not one species but many—certainly more than the thirty-six species of wild dogs that live in nature today."

Even incredibly closely related populations of organisms are typically considered different species if there is some kind of reproductive barrier between them. And it doesn't have to be mismatched chromosomes. Could be a mountain if you're not a goat. Could be a molehill if you're not a mole.

Duke University's Mohamed Noor, who was also lecturing onboard the ship, studies such barriers. His accomplishments include winning the Linnean Society's Darwin-Wallace Medal, given out every 50 years for evolutionary research. If Jonathan Wells studied the right 49-year period, he might argue that it's impossible for anyone to win the award because that kind of recognition has never been observed.

Noor looked at the fruit flies *Drosophila pseudoobscura* and *D. persimilis*. In the lab, he can get a female *D. pseudoobscura* to mate and produce some fertile offspring with a male *D. persimilis*. Out in the world, however, it doesn't happen—she hates his smell, his song, his mating dance.

So here's the idea you've been patiently waiting for: let's simply say that dog breeds are different species. Take two that Coyne highlights for their differences—the 180-pound English Mastiff and the two-pound Chihuahua. They're both considered members of *Canis lupus familiaris,* and in principle artificial insemination could produce some sort of mix or possibly an exploding Chihuahua. But face it, the only shot a male Chihuahua has with a female Mastiff involves rock climbing or spelunking equipment.

Biologists clearly continue to include the two types of dogs within the same species out of modesty. But with creationists fighting evolution education throughout the country, the time calls for bold action. Let's reassign the trembling, bug-eyed Chihuahua to its own species. Voilà, humans have observed speciation. We could call the new dog *C. nervosis*. Or *C. cantseetheparadis*. Or *C. canyoupresstwelveformepleasis*. Amazingly, right now Chihuahuas are still considered *C. lupus familiaris,* a subspecies of wolf. And calling a Chihuahua a wolf is like calling someone at the Discovery Institute a scientist. ■

PHOTOGRAPH BY FLYNN LARSEN; ILLUSTRATION BY MATT COLLINS

RON MILLER

KEY CONCEPTS

- Few if any astronomers expected the sheer diversity of planets beyond our solar system. The most extreme systems are those that orbit neutron stars, white dwarfs and brown dwarfs.
- Neutron stars are born in supernova explosions, and planets orbiting them probably congealed from the debris. The bodies orbiting white dwarfs are the hardy survivors of the demise of a sunlike star. And brown dwarfs, themselves barely more massive than planets, nonetheless appear to be sites of planet formation.

—The Editors

Among the most poignant sights in the heavens are white dwarfs. Although they have a mass comparable to our sun's, they are among the dimmest of all stars and becoming ever dimmer; they do not follow the usual pattern relating stellar mass to brightness. Astronomers think white dwarfs must not be stars so much as the corpses of stars. Each white dwarf was once much like our sun and shone with the same brilliance. But then it began to run out of fuel and entered its stormy death throes, swelling to 100 times its previous size and brightening 10,000-fold, before shedding its outer layers and shriveling to a glowing cinder the size of Earth. For the rest of eternity, it will sit inertly, slowly fading to blackness.

As if this story were not gloomy enough, it gets worse. We and our colleagues have found more than a dozen white dwarfs in our galaxy that are orbited by asteroids, comets and perhaps even planets—entire graveyards of worlds. While the stars were still alive, they rose every day in the skies of these worlds. They gently warmed the soil and stirred the wind. Living organisms may have soaked up their rays. But when the stars died, they vaporized or engulfed and incinerated their inner planets, leaving only the bodies that resided in the chilly outposts. Over time the dwarfs shredded and consumed many of the survivors as well. These decimated systems offer a grim look at the fate of our own solar system when the sun dies five billion years from now.

Astronomers have always suspected that planets might orbit stars other than our sun. We imagined, though, that we would find systems much like our own solar system, centered on a star much like the sun. Yet when a flood of discoveries began 15 years ago, it was apparent right away that extrasolar planetary systems can differ dramatically from our solar system. The first example was the sunlike star 51 Pegasi, found to have a planet more massive than Jupiter on an orbit smaller than that of Mercury. As instruments became more sensitive, they found ever stranger instances. The sunlike star HD 40307 hosts three planets with masses between four and 10 Earth

IMPROBABLE PLANETS

Astronomers are finding planets where there were not supposed to be any

By Michael W. Werner and Michael A. Jura

masses, all on orbits less than half the size of Mercury's. The sunlike star 55 Cancri A has no fewer than five planets, with masses ranging from 10 and 1,000 Earth masses and orbital radii ranging from one tenth that of Mercury to about that of Jupiter. Planetary systems imagined in science fiction scarcely compare.

The white dwarf systems demonstrate that the stars do not even need to be sunlike. Planets and planetary building blocks can orbit bodies that are themselves no larger than planets. The variety of these systems equals that of systems around ordinary stars. Astronomers hardly expected the ubiquity of planetary systems, their hardiness and the apparent universality of the processes by which they form. Solar systems like our own might not be the most common sites for planets, or even life, in the universe.

Phoenix from the Ashes

It is sometimes forgotten today, but the first confirmed discovery of any extrasolar planets was around a very unsunlike star: the neutron star PSR 1257+12, an even more extreme type of stellar corpse than a white dwarf. It packs a mass greater than the sun's into the size of a small asteroid, some 20 kilometers across. The event that created this beast, the supernova explosion of a star 20 times the mass of the sun, was more violent than the demise of a sunlike star, and it is hard to imagine planets surviving it. Moreover, the star that exploded probably had a radius larger than 1 AU (astronomical unit, the Earth-sun distance), which is larger than the orbits of the planets we see today. For both reasons, those planets must have risen up out of the ashes of the explosion.

Although supernovae typically eject most of their debris into interstellar space, a small amount remains gravitationally bound and falls back to form a swirling disk around the stellar remnant. Disks are the birthing grounds of planets. Astronomers think our solar system took shape when an amorphous interstellar cloud of dust and gas collapsed under its own weight. The conservation of angular momentum, or

▲ **BROWN DWARF** is a star so small—some are hardly more massive than a large planet—that it never lit up. Astronomers scarcely even bothered to look for planets around such runts. Yet they have now seen hints of mini solar systems forming around brown dwarfs and similarly unlikely objects.

[THE AUTHORS]

Michael W. Werner is project scientist for NASA's Spitzer Space Telescope and chief scientist for astronomy and physics at the NASA Jet Propulsion Laboratory. He has been an active researcher in infrared astronomy for more than 35 years, studying star formation, the interstellar medium and the central regions of our galaxy. Next to Spitzer, Werner's favorite pastime is drawing.

Michael A. Jura is professor of astronomy at the University of California, Los Angeles. He has worked on the astrophysics of cold, low-density environments and on extrasolar planetary systems. Jura traces his interest in exoplanets to the science fiction he read as a child.

spin, kept some of the material from simply falling all the way to the newborn sun; instead it settled into a pancake shape. Within this disk, dust and gas coagulated into planets [see "The Genesis of Planets," by Douglas N. C. Lin; SCIENTIFIC AMERICAN, May 2008]. Much the same process could have occurred in the postsupernova fallback disk.

Astronomers discovered the system around PSR 1257+12 by detecting periodic deviations in the timing of the radio pulses it gives off; such deviations arise because the orbiting planets pull slightly on the star, periodically shifting its position and thus altering the distance the pulses must travel. Despite intensive searches of other stars' pulses, observers know of no other comparable system. Another pulsar, PSR B1620–26, has at least one planet, but it orbits so far from the star that astronomers think it did not form in a fallback disk but rather was captured gravitationally from another star.

In 2006, however, NASA's Spitzer Space Telescope discovered unexpected infrared emission from the neutron star 4U 0142+61. The infrared light might arise from the star's magnetosphere or from a circumstellar disk. This star formed in a supernova explosion about 100,000 years ago, and it typically takes about a million years or so for planets to agglomerate, so if the radiation does signal the presence of a disk, this system may one day resemble that revolving around PSR 1257+12.

Many white dwarfs also have disks, albeit of a somewhat different type: disks that indicate the actual presence of orbiting bodies rather than merely the potential to form them. As with 4U 0142+61, the clue is the unexpected emission of infrared light. The first hint dates to 1987, when one of NASA's ground-based observatories, the Infrared Telescope Facility on the summit of Mauna Kea in Hawaii, found excess infrared light from the white dwarf G29–38. The spectrum of this excess was that of a body with a temperature of 1,200 kelvins, much cooler than the surface of the star, which is 12,000 kelvins.

Initially astronomers thought that the dwarf must be orbited by a second, cooler star. But in 1990 they showed that the infrared emission varied in unison with the star's own brightness, indicating that it was reflected or reprocessed starlight. The most plausible explanation is a circumstellar disk heated by the star.

This star has another peculiar property. Its outermost layers contain heavy elements such as calcium and iron, which is odd because the gravitational field near the surface of a white dwarf

[WHAT ASTRONOMERS LOOK FOR]

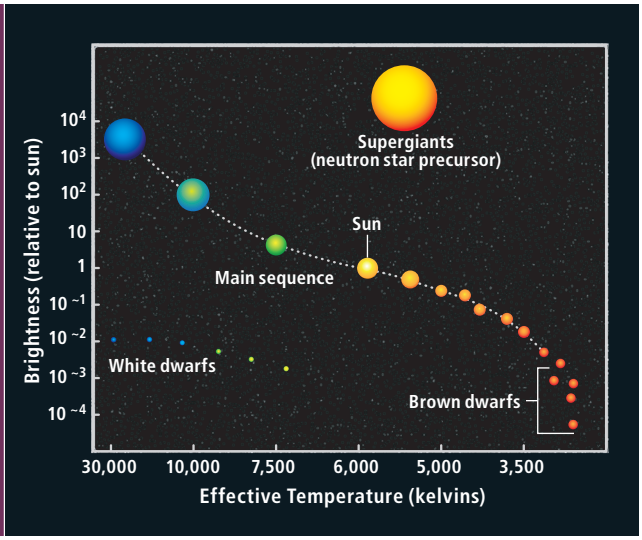
Glowing in the Dark

Astronomers generally detect planets indirectly, by virtue of their effects on the velocity, position or brightness of their host stars. For most of the cases discussed in the article, astronomers focus on one type of indirect sign: the presence of a disk of dust orbiting the star. A so-called protoplanetary disk occurs around newly born stars and is thought to be the site of planet formation. A so-called debris disk occurs around mature stars and is thought to arise from collisions or evaporation of comets and asteroids, thus signaling the likely presence of planets now or in the past.

Observers identify both types of disk from how they absorb starlight and reradiate the absorbed energy at infrared wavelengths (*right*). NASA's Spitzer Space Telescope, launched in 2003, has proved to be a veritable disk discovery machine. Its large field-of-view infrared cameras can capture hundreds of stars in a single image and pinpoint those with evidence of disks for further study.

Spitzer builds on the successes of past infrared telescopes, such as the Infrared Astronomical Satellite (IRAS) mission in the 1980s and the European Space Agency's Infrared Space Observatory (ISO) in the mid-1990s. Unlike IRAS, which was an all-sky survey, Spitzer points at specific celestial bodies for intensive study, and the five-year-plus lifetime of its liquid-helium coolant far exceeds that of any previous mission. The telescope has studied everything from extrasolar planets to galaxies in the early universe.

The coolant is now running out, and the telescope will soon start to warm from nearly absolute zero to 30 kelvins. Even so, it will be able to operate at the short-wavelength end of the infrared band through at least the middle of 2011. Taking up the slack will be the newly launched Herschel Space Observatory and the James Webb Space Telescope (JWST), planned for launch in 2013. —***M.W.W. and M.A.J.***

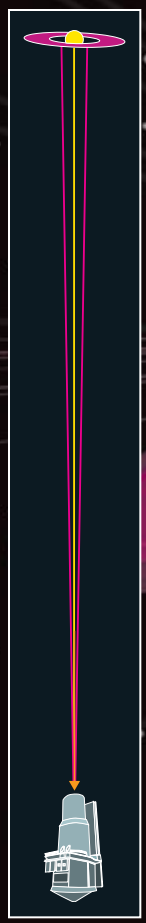


ORDINARY STARS, which lie on the so-called main sequence relating temperature and brightness, struck astronomers as the most natural places to find analogues of our solar system. But systems are also turning up around objects that lie off this sequence, such as white and brown dwarfs.

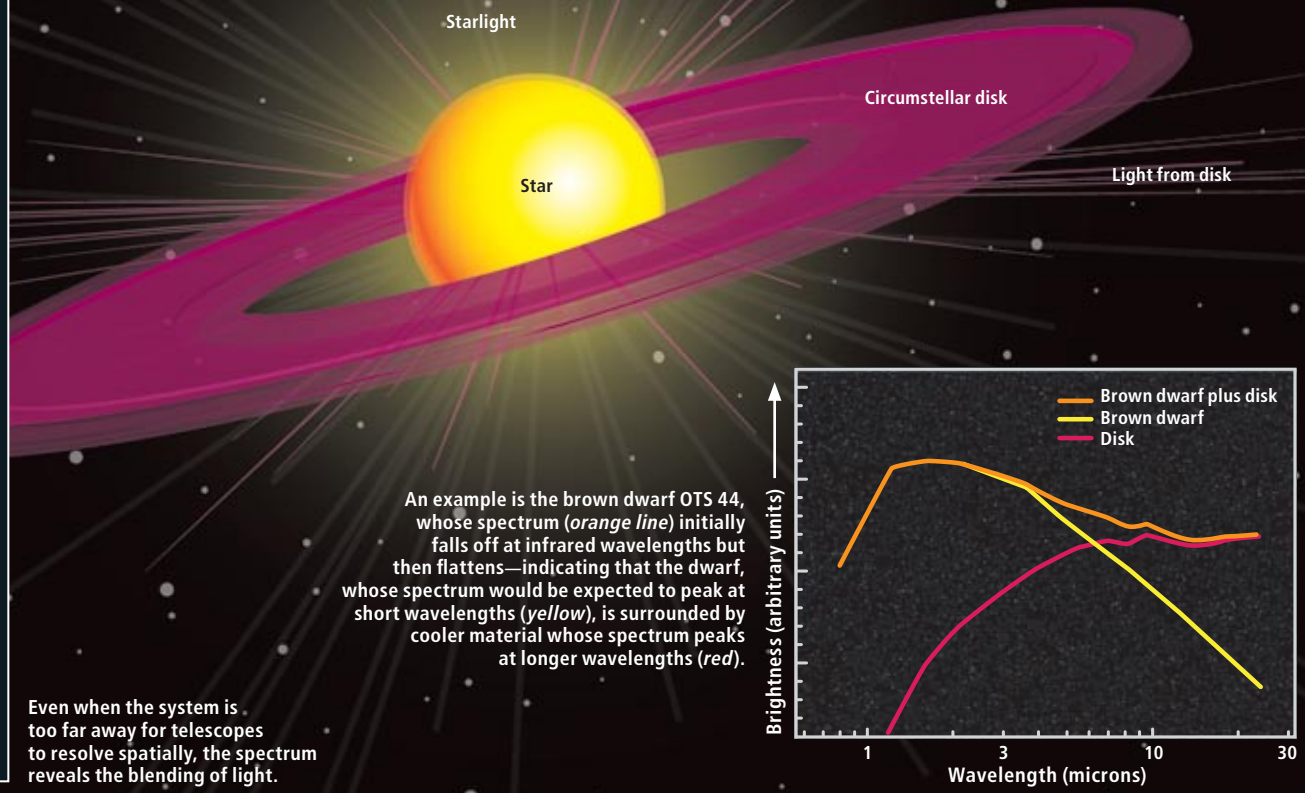
NASA/JPL-CALTECH (*Werner*); COURTESY OF MICHAEL A. JURA (*Jura*); MELISSA THOMAS (*graph*)

Infrared Light Reveals Disks and Thus Planets or Their Building Blocks

A circumstellar disk of dust and gas, like the one that gave rise to the planets of our solar system, absorbs starlight and emits infrared radiation. We observe a composite of direct starlight and disk emission.



Even when the system is too far away for telescopes to resolve spatially, the spectrum reveals the blending of light.



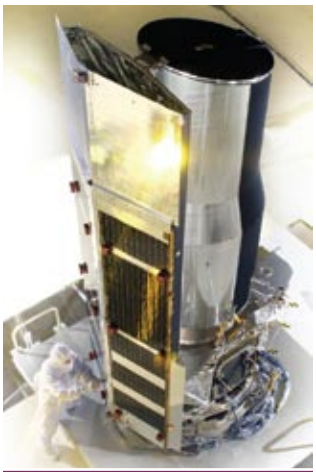
An example is the brown dwarf OTS 44, whose spectrum (*orange line*) initially falls off at infrared wavelengths but then flattens—indicating that the dwarf, whose spectrum would be expected to peak at short wavelengths (*yellow*), is surrounded by cooler material whose spectrum peaks at longer wavelengths (*red*).

RUSS UNDERWOOD *Lockheed Martin Space Systems (Spitzer telescope);* MELISSA THOMAS *(illustrations)*

is so strong that those elements should sink into the interior. In 2003 one of us (Jura) proposed a simple explanation for both the infrared excess and the presence of heavy elements: the white dwarf recently shredded an asteroid that strayed into its intense gravitational field. A cascade of collisions reduced the debris to an orbiting dust disk, which dribbled onto the star.

Asteroids for Dessert

Observations have since confirmed this scenario. Astronomers using both ground-based telescopes and the Spitzer telescope have identified some 15 white dwarfs with similar infrared excesses and elemental anomalies. For G29–38 and seven other stars, Spitzer has gone further and identified infrared emission from silicates in the disks. These silicates resemble those in dust particles in our solar system and appear quite different from those in dust in interstellar



SPITZER SPACE TELESCOPE, shown here under construction, is the infrared counterpart to the Hubble Space Telescope.

space [*see box on page 43*]. Moreover, although the stars' outer layers contain heavy elements, they do not contain those elements in equal amounts. They are deficient in volatile elements such as carbon and sodium compared with elements that tend to remain in solid form, such as silicon, iron and magnesium. This elemental pattern matches that of the asteroids and rocky planets of the solar system. Both these facts support the contention that the disks are ground-up asteroids.

The disks around white dwarfs are much smaller than the disks that give rise to planets around newborn sunlike stars. Judging from their infrared emission, they extend to only about 0.01 AU and have a mass as low as that of an asteroid 30 kilometers in diameter—a fact consistent with their possible origin in the disintegration of such an object. They are not potential sites of the formation of new planets but

rather indicators that some planetary material survived the demise of the star. Theoretical calculations suggest that asteroids and Earth-like planets can escape destruction if they orbit farther than 1 AU. When our sun dies, Mars should make it, but Earth may or may not.

To study how parts of a planetary system might endure, two years ago Spitzer observed the white dwarf WD 2226–210. This dwarf is so young that the outer layers of the original sunlike star remain visible as the Helix nebula, one of the best-known planetary nebulae [see "The Extraordinary Deaths of Ordinary Stars," by Bruce Balick and Adam Frank; SCIENTIFIC AMERICAN, July 2004].

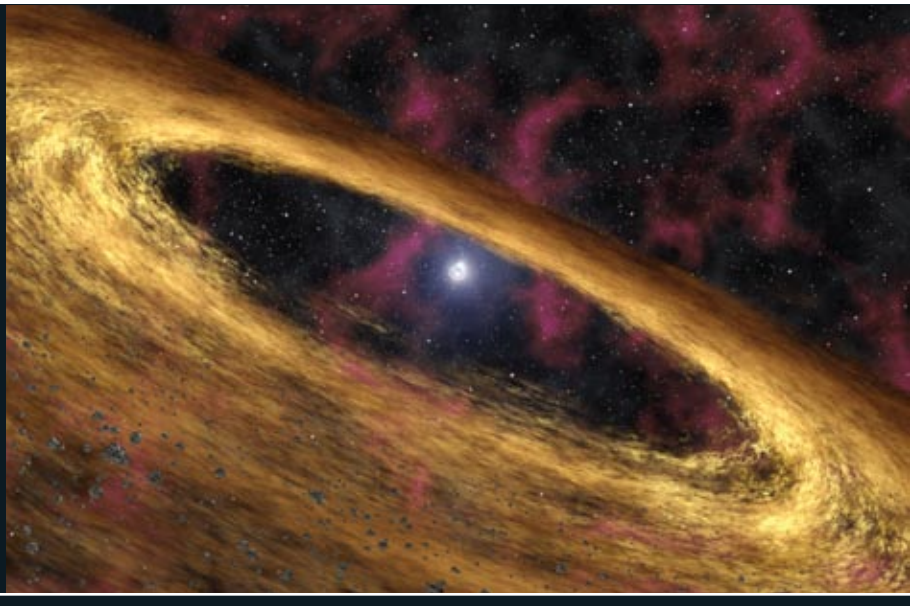
Consequently, WD 2226–210 provides the missing link between sunlike stars and older white dwarfs such as G29–38. Around it is a dusty disk at a distance of 100 AU, comparable to the scale of our solar system. That is much farther than disks around other white dwarfs extend—too far, in fact, to consist of asteroids torn up by the dwarf's gravity. This disk must instead consist of dust released as asteroids and comets collide. Similar debris disks exist around the sun and sunlike stars [see "The Hidden Members of Planetary Systems," by David R. Ardila; SCIENTIFIC AMERICAN, April 2004].

This discovery confirms that when a sunlike star dies, distant asteroids and comets can survive. And if asteroids and comets can survive, planets (which are, if anything, more durable) should be able to survive as well. As WD 2262–210 cools, it will give off less light to illuminate the dust, and the distant belt of asteroids and comets will fade into invisibility. But occasionally one of its members may wander close enough to the white dwarf to be shredded.

[EXTREME PLANETS #1]

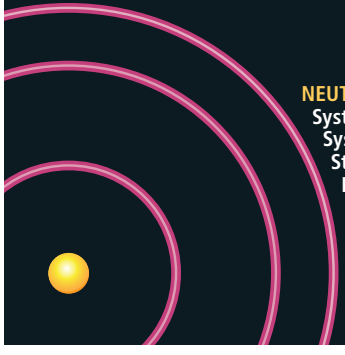
Neutron Star Systems

Neutron stars are probably the strangest and least expected hosts of planetary systems. The neutron star 4U 0142+61, remnant of a star that exploded as a supernova 100,000 years ago, is swaddled in a disk of stellar debris (*artist's impression at right*). The debris may be clumping into planetary building blocks (*gray chunks*).

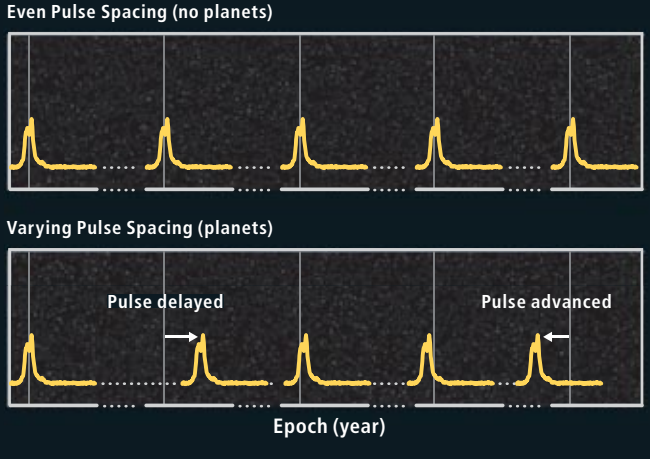


NEUTRON STAR + DISK
System name: 4U 0142+61
System age: 100,000 years
Star radius: 10 kilometers
Disk radius: 1 astronomical unit (AU)

Another neutron star, PSR 1257+12, has bona fide planets. Its pulses of radio emission oscillate slightly in their arrival times (*right*), indicating that the star is being yanked around by three orbiting worlds (*below*).



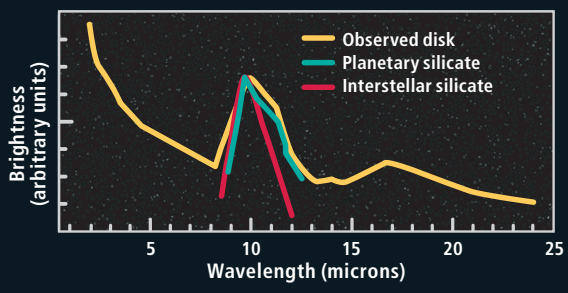
NEUTRON STAR + PLANETS
System name: PSR 1257+12
System age: 800 million years
Star radius: 10 km
Planet orbital radii: 0.19, 0.36, 0.46 AU
Planet masses: 0.02, 4.3, 3.9 Earth masses

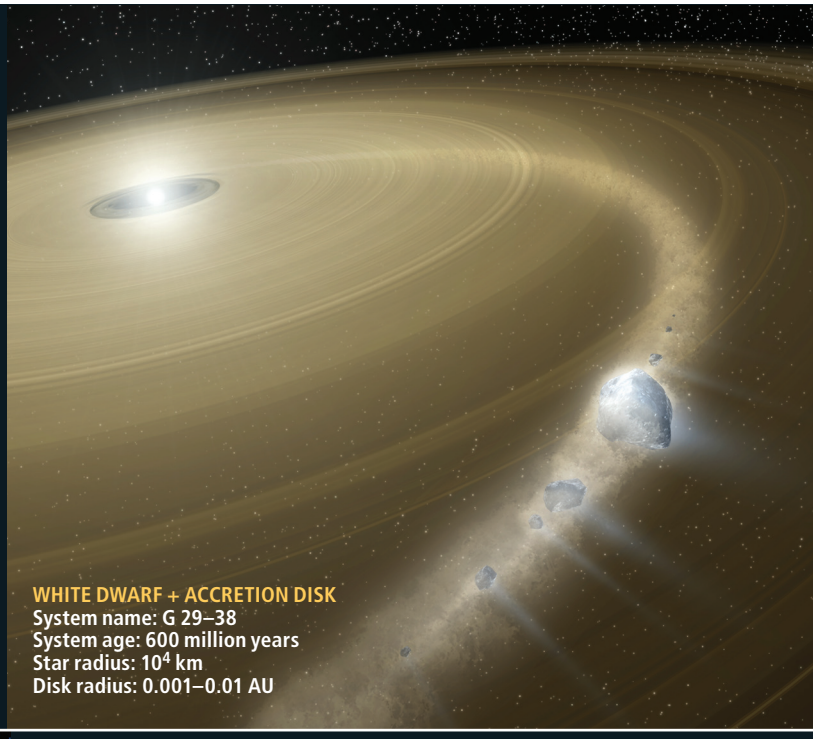


[EXTREME PLANETS #2]

White Dwarf Systems

Many a white dwarf is hugged by a tiny disk of material, probably the remains of an asteroid (*artist's impression at right*). In some of these disks, astronomers have seen the spectral signature of silicate. The spectrum matches that of planetary silicate (*green curve in graph below*)—in essence, stone—as opposed to interstellar silicate (*red curve*). This and other evidence suggest that orbiting bodies, possibly including planets as well, survived the tumultuous creation of the dwarf and still trundle through the unseen outskirts of the system.





WHITE DWARF + ACCRETION DISK
System name: G 29–38
System age: 600 million years
Star radius: 10^4 km
Disk radius: 0.001–0.01 AU

A second type of debris disk around a white dwarf shows up as a red dot at the center of this infrared image of the Helix nebula. This disk is probably the equivalent of the Kuiper belt of comets in our own solar system. Such disks may exist around other white dwarfs, too, but are undetectable because those dwarfs are older and thus provide less illumination.

WHITE DWARF + DEBRIS DISK
System name: WD 2226–210 (Helix nebula)
System age: 10,000 years
Star radius: 10^4 km
Disk radius: 100 AU

NASA/JPL-CALTECH/R. HURT *Spitzer Science Center (opposite page)*; NASA/JPL-CALTECH/T. PYLE *Spitzer Science Center (top)*; NASA/JPL-CALTECH/K. SU *University of Arizona (bottom)*; MELISSA THOMAS *(graphs)*

Starlets

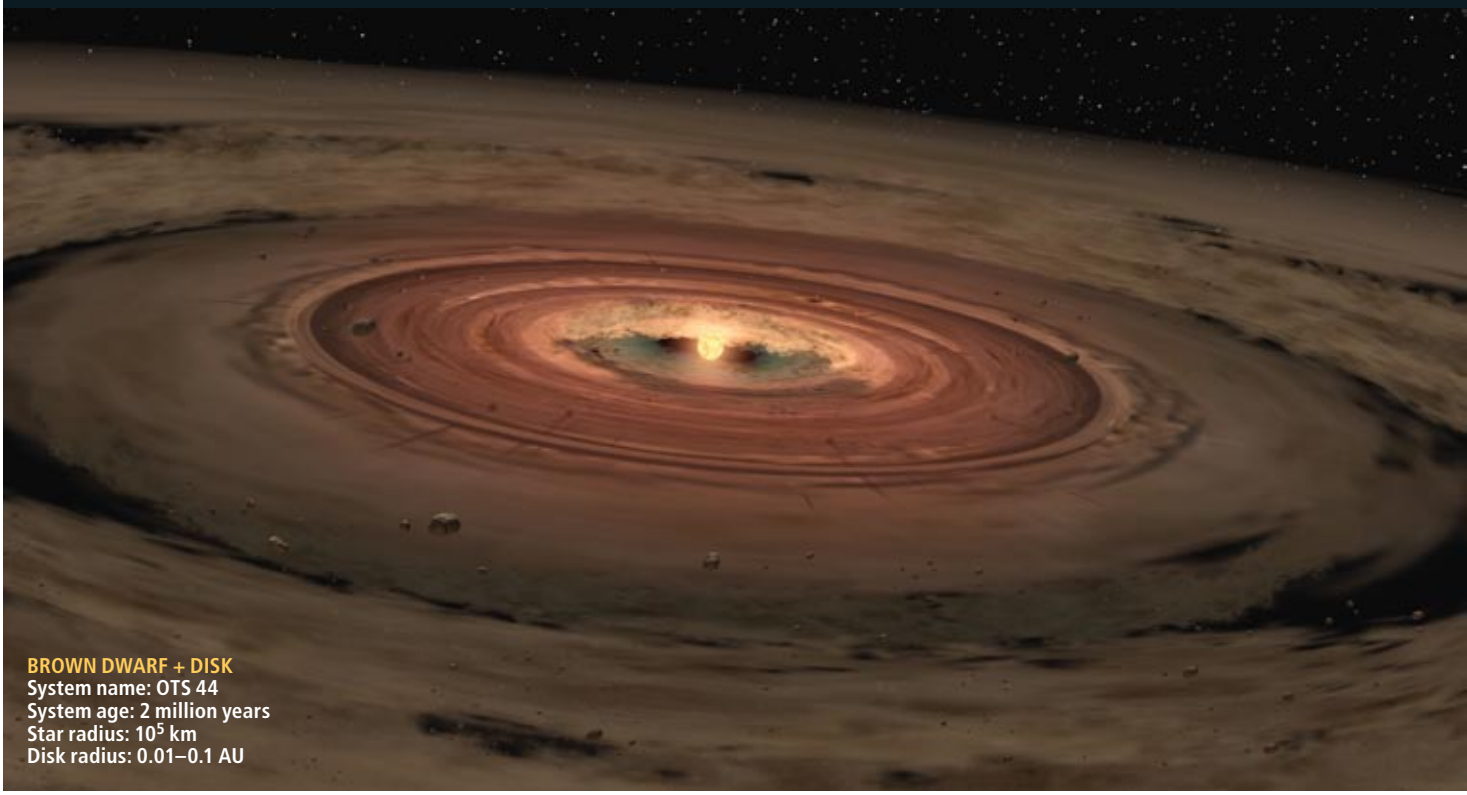
A third type of nonsunlike star that might host planets is the brown dwarf. Brown dwarfs are very different from white dwarfs, despite the similar names. They are not stellar corpses but stellar runts. They form in the same way stars do, but their growth is stunted, leaving them with less than about 8 percent the mass of the sun—the threshold required for a stellar core to become hot and dense enough to ignite sustained nuclear fusion. The most they manage is a feeble infrared glow as they radiate away the heat they accumulated during their formation (and perhaps a brief early period of fusion). Over the past 15 years astronomical surveys have found hundreds of brown dwarfs, and the least massive of them is scarcely heavier than a giant planet.

Astronomers have found that these bodies, even the smallest among them, can have disks and therefore perhaps planets as well [see "The Mystery of Brown Dwarf Origins," by Subhanjoy Mohanty and Ray Jayawardhana; SCIENTIFIC AMERICAN, January 2006]. The possibility of planets is supported by observations showing that brown dwarf disks undergo a series of systematic changes—including a drop in the prominence of the infrared emission from silicates—attributable to coagulation of the dust particles. The same changes also occur in disks around larger stars and signal the growth of planetary building blocks. The brown dwarf disks are too

[EXTREME PLANETS #3]

Brown Dwarf Systems

Many brown dwarfs have disks in which planets may be forming. The one around OTS 44 has enough material for a Uranus or Neptune. This dwarf is about two million years old; when the sun was the same age, the planets in our solar system were beginning to take shape. The intimation that planets can arise in such an unpromising setting as the environs of a brown dwarf, white dwarf or neutron star suggests that planet formation is far more robust than astronomers used to think.



BROWN DWARF + DISK
System name: OTS 44
System age: 2 million years
Star radius: 10^5 km
Disk radius: 0.01–0.1 AU

MORE TO EXPLORE

First Fruits of the Spitzer Space Telescope: Galactic and Solar System Studies. M. Werner, G. Fazio, G. Rieke, T. L. Roellig and D. M. Watson in *Annual Reviews of Astronomy and Astrophysics,* Vol. 44, pages 269–321; 2006. Available at **http://arxiv.org/abs/astro-ph/0606563**

Externally-Polluted White Dwarfs with Dust Disks. M. Jura, J. Farihi and B. Zuckerman in *Astrophysical Journal*, Vol. 663, No. 2, pages 1285–1290; July 10, 2007. Available at **http://arxiv.org/abs/0704.1170**

The Chemical Composition of an Extrasolar Minor Planet. B. Zuckerman, D. Koester, C. Melis, B. Hansen and M. Jura in *Astrophysical Journal*, Vol. 671, No. 1, pages 872–877; December 10, 2007. Available at **http://arxiv.org/abs/0708.0198**

meager for planets as large as Jupiter to form but contain plenty of material for a Uranus or Neptune. Some astronomers have claimed the discovery of planets that formed around brown dwarfs, but none of these claims is definitive.

In short, astronomers have found planets around at least one neutron star; asteroids and comets around more than a dozen white dwarfs; and evidence for the early stages of planet formation around brown dwarfs. Ultimately, the study of these and other extrasolar systems has two goals: First, astronomers hope to learn more about our own solar system, particularly about its evolution and large-scale structure, features that are hard to discern from our limited temporal and spatial perspective. We also hope to place our solar system in its context. Is it average or an outlier? Despite the diversity of planetary systems, do they follow some common pathways in their formation? The similarity between the composition of asteroids in our solar system and of the material that has fallen onto white dwarfs suggests that the answer is yes.

The second goal is to determine how widespread life might be in the universe. In our galactic neighborhood, brown dwarfs are roughly as numerous as stars. Might the nearest "star" to our sun be a yet to be discovered brown dwarf? Might the nearest planets to our solar system orbit a brown dwarf? The Wide-field Infrared Survey Explorer (WISE) satellite, which NASA plans to launch at the end of the year, may well discover several brown dwarfs closer than the nearest known star. The formation of terrestrial planets around brown dwarfs would not only extend the range of potential habitats but also lead to the intriguing possibility that the nearest extraterrestrial life may wake up in the morning to a brown dwarf.

Similarly, the presence of asteroids and comets around white dwarfs raises the possibility not only that planets can survive the demise of a sunlike star but also that life, if it could adapt to the changing conditions, may hold out in the environs of these dead stars. Perhaps, then, white dwarfs are not such a gloomy sight after all. ■

NASA/JPL-CALTECH/T. PYLE *Spitzer Science Center*

[UPDATE ON OTHER PLANET SEARCHES]

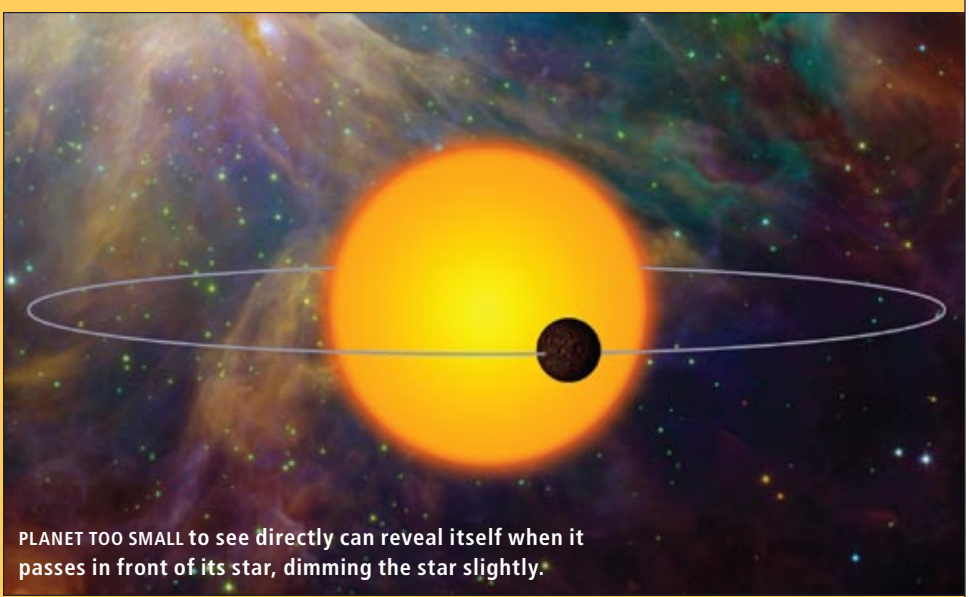
The Planetary Tease

Astronomers are on the verge of finding other Earths—but still far from knowing whether they are inhabited

By Donald Goldsmith

On March 6 NASA's Kepler space telescope embarked on a four-year mission to discover Earth-like planets in the Milky Way. Like its predecessor, the French-led COROT mission launched in December 2006, Kepler will monitor a selection of stars for temporary decreases in brightness. One dip could mean anything, probably just a blip in the star's energy output; a second dip would still signify relatively little; a third dip, occurring after the same time interval as that between the first and second, would seem highly provocative; and a fourth dip after an identical interval would almost certainly mean that a planet is on an orbit that carries it directly between the star and us. Every time the planet passed, or transited, across the face of its star, it would block some of the starlight. A world roughly the size of ours diminishes its star's light by about one part in 10,000 [see "Searching for Shadows of Other Earths," by Laurance R. Doyle, Hans-Jörg Deeg and Timothy M. Brown; SCIENTIFIC AMERICAN, September 2000].

Earlier this year COROT found a planet with about twice Earth's diameter, orbiting so close to its parent star that each revolution takes only 20 hours. Kepler, with a mirror three and a half times wider than COROT's, should find dozens or hundreds of Earths orbiting at more comfortable distances from their star. Most current searches, which look for the slight gravitational tug that a planet exerts on its parent star, could not detect such comparatively small worlds. The trade-off is that the planets' orbits must be aligned with our line of sight, and the laws of probability suggest that only about one in 100 will be so lucky. Nevertheless, Kepler will be able to create a statistically valid sample of Earth's galactic cousins.



PLANET TOO SMALL to see directly can reveal itself when it passes in front of its star, dimming the star slightly.

But if this triumph occurs, astronomers will find themselves bereft of the information that they would most dearly like to obtain: What conditions exist on these planets? Are they suitable for life? When a gas-giant planet transits its star, astronomers can analyze its atmosphere by measuring the amount of dimming produced at different wavelengths. But planets the size of Earth are far too small for this technique to work. So the search strategy employed by COROT and Kepler can find Earths but cannot tell us much about them. They cannot discern any of the signs of life, such as the distinctive colors of chlorophyll or its alien equivalents [see "The Color of Plants on Other Worlds," by Nancy Y. Kiang; SCIENTIFIC AMERICAN, April 2008]. Even the Space Interferometry Mission (SIM), loosely planned for launch in 2015, will say little about the Earths it discovers.

The instruments capable of assessing habitability lie still further in the future, primarily because they are so expensive. NASA's Terrestrial Planet Finder (TPF) and the European Space Agency's Darwin mission could take spectroscopic measurements of planets' surfaces and atmospheres, but neither has yet proceeded beyond the design study phase. Even if the agencies pool their resources, the mission could cost about $2 billion and take nearly a decade to build. For now, the best hopes for gleaning more information about planets are the James Webb Space Telescope (JWST), scheduled for launch in 2013, and the next generation of ground-based telescopes [see "Giant Telescopes of the Future," by Roberto Gilmozzi; SCIENTIFIC AMERICAN, May 2006]. Although they were not specifically designed for planet analysis, these telescopes will be equipped with coronagraphic instruments designed to block starlight, allowing researchers to see any small bodies hiding in the glare. These instruments could produce images of young gas-giant planets, if they exist, around some of the nearest stars. They might also be able to piece together spectroscopic information about tightly orbiting objects.

The bottom line is that the next several years of the COROT and Kepler missions will be hugely exciting, and then we will enter a frustrating period of dreaming of what might yet be found. That is not unusual: scientific understanding proceeds incrementally. Positive results may inspire the funding and completion of new spaceborne observatories. The search for planets in extreme settings such as the environs of neutron stars, white dwarfs and brown dwarfs will show us how robust planet formation is [*see main article*]. But we need to prepare ourselves for a long struggle to discover our planet's rightful place in the cosmos.

Donald Goldsmith is author of the new book 400 Years of the Telescope *(Interstellar Media Productions, 2009). He was science editor and co-writer of the PBS television series* The Astronomers *and co-writer of* NOVA*'s "Is Anybody Out There?"*

RON MILLER

The PRICE of SILENT MUTATIONS

Small changes to DNA that were once considered innocuous enough to be ignored are proving to be important in human diseases, evolution and biotechnology

By J. V. Chamary and Laurence D. Hurst

KEY CONCEPTS

- Scientists long assumed that any DNA mutation that does not change the final protein encoded by a gene is effectively "silent."
- Mysterious exceptions to the rule, in which silent changes seemed to be exerting a powerful effect on proteins, have revealed that such mutations can affect health through a variety of mechanisms.
- Understanding the subtler dynamics of how genes work and evolve may reveal further insights into causes and cures for disease. —*The Editors*

Biologists long thought they understood how genetic mutations cause disease. But recent work has revealed an important twist in the tale and uncovered surprising—even counterintuitive—ways that alterations in DNA can make people sick. The classic view assumed that what are termed "silent" mutations were inconsequential to health, because such changes in DNA would not alter the composition of the proteins encoded by genes. Proteins function in virtually every process carried out by cells, from catalyzing biochemical reactions to recognizing foreign invaders. Hence, the thinking went, if a protein's makeup ends up being correct, any small glitches in the process leading to its construction could not do a body harm.

Yet detective work occasionally traced a disorder to a silent mutation, even though researchers presumed that it could not possibly be the culprit. Similar mysteries popped up in studies of genome evolution, where patterns of changes in the DNA of various species indicated that many silent mutations were preserved over time—a sign that they were useful to the organisms possessing them. In many species, these changes seemed to help cells make proteins more efficiently, but not in people.

Now investigators are beginning to tease out the effects that silent mutations can have on human health and disease. And findings are suggesting intriguing new avenues for improving the design of genes meant to be used as therapies and for genetic engineering.

Synonymous but Not the Same

How a gene mutation can leave a protein unaffected becomes clear when one looks at the way cells make proteins. The basic formula is simple: a string of DNA nucleotides gives rise to a nearly identical sequence of RNA nucleotides, which in turn is translated into an amino acid chain that folds itself neatly into a protein. The letters of this nucleic acid alphabet are distinguished from one another by their chemical bases—adenine (A), cytosine (C), guanine (G) and thymine (T) in DNA, with uracil (U) substituting for thymine in RNA.

In other words, the instructions encoded in nucleic acids must be converted into the language of amino acids so that their "meaning" (a useful protein) can be expressed. When a gene is thus "expressed," the strands of the DNA double helix separate and cellular machinery transcribes the nucleotide sequence along a single strand into a copy made of RNA. Then this messenger RNA (mRNA) transcript must often be edited into a briefer form before it is ready to be translated into a protein by ribosomes and smaller RNAs called transfer RNA (tRNA). As ribosomes ride along the mRNA, tRNAs arrive to deliver the encoded amino acids. Each tRNA carries a specific amino acid, and most are able to recognize just one particular three-nucleotide sequence in the mRNA strand. When a tRNA meets its mRNA match, the ribosome adds the tRNA's amino acid cargo to the growing amino acid chain [*see box on page 49*].

JON KRAUSE

The code that cells use to translate the language of DNA and RNA into protein—the famous genetic code—is thus merely the set of rules that govern which tRNA bears which amino acid. This code has a critical feature: it is redundant. All genes and their mRNAs are organized into three-letter "words," called codons. Sixty-four three-letter codons can be constructed from the four-nucleotide alphabet. Three codons act as stop signals to halt RNA translation, which still leaves 61 possible codons to specify a protein alphabet of only 20 amino acids, so nearly every amino acid is specified by more than one codon. For instance, all codons starting with GG (GGA, GGC, GGG, GGU) are translated to the amino acid glycine, making those codons synonyms.

Single-letter changes to the DNA, known as point mutations, can therefore change a codon to one that specifies the wrong amino acid (known as a missense mutation) or to a stop signal (nonsense mutation), causing the final protein to be truncated. A single-base change can also alter a stop codon so that it then encodes an amino acid (sense mutation), resulting in a lengthened protein. And a final change is possible: a mutation that alters a nucleotide but yields a synonymous codon. These mutations are the ones termed "silent."

Evidence of Bias

Examples certainly abound of the first three types of point mutations having a major impact on human health. Three different point mutations in the genes encoding proteins that make up the hemoglobin molecules in red blood cells are responsible for three separate and grave diseases, for instance. In the case of sickle cell anemia, a missense mutation exchanges a water-loving (hydrophilic) amino acid for a water-avoiding one (hydrophobic), causing the proteins to clump together and produce characteristic sickle-shaped blood cells. In polycythemia disorders, a nonsense mutation truncates one of the hemoglobin proteins, resulting in thickened blood. And in thalassemia, a sense mutation changes a stop codon (TAA) to the codon for glutamine (CAA), creating a much longer and nonfunctional protein.

Only in the 1980s did scientists realize that silent mutations could also affect protein production—at least in bacteria and yeast. A key discovery at the time was that the genes of those organisms did not use synonymous codons in equal numbers. When the bacterium *Escherichia coli* specifies the amino acid asparagine, for instance, the codon AAC appears in its DNA much more often than AAT. The reason for this biased usage of codons soon became apparent: cells were preferentially employing certain codons because those choices enhanced the rate or accuracy of protein synthesis.

It turned out that tRNAs corresponding to those synonymous codons typically are not equally abundant within the cell. Most important, then, a gene that contains more of the codons matching the relatively abundant tRNAs would be translated faster, because the higher concentration of those tRNAs would make them more likely to be present when needed. In other cases, a single tRNA variety matches more than one synonymous codon but binds more readily to one codon in particular, so the use of that codon maximizes the accuracy of translation. Consequently, a cell has good reasons not to use all codons equally. As expected, in bacteria and yeast the genes that encode especially abundant proteins exhibit the greatest codon bias, with the preferred codons matching the most common or better-binding tRNAs.

Later observations in other organisms—including plants, flies and worms—revealed similar biases. With such a diverse array of species employing this technique to improve the efficiency of protein production, it seemed likely that mammals would, too. Analyses of mammalian genes did indeed reveal tendencies toward favoring certain codons. The similarity between simple organisms and mammals, however, proved to be only superficial. For reasons not yet fully understood, mammalian genomes are organized into large blocks, each with a distinctively skewed nucleotide content: some regions are rich in G and C bases, whereas others are enriched for A and T. As a result, genes residing in a GC-rich region of the genome tend to have many codons containing those bases. Our genes, then, do show a bias for using certain codons, but unlike simpler organisms, the mammalian pattern does not obviously suggest that the reason is to optimize protein synthesis.

For many years these findings seemed to diminish the likelihood that silent mutations influenced the functioning of the human body. Starting in the early 2000s, however, comparisons of the same gene in different species began to hint that this orthodoxy was wrong. One can measure the rate at which gene sequences in two species have diverged by comparing the sites where nucleotides have changed and those

BROKEN SILENCE

Some 50 diseases have been shown to be caused entirely or in part by silent mutations. In this sampling, the mutations result in disrupted RNA editing that affects protein production.

Androgen-insensitivity syndrome

Ataxia telangiectasia

Cholesteryl ester storage disease

Chronic granulomatous disease

Familial adenomatous polyposis

Hereditary nonpolyposis colorectal cancer

Hirschsprung disease

Marfan syndrome

McArdle disease

Phenylketonuria

Seckel syndrome

X-linked hydrocephalus

MARFAN SYNDROME sufferers have elongated body parts and two silent mutations that disrupt RNA splicing in cells.

M. A. ANSARY *Photo Researchers, Inc.*

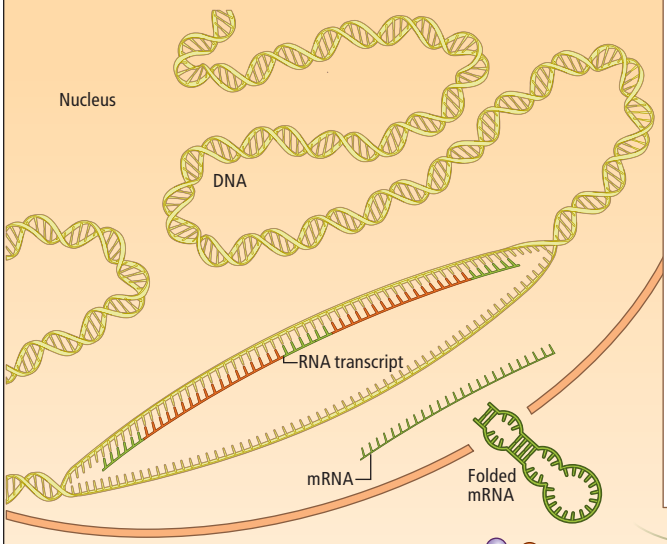
[BASICS]

SILENCE IN THE CODE

The genetic code, which governs how a cell translates DNA instructions, via RNA, into functional proteins, is unusual in that it is redundant. Genes "written" in RNA nucleotides spell out the sequence of amino acids in an encoded protein using three-letter words called codons that correspond to one of 20 amino acids (*table*). With an alphabet of four nucleotide bases, 64 codon triplets are possible—resulting in several codons that specify the same amino acid. A DNA mutation that changes one of these codons to its synonym should therefore be "silent" in protein terms.

▼ TRANSCRIPTION AND EDITING

Inside the cell nucleus, the DNA double helix unwinds to allow an RNA copy of a gene to be made. The resulting transcript is then edited to remove segments that do not encode amino acids, producing a shorter messenger RNA (mRNA) version. Pairing of the bases in the RNA nucleotides causes the mRNA molecule to adopt a folded structure.

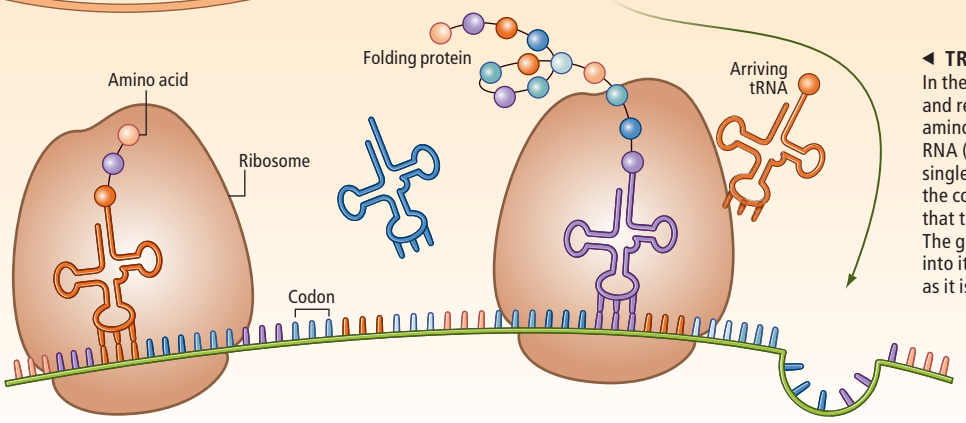


▼ THE CODON–AMINO ACID CODE

Because the four RNA bases (A, C, G, U) yield 64 possible triplet combinations, more than one codon can specify a particular amino acid. Often such synonymous codons differ only in their third nucleotide positions.

Second nucleotide position

First nucleotide position	U	C	A	G
U	UUU Phenylanaline UUC Phenylanaline UUA Leucine UUG Leucine	UCU Serine UCC Serine UCA Serine UCG Serine	UAU Tyrosine UAC Tyrosine UAA STOP UAG STOP	UGU Cysteine UGC Cysteine UGA STOP UGG Tryptophan
C	CUU Leucine CUC Leucine CUA Leucine CUG Leucine	CCU Proline CCC Proline CCA Proline CCG Proline	CAU Histidine CAC Histidine CAA Glutamine CAG Glutamine	CGU Arginine CGC Arginine CGA Arginine CGG Arginine
A	AUU Isoleucine AUC Isoleucine AUA Isoleucine AUG Methionine	ACU Threonine ACC Threonine ACA Threonine ACG Threonine	AAU Asparagine AAC Asparagine AAA Lysine AAG Lysine	AGU Serine AGC Serine AGA Arginine AGG Arginine
G	GUU Valine GUC Valine GUA Valine GUG Valine	GCU Alanine GCC Alanine GCA Alanine GCG Alanine	GAU Aspartate GAC Aspartate GAA Glutamate GAG Glutamate	GGU Glycine GGC Glycine GGA Glycine GGG Glycine



◄ TRANSLATION TO PROTEIN

In the cellular cytoplasm, ribosomes unfold and read the mRNA and produce the encoded amino acid chain with the help of transfer RNA (tRNA) molecules. Each tRNA delivers a single amino acid to the ribosome, binding to the corresponding mRNA codon to confirm that the correct amino acid is being added. The growing amino acid chain begins folding into its three-dimensional protein shape even as it is still forming.

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where they have remained the same. In principle, any mutation that does not affect an organism is invisible to the force of natural selection, which preserves variations that are beneficial. According to the thinking at the time, regions invisible to selection would include sites of silent mutations within genes as well as the 98 percent of the genome that does not specify protein—the noncoding DNA. Yet when scientists began looking at whether silent sites in genes evolved at the same rate as noncoding regions, they unexpectedly found differences—a sign that silent mutations could affect physiology after all.

Breaking the Silence

Initially researchers had no idea how such mutations could disturb protein manufacture in mammals. Lately, however, studies of human disease have provided not just one mechanism but many. Silent disease-causing mutations interfere with several stages of the protein-making process, from DNA transcription all the way through to the translation of mRNA into proteins.

One example involves silent mutations changing how a gene transcript is edited. Shortly after a gene is transcribed into RNA form,

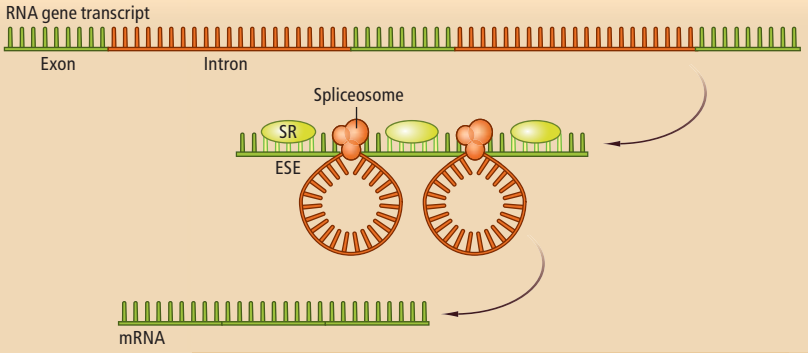
[EDITING PROBLEM]

SPLICING CUES ALTERED

Synonymous codons may specify the same amino acid, but a mutation that changes one codon to its synonym can alter a gene's encoded message if it interferes with the cell's editing of mRNA. Many diseases are caused by such editing errors, and a gene involved in cystic fibrosis illustrates how even so-called silent mutations can cause a gene's protein meaning to change (*bottom*).

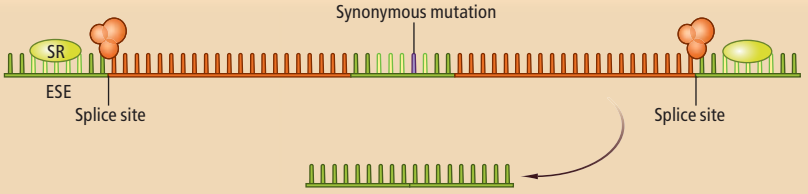
NORMAL RNA SPLICING

The raw RNA transcript of a gene contains exons, which encode amino acids, and long noncoding intron segments that must be edited out of the final mRNA. Within each exon, short nucleotide sequences act as exonic splicing enhancers (ESE) that flag the boundaries of the exon to cellular editing machinery. The binding of splicing regulatory (SR) proteins to enhancer sites directs "spliceosome" proteins to both ends of an intron, which they excise from the transcript, before joining the exon ends together.



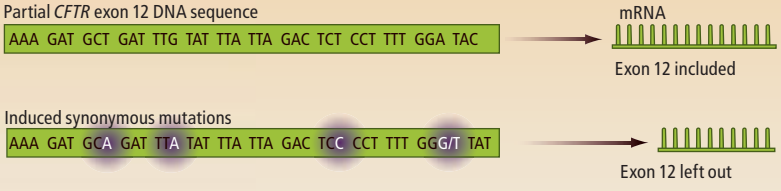
EXON SKIPPING

Single-nucleotide synonymous changes in an exon can render splicing enhancer sequences invisible to the splicing machinery, causing an entire exon to be left out of the final mRNA.



PROTEIN ALTERING

Mutations in the *cystic fibrosis transmembrane-conductance receptor* (*CFTR*) gene that disable the receptor protein are implicated in cystic fibrosis and several other related disorders. In an experiment to test whether silent mutations could also affect the CFTR protein, scientists induced single-nucleotide mutations, one by one, to create synonymous codons in *CFTR* exon 12, then analyzed the resulting proteins. The six synonymous mutations shown (one quarter of those tested) each caused exon 12 to be skipped during mRNA editing, yielding a truncated CFTR protein.



that transcript is trimmed to remove noncoding regions known as introns. Like a movie editor who cuts out unwanted film, cellular splicing machinery needs to find the good bits that encode amino acids, known as exons, and then splice them together to produce the final mRNA version of the gene. Human genes are especially rich in introns, with each gene having an average of eight long intronic stretches, so the splicing machinery needs a way to tell where each exon starts and ends.

Research over the past few years has revealed that exons not only specify amino acids, they also contain within their sequences cues necessary for intron removal. Chief among these are exonic splicing enhancer (ESE) motifs—short sequences of about three to eight nucleotides that sit near the ends of the exons and define the exon for the cellular splicing machinery. The need for such motifs can in fact explain a preference for certain nucleotides in human genes. Although the codons GGA and GGG, which encode glycine, can both occur in splicing enhancers, the former codon acts as a more potent enhancer, leading to more efficient splicing. GGA is also correspondingly more common close to the ends of exons.

In support of the view that preserving codon sequence in splicing enhancers matters, research we did with our former University of Bath colleague Joanna L. Parmley has shown that exonic motifs that apparently function as splicing enhancers show slower evolution in their synonymous codons than do neighboring sequences uninvolved in splicing. This slow evolution indicates that natural selection has kept enhancer motifs relatively unchanged because their specific sequences are so significant. Silent altera-

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tions to codons containing these enhancers, although they do not change an amino acid, can nonetheless have a major effect on a protein simply because they disrupt the proper removal of introns.

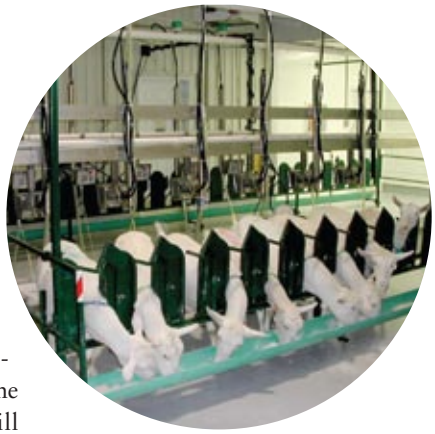
Indeed, when William Fairbrother, now at Brown University, and his colleagues in Christopher Burge's laboratory at the Massachusetts Institute of Technology compared the ends of exons, they found that people are rather similar to one another. These splice-associated regions lack much variation, even at sites where a mutation would be silent. The reason is not that mutations are not happening at the ends of our exons, but that when they appear, the mutations are so damaging to protein production that they tend to be disruptive and disappear from the population.

To date, some 50 genetic disorders have been linked to silent mutations, many of which also appear to interfere with intron removal. Splicing enhancers can overlap with a considerable length of a gene's protein-coding sequence, imposing significant limitations on where a silent mutation would be tolerated. A striking example of the damage a mutation in a splicing enhancer can do was recently documented by Francisco Baralle of the International Center for Genetic Engineering and Biotechnology in Trieste, Italy. The investigators found that 25 percent of the silent mutations they induced in one exon of the *cystic fibrosis transmembrane-conductance regulator* (*CFTR*) gene disrupted splicing and presumably would thus contribute to cystic fibrosis or related disorders.

That is not to say that disruption of splicing is the only mechanism by which silent mutations can cause disease. Even if the introns are correctly removed from an RNA transcript, the mRNA might not fold properly. Contrary to what is sometimes (for simplicity) depicted in textbooks, an mRNA is not just an unstructured linear string. Like the nucleotide pairs that form between the two DNA strands, separate regions of an mRNA can be complementary and will pair up to create an intricate folded structure known as a stem-loop. The way an mRNA folds determines its stability, which in turn can affect the speed of its translation by ribosomes as well as its subsequent degradation by cellular garbage disposals.

In the *dopamine receptor D2* gene, which encodes a cell-surface receptor that detects the presence of the neurotransmitter dopamine, one silent mutation causes the mRNA to be degraded more rapidly than normal. As a result, less of the encoded protein is made, leading to cognitive disorders. Conversely, in the *catechol-O-methyltransferase* (*COMT*) gene, a silent mutation increases the extent of mRNA folding, possibly creating too much structure that may be hard to unpack before translation—lowering protein synthesis. Andrea G. Nackley and her colleagues at the University of North Carolina at Chapel Hill found that this mutation affects pain tolerance; perhaps it is no surprise that this research was done in a dental school.

Another instance of a silent mutation affecting a protein is also among the most direct effects and involves a gene known as *multidrug resistance 1*. The gene is so named because its protein product is a cellular pump that in cancer cells helps to expel chemotherapy drugs, thus conferring drug resistance on those cells. Chava Kimchi-Sarfaty and her colleagues at the National Cancer Institute found that the silent change caused the pump protein to misfold, reducing cells' ability to eject drugs. Because the translation process and protein folding can occur simultaneously, the researchers theorized that the rarer synonymous codon produced by the silent mutation caused a pause during translation, which in turn allowed the protein time to adopt an unusual structure. If this pause occurs, the precise cause is unclear and can be added to the list of as yet unsolved mysteries about the workings of genes and proteins.

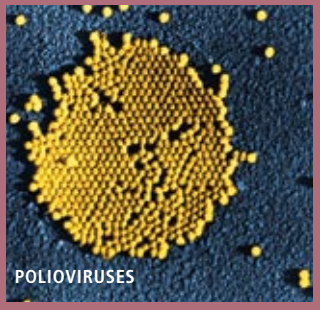


DESIGNER GOATS carry genes for the human protein butylcholinesterase, which is extracted from their milk to make an antitoxin drug. The design of genes for use in biotechnology can benefit from an understanding of which synonymous nucleotide changes are truly silent and which might affect the resulting protein or how efficiently it is produced.

[APPLICATION]

Biased Vaccine

Manipulating the sites of synonymous mutations has allowed scientists to design genes that speed up protein manufacture, but the same technique can also be used to slow it down. Steffen Mueller and his colleagues at Stony Brook University recently took this approach to design a safer polio vaccine. Live viruses make the most potent vaccines because they provoke a strong immune response in the recipient, but live vaccines can reproduce and mutate, potentially causing disease. Mueller's group took advantage of microbes' preference for using certain codons to maximize the efficiency of protein production by designing a poliovirus that substituted rarer, less efficient codons in sequences encoding the viral shell. The resulting virus was able to copy itself, albeit more slowly. After the investigators administered the engineered virus to mice, the animals were protected from infection when they were later exposed to wild poliovirus. This technique for taking advantage of codon bias to create a live but weakened vaccine could be applied to other pathogens as well to produce potent but safer vaccines.



POLIOVIRUSES

SOURCE: ADAPTED FROM "HUMAN CATECHOL-*O*-METHYLTRANSFERASE HAPLOTYPES MODULATE PROTEIN EXPRESSION BY ALTERING MRNA SECONDARY STRUCTURE," BY ANDREA G. NACKLEY ET AL., IN ***SCIENCE***, VOL. 314; DECEMBER 2006; COURTESY OF PHARMATHENE (*goats*); SCIENCE SOURCE *Photo Researchers, Inc.* (*poliovirus*)

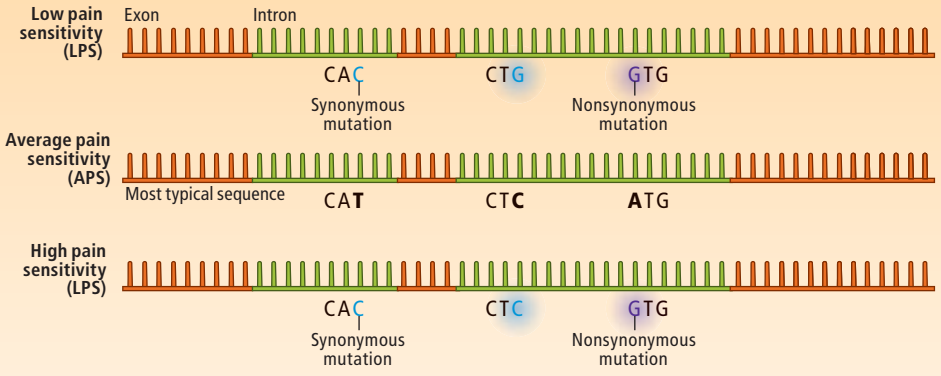
[TRANSLATION PROBLEM]

MUFFLED MESSAGE

A synonymous mutation was found to affect pain sensitivity by changing the amount of an important enzyme that cells produced. The difference results from alterations in the shape of mRNA that can influence how easily ribosomes are able to unpackage and read the strand. The folded shape is caused by base-pairing of the mRNA's nucleotides; therefore, a synonymous mutation can alter the way nucleotides match up.

COMT GENE VARIANTS

Three common versions of the gene for catechol-*O*-methyltransferase (COMT) are associated with low (LPS), average (APS) or high pain sensitivity (HPS). Differences between the most typical sequence (APS) and the other variants occur at three sites in the gene's exons; however, only one of the changes (*purple glow*) alters the encoded amino acid. That mutation was once thought to account for differences in pain sensitivity among individuals, but both LPS and HPS subjects have the same G in that position, so it cannot be the sole influence. In fact, one of the synonymous mutations (*blue glow*) was found to account for 7 percent of the pain sensitivity variation.



Efficient Genes, Effective Medicine

One lesson scientists can take from the recent discoveries about the effects of silent mutations is to be careful in our assumptions. Confidence that synonymous mutations must be "silent" was widespread when there was no mechanism to connect a silent change with an alteration in protein production. But in light of the striking examples described above, this position is no longer tenable.

Recognizing the power of not so silent mutations is beginning to help investigators improve methods for genetic engineering. Knowing which nucleotides in a gene need to be retained and which could potentially be replaced has an immediate application in biotechnology. Both gene therapy and the industrial manufacture of proteins (such as therapeutic drugs), using animals or microbes, rely on the ability to design and fabricate a gene and insert it into a cell's genome. Creating genes that work efficiently is fraught with difficulties, among them ensuring that the newly introduced transgene is activated by the cell, so that adequate amounts of its encoded protein are produced. This is where sensitivity to the effects of synonymous, but not silent, mutations comes in.

In human genes, most introns seem to be dispensable (only one, usually the first intron, appears to be required for the gene to give rise to a protein). This observation means that transgenes can be made compact by removing introns. It also implies that some silent mutation sites could be tweaked without detrimental effect, because leaving out introns does away with the need for splicing enhancers. Released from that constraint, geneticists could exploit those silent sites for other purposes.

A recent experiment at the International Institute of Molecular and Cell Biology in Warsaw illustrates how silent mutation sites could be manipulated for human benefit. Grzegorz Kudla and his colleagues took three genes and did nothing more than change the relative proportion of specific nucleotide bases at the silent sites, then transferred the altered genes to mammalian cells. Remarkably, the investigators found that increasing G and C content led to gene activity and protein manufacture that was up to 100-fold more efficient as compared with GC-poor versions of the same genes.

The new understanding should also inform efforts to understand the root causes of disease. Central to many hunts for the genes underlying diseases are ongoing genome mapping projects to catalogue genetic variation among humans. By identifying all the point mutations, or single-nucleotide polymorphisms (SNPs), in individuals with a given disease, scientists can now home in on regions of the genome containing gene variants that may cause the disease.

Until recently, such searches assumed that if several mutations in a gene correlate with the presence of a disease, those that change the protein's amino acid sequence must be the causal variants. Indeed, the *COMT* gene associated with pain tolerance is known to have a mutation that changes one amino acid to another, and that variant was long assumed to be the only cause of intolerance to pain. Yet individuals with very

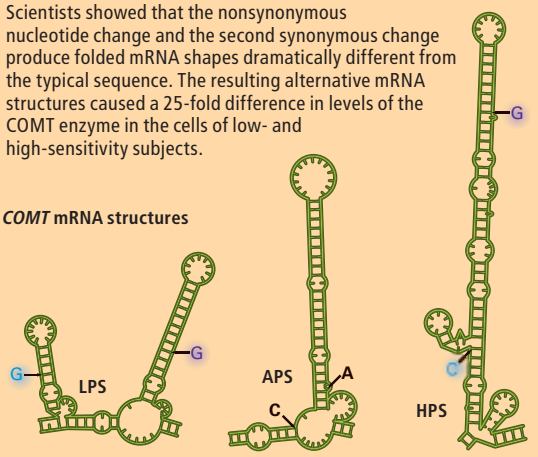
[THE AUTHORS]

J. V. Chamary and Laurence D. Hurst used bioinformatics to study the evolution of genome sequences when Chamary was a graduate student in Hurst's laboratory at the University of Bath in the U.K. Chamary now writes about science and technology for *BBC Focus* magazine. Hurst, a Royal Society Wolfson Research Merit Award holder, is a professor of evolutionary genetics whose work centers on understanding the forces that shape genes and genomes.

COURTESY OF J. V. CHAMARY; COURTESY OF LAURENCE D. HURST

MORE COMPLEX STRUCTURES PRODUCE LESS ENZYME

Scientists showed that the nonsynonymous nucleotide change and the second synonymous change produce folded mRNA shapes dramatically different from the typical sequence. The resulting alternative mRNA structures caused a 25-fold difference in levels of the COMT enzyme in the cells of low- and high-sensitivity subjects.



high or very low pain intolerance were shown to have the same nucleotides at the site of that mutation, indicating there must be some other reason for their differences. Experimental results revealing the silent mutations in *COMT* as the culprits were accepted only once the mechanism by which they might have an effect had been worked out.

It is likely that the causes of some diseases have been wrongly attributed to mutations that change proteins, when in fact synonymous mutations are at fault. Investigators need to keep this possibility in mind as they look for a damaging mutational needle in the genomic haystack. And who knows what additional mechanisms of disease such surveys will turn up?

Do the findings so far mean that silent mutations cause disease frequently? Perhaps. One could argue that silent changes are intellectually interesting and potentially of practical importance, but they are not obviously a cause of much illness. Recent examinations of how genes evolve suggest, however, that such a view may be too complacent. Several years ago one of us (Hurst) showed that in one segment of the *BRCA1* gene (associated with early-onset breast cancer), silent sites evolve very slowly in both rodents and humans. In contrast, the other sequences in this gene segment evolve at a normal rate. The difference does not mean that mutations in the slow-evolving silent sites were rare but rather that individuals who carried the mutations died without passing them on. The segment was later shown to coincide with the location of a splicing enhancer—in other words, it was another example of an area where silent mutation was so damaging its carriers died out.

Just how common are gene segments in which natural selection exerts pressure for the silent sites not to change? Hurst and Parmley investigated that question by scanning genes, searching for regions in which the rate of evolution at silent sites differed markedly from the rates at sites that change amino acids. To our surprise, we discovered that DNA segments containing unusually slow-evolving silent sites are relatively common. Indeed, they are more prevalent than regions where encoded amino acids evolve exceptionally quickly. A stretch of very highly conserved silent mutation sites occurs, on average, once every 10,000 to 15,000 nucleotides of gene sequence.

We estimate that between 5 and 10 percent of human genes contain at least one region where silent mutations could be harmful. Peter Schattner and Mark Diekhans of the University of California, Santa Cruz, performed a similar analysis, looking for large regions in genes with unusually hyperconserved silent sites. They estimated that there were about 1,600 such blocks in the nearly 12,000 genes they examined, which approximately corresponds with our estimates. Both these estimates are, however, likely to be low, and the true figure may well be considerably greater. If these conserved sites indicate the locations of silent mutations that can cause disease, as seems probable, ignoring them will inevitably lead to misidentification of disease-associated mutations.

Recognition that natural selection does take notice of not so silent mutations has gone hand in hand with scientists' realization that the process through which genes make proteins is vastly more complex and more nuanced than previously imagined. The way genes evolve and the ways in which they work are also intimately coupled to a degree barely understood even a decade ago. Further study of both these processes will continue to illuminate the remarkable complexity of the workings of genomes. DNA, for example, is not simply a linear molecule but is wrapped into coils and must be unpacked to enable transcription. Does the control of this process leave a fingerprint on silent sites as well? Likewise, runs of rare codons are more common than they should be, but what are they doing and why?

Answers to these and related questions will not just make greater sense of making proteins, they could well provide insights that cure disease. ■

MORE TO EXPLORE

Evolution Encoded. Stephen J. Freeland and Laurence D. Hurst in *Scientific American,* Vol. 290, No. 4, pages 84–91; April 2004.

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Human Catechol-*O*-Methyltransferase Haplotypes Modulate Protein Expression by Altering mRNA Secondary Structure. Andrea G. Nackley et al. in *Science,* Vol. 314, pages 1930–1933; December 2006.

Silent Polymorphisms Speak: How They Affect Pharmacogenomics and the Treatment of Cancer. Zuben E. Sauna, Chava Kimchi-Sarfaty, Suresh V. Ambudkar and Michael M. Gottesman in *Cancer Research,* Vol. 67, No. 20, pages 9609–9612; October 15, 2007.

Splicing in Disease: Disruption of the Splicing Code and the Decoding Machinery. G.-S. Wang and T. A. Cooper in *Nature Reviews Genetics,* Vol. 8, No. 10, pages 749–761; October 2007.

TAMI TOLPA

Phosphorus: A Looming

This underappreciated resource—a key part of fertilizers—is still decades from running out. But we must act now to conserve it, or future agriculture will collapse • By David A. Vaccari

KEY CONCEPTS

- Mining phosphorus for fertilizer is consuming the mineral faster than geologic cycles can replenish it. The U.S. may run out of its accessible domestic sources in a few decades, and few other countries have substantial reserves, which could also be depleted in about a century.
- Excess phosphorus in waterways helps to feed algal blooms, which starve fish of oxygen, creating "dead zones."
- Reducing soil erosion and recycling phosphorus from farm and human waste could help make food production sustainable and prevent algal blooms.

—The Editors

As complex as the chemistry of life may be, the conditions for the vigorous growth of plants often boil down to three numbers, say, 19-12-5. Those are the percentages of nitrogen, phosphorus and potassium, prominently displayed on every package of fertilizer. In the 20th century the three nutrients enabled agriculture to increase its productivity and the world's population to grow more than sixfold. But what is their source? We obtain nitrogen from the air, but we must mine phosphorus and potassium. The world has enough potassium to last several centuries. But phosphorus is a different story. Readily available global supplies may start running out by the end of this century. By then our population may have reached a peak that some say is beyond what the planet can sustainably feed.

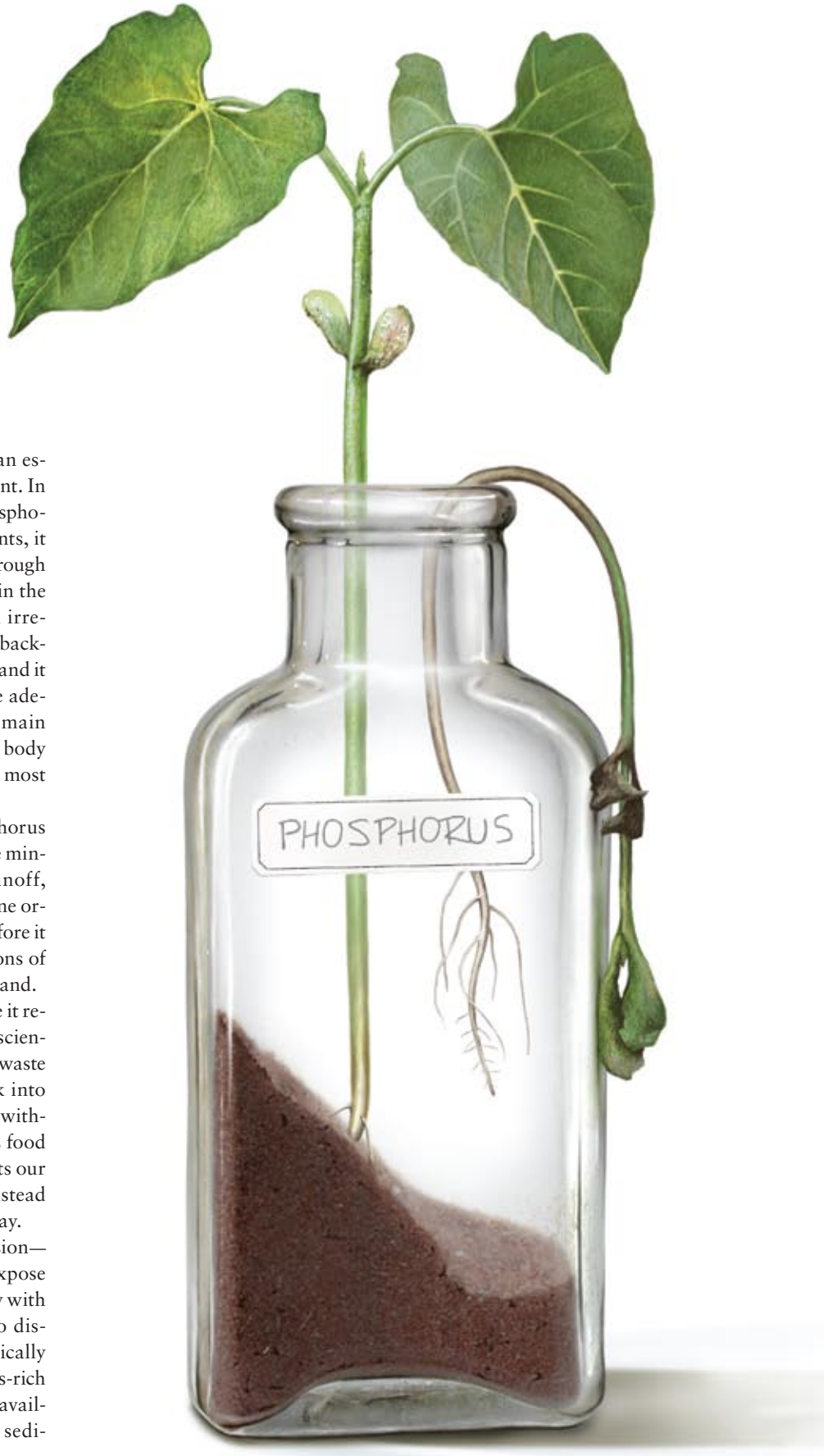
Moreover, trouble may surface much sooner. As last year's oil price swings have shown, markets can tighten long before a given resource is anywhere near its end. And reserves of phosphorus are even less evenly distributed than oil's, raising additional supply concerns. The U.S. is the world's second-largest producer of phosphorus (after China), at 19 percent of the total, but 65 percent of that amount comes from a single source: pit mines near Tampa, Fla., which may not last more than a few decades. Meanwhile nearly 40 percent of global reserves are controlled by a single country, Morocco, sometimes referred to as the "Saudi Arabia of phosphorus." Although Morocco is a stable, friendly nation, the imbalance makes phosphorus a geostrategic ticking time bomb.

In addition, fertilizers take an environmental toll. Modern agricultural practices have tripled the natural rate of phosphorus depletion from the land, and excessive runoff into waterways is feeding uncontrolled algal blooms and throwing aquatic ecosystems off-kilter. While little attention has been paid to it as compared with other elements such as carbon or nitrogen, phosphorus has become one of the most significant sustainability issues of our time.

Green Revelation

My interest in phosphorus dates back to the mid-1990s, when I became involved in a NASA program aiming to learn how to grow food in space. The design of such a system requires a careful analysis of the cycles of all elements that go into food and that would need to be recycled within the closed environment of a spaceship. Such know-how may be necessary for a future trip to Mars, which would last almost three years.

Crisis



Our planet is also a spaceship: it has an essentially fixed total amount of each element. In the natural cycle, weathering releases phosphorus from rocks into soil. Taken up by plants, it enters the food chain and makes its way through every living being. Phosphorus—usually in the form of the phosphate ion PO_4^{3-}—is an irreplaceable ingredient of life. It forms the backbone of DNA and of cellular membranes, and it is the crucial component in the molecule adenosine triphosphate, or ATP—the cell's main form of energy storage. An average human body contains about 650 grams of phosphorus, most of it in our bones.

Land ecosystems use and reuse phosphorus in local cycles an average of 46 times. The mineral then, through weathering and runoff, makes its way into the ocean, where marine organisms may recycle it some 800 times before it passes into sediments. Over tens of millions of years tectonic uplift may return it to dry land.

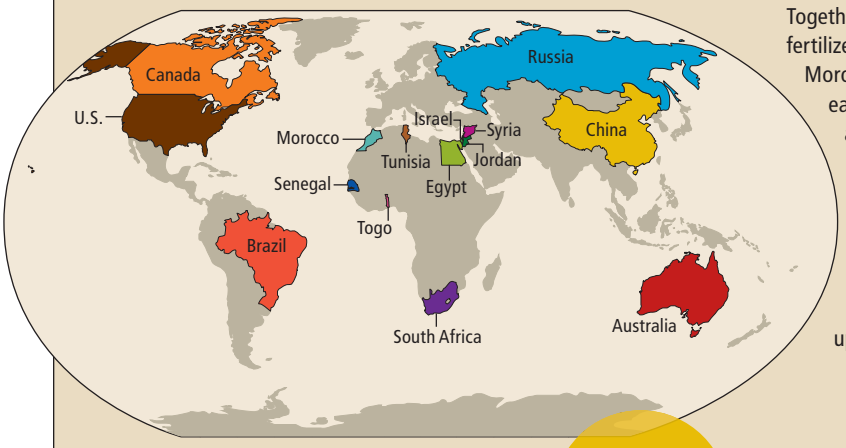
Harvesting breaks up the cycle because it removes phosphorus from the land. In prescientific agriculture, when human and animal waste served as fertilizers, nutrients went back into the soil at roughly the rate they had been withdrawn. But our modern society separates food production and consumption, which limits our ability to return nutrients to the land. Instead we use them once and then flush them away.

Agriculture also accelerates land erosion—because plowing and tilling disturb and expose the soil—so more phosphorus drains away with runoff. And flood control contributes to disrupting the natural phosphorus cycle. Typically river floods would redistribute phosphorus-rich sediment to lower lands where it is again available for ecosystems. Instead dams trap sedi-

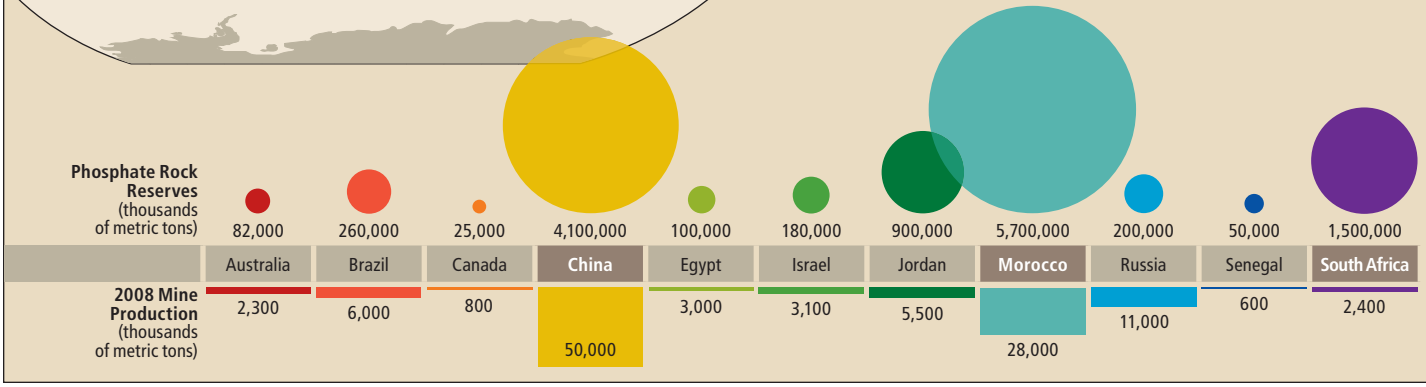
JEN CHRISTIANSEN

[PHOSPHORUS RESERVES]

CONCENTRATED RESOURCES



Together with nitrogen and potassium, phosphorus is a crucial ingredient in fertilizer. It is extracted from phosphorus-rich rock in the form of phosphate. Morocco, China, South Africa and the U.S. hold 83 percent of the world's easily exploitable phosphate rock and contribute two thirds of the annual phosphorus production (*circles, below*). At current rates of extraction (*bars, below*), known U.S. reserves are projected to last 40 years. Globally about 90 years' worth of phosphorus remains. Once the resource starts running out, less economical supplies may have to be tapped, which could result in higher prices and market disruptions. Already production has been declining despite the incentive of increasing prices (*graph, right*); last year the price spiked up because of tight supply and increased demand.



ment, or levees confine it to the river until it washes out to sea.

So too much phosphorus from eroded soil and from human and animal waste ends up in lakes and oceans, where it spurs massive, uncontrolled blooms of cyanobacteria (also known as blue-green algae) and algae. Once they die and fall to the bottom, their decay starves other organisms of oxygen, creating "dead zones" [*see box on opposite page*] and contributing to the depletion of fisheries.

While Supplies Last

Altogether, phosphorus flows now add up to an estimated 37 million metric tons per year. Of that, about 22 million metric tons come from phosphate mining. The earth holds plenty of phosphorus-rich minerals—those considered economically recoverable—but most are not readily available. The International Geological Correlation Program (IGCP) reckoned in 1987 that there might be some 163,000 million metric tons of phosphate rock worldwide, corresponding to more than 13,000 million metric tons of phosphorus, seemingly enough to last nearly a millennium. These estimates, however, include types of rocks, such as high-carbonate minerals, that are impractical as sources because no economical technology exists to extract the phosphorus from them. The tallies also include deposits that are inaccessible because of their depth or location offshore; moreover, they may exist in underdeveloped or environmentally sensitive land or in the presence of high levels of toxic or radioactive contaminants such as cadmium, chromium, arsenic, lead and uranium.

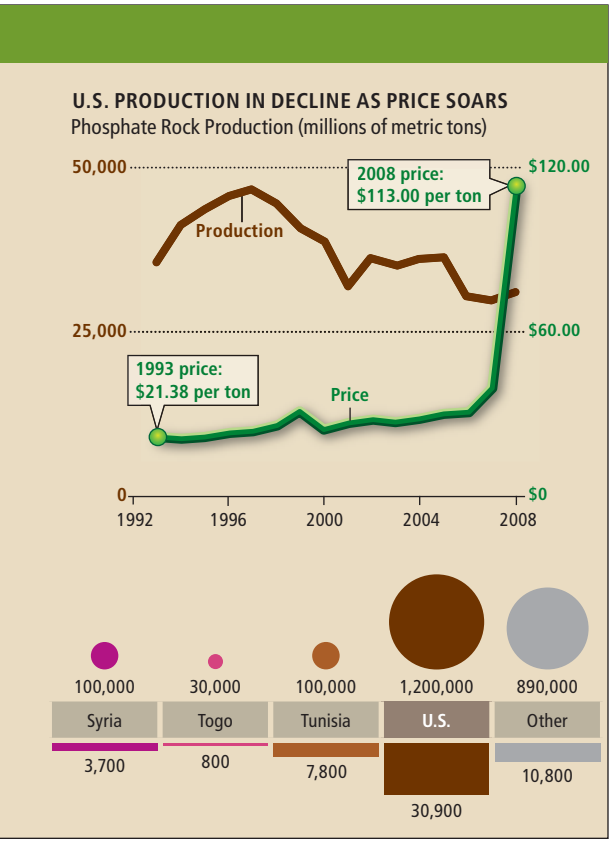
Estimates of deposits that are economically recoverable with current technology—known as reserves—are at 15,000 million metric tons. That is still enough to last about 90 years at current use rates. Consumption, however, is likely to grow as the population increases and as people in developing countries demand a higher standard of living. Increased meat consumption, in particular, is likely to put more pressure on the land, because animals eat more food than the food they become.

Phosphorus reserves are also concentrated geographically. Just four countries—the U.S., China, South Africa and Morocco, together with its Western Sahara Territory—hold 83 percent of the world's reserves and account for two thirds of annual production [*see box above*]. Most U.S. phosphate comes from mines in Florida's Bone Valley, a fossil deposit that formed in the Atlantic Ocean 12 million years ago. Ac-

COURTESY OF JAN NAZALEWICZ (*Vaccari*); JEN CHRISTIANSEN (*map and graphs*); SOURCE: U.S. GEOLOGICAL SURVEY, MINERAL COMMODITY SUMMARIES, JANUARY 2009

[THE AUTHOR]

David A. Vaccari is associate professor and director of the department of civil, environmental and ocean engineering at the Stevens Institute of Technology. He is a specialist in biological wastewater treatment and in modeling the effects of pollution in rivers and streams. He co-authored the textbook *Environmental Biology for Engineers and Scientists* and has been involved in the development of recycling processes for manned Mars missions for NASA.



cording to the U.S. Geological Survey, the nation's reserves amount to 1,200 million metric tons. The U.S. produces about 30 million metric tons of phosphate rock a year, which should last 40 years, assuming today's rate of production.

Already U.S. mines no longer supply enough phosphorus to satisfy the country's production of fertilizer, much of which is exported. As a result, the U.S. now imports phosphate rock. China has high-quality reserves, but it does not export; most U.S. imports come from Morocco. Even more than with oil, the U.S. and much of the globe may come to depend on a single country for a critical resource.

Some geologists are skeptical about the existence of a phosphorus crisis and reckon that estimates of resources and their duration are moving targets. The very definition of reserves is dynamic because, when prices increase, deposits that were previously considered too expensive to access reclassify as reserves. Shortages or price swings can stimulate conservation efforts or the development of extraction technologies.

And mining companies have the incentive to do exploration only once a resource's lifetime falls below a certain number of decades. But the depletion of old mines spurs more exploration, which expands the known resources. For instance, 20 years ago geologist R. P. Sheldon pointed out that the rate of new resource discovery had been consistent over the 20th century. Sheldon also suggested that tropical regions with deep soils had been inadequately explored: these regions occupy 22 percent of the earth's land surface but contain only 2 percent of the known phosphorus reserves.

Yet most of the phosphorus discovery has occurred in just two places: Morocco/Western Sahara and North Carolina. And much of North Carolina's resources are restricted because they underlie environmentally sensitive

Harvesting breaks up the natural cycle because it removes phosphorus from the land.

[THE DIRTY SIDE OF PHOSPHORUS]

Toxic Assets

Fertilizer runoff and wastewater discharge contribute to eutrophication, uncontrolled blooms of cyanobacteria in lakes and oceans, often large enough to be seen from orbit. Cyanobacteria (also known as blue-green algae) feed on nitrogen and phosphorus from fertilizers. When they die, their decomposition depletes the water of oxygen and slowly chokes aquatic life, producing "dead zones." The largest dead zone in U.S. waters, topping 20,000 square kilometers in July 2008, is off the Mississippi delta; silt from the river is visible in a 2001 satellite image at the right. More than 400 dead zones now exist worldwide, covering a combined area of more than 245,000 square kilometers. Researchers disagree about which element—phosphorus or nitrogen—should be the main focus of cost-effective water treatment to prevent eutrophication. Cyanobacteria living in freshwater can extract nitrogen from the air, so limiting phosphorus runoff is essential, as was confirmed in 2008 by a 37-year-long study in which researchers deliberately added nutrients to a Canadian lake. "There's not a single case in the world where anyone has shown that you can reduce eutrophication by controlling nitrogen alone," says lead author David Schindler of the University of Alberta in Edmonton. Cyanobacteria living in seawater seem unable to take in atmospheric nitrogen but may get enough phosphorus from existing sediment, other researchers point out, urging controls on nitrogen as well. ***—Davide Castelvecchi, staff editor***

IMAGE COURTESY OF LIAM GUMLEY *Space Science and Engineering Center,* UNIVERSITY OF WISCONSIN–MADISON AND THE MODIS SCIENCE TEAM

[SOLUTIONS]

Restoring Balance to the Phosphorus Cycle

Nature takes phosphorus through cycles of weathering, biological use, sedimentation and—tens of millions of years later—geologic uplift (*green arrows*). Modern agriculture's voracious need of fertilizers has tripled the rate of consumption of the phosphorus on land (*orange arrows*), but a combination of tactics (*boxes*) could mitigate the problem.

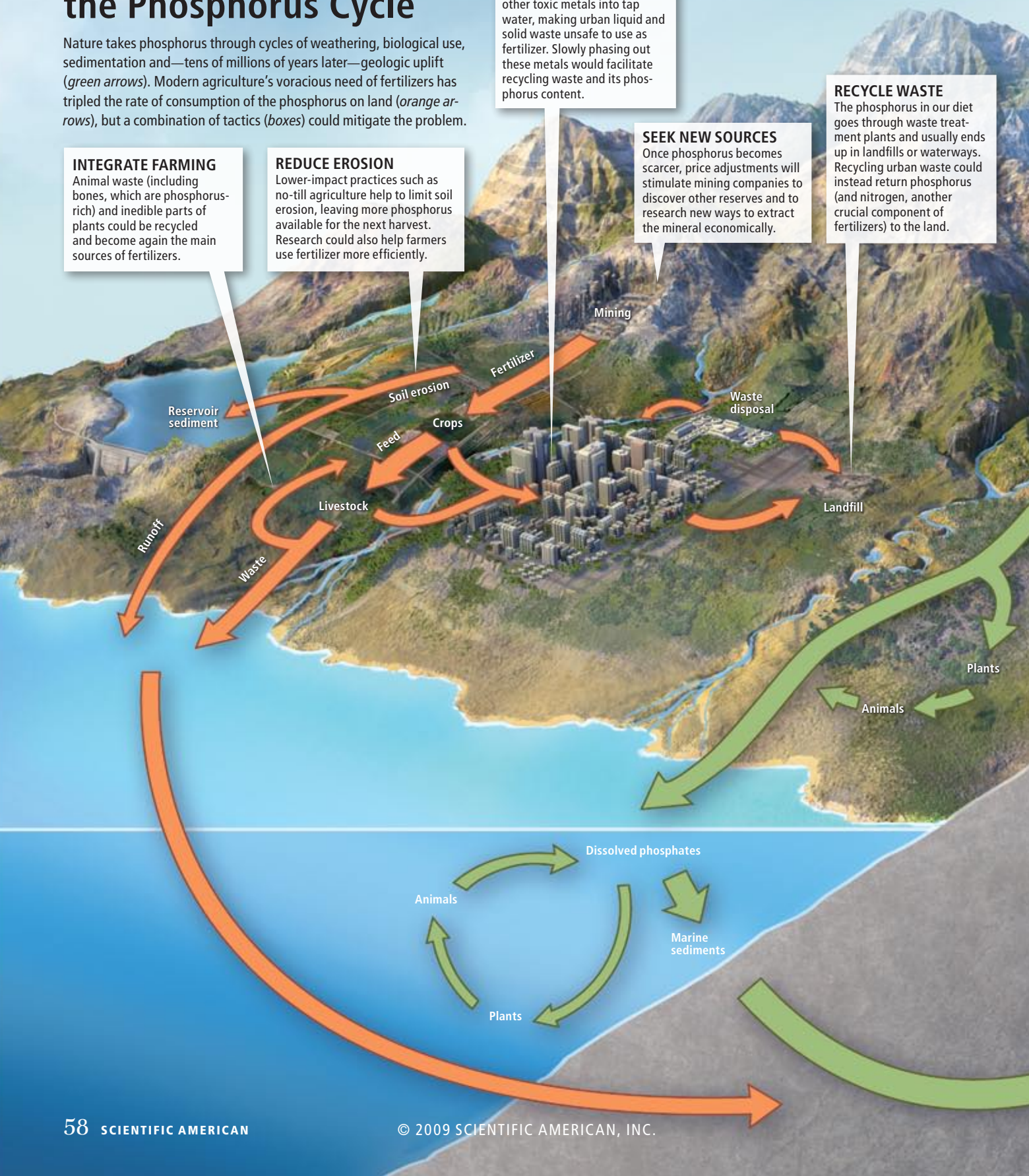
INTEGRATE FARMING
Animal waste (including bones, which are phosphorus-rich) and inedible parts of plants could be recycled and become again the main sources of fertilizers.

REDUCE EROSION
Lower-impact practices such as no-till agriculture help to limit soil erosion, leaving more phosphorus available for the next harvest. Research could also help farmers use fertilizer more efficiently.

PHASE OUT LEAD
Old plumbing leaches lead and other toxic metals into tap water, making urban liquid and solid waste unsafe to use as fertilizer. Slowly phasing out these metals would facilitate recycling waste and its phosphorus content.

SEEK NEW SOURCES
Once phosphorus becomes scarcer, price adjustments will stimulate mining companies to discover other reserves and to research new ways to extract the mineral economically.

RECYCLE WASTE
The phosphorus in our diet goes through waste treatment plants and usually ends up in landfills or waterways. Recycling urban waste could instead return phosphorus (and nitrogen, another crucial component of fertilizers) to the land.



areas. Thus, the findings to date are not enough to allay concerns about future supply. Society should therefore face the reality of an impending phosphorus crisis and begin to make a serious effort at conservation.

Rock Steady

The standard approaches to conservation apply to phosphorus as well: reduce, recycle and reuse. We can reduce fertilizer usage through more efficient agricultural practices such as terracing and no-till farming to diminish erosion [see "No-Till: The Quiet Revolution," by David R. Huggins and John P. Reganold; Scientific American, July 2008]. The inedible biomass harvested with crops, such as stalks and stems, should be returned to the soil with its phosphorus, as should animal waste (including bones) from meat and dairy production, less than half of which is now used as fertilizer.

We will also have to treat our wastewater to recover phosphorus from solid waste. This task is difficult because residual biosolids are contaminated with many pollutants, especially heavy metals such as lead and cadmium, which leach from old pipes. Making agriculture sustainable over the long term begins with renewing our efforts to phase out toxic metals from our plumbing.

Half the phosphorus we excrete is in our urine, from which it would be relatively easy to recover. And separating solid and liquid human waste—which can be done in treatment plants or at the source, using specialized toilets—would have an added advantage. Urine is also rich in nitrogen, so recycling it could offset some of the nitrogen that is currently extracted from the atmosphere, at great cost in energy.

Meanwhile new discoveries are likely just to forestall the depletion of reserves, not to prevent it. For truly sustainable agriculture, the delay would have to be indefinite. Such an achievement would be possible only with a world population small enough to be fed using natural and mostly untreated minerals that are low-grade sources of phosphorus. As with other resources, the ultimate question is how many humans the earth can really sustain.

We are running out of phosphorus deposits that are relatively easily and cheaply exploitable. It is possible that the optimists are correct about the relative ease of obtaining new sources and that shortages can be averted. But given the stakes, we should not leave our future to chance. ■

CHUCK CARTER

PHOSPHORUS FACTS

The average adult needs about one gram of phosphorus a day. To sustain one person's balanced diet, modern agriculture requires mining 22.5 kilograms of phosphate rock a year.

At least as much phosphorus ends up washed away by erosion as ends up in food. In the Illinois River basin, for example, about 1.2 kilograms of soil is eroded for each kilogram of corn produced.

A phosphorus-fueled outburst of plant growth 40 million years ago took enough carbon dioxide from the atmosphere to cause a period of global cooling. The extra phosphorus came from the uplift of the Himalayan-Tibetan plateau.

MORE TO EXPLORE

Phosphorus in the Environment: Natural Flows and Human Interferences. Vaclav Smil in *Annual Review of Energy and the Environment,* Vol. 25, pages 53–88; November 2000.

Eutrophication of Lakes Cannot Be Controlled by Reducing Nitrogen Input: Results of a 37-Year Whole-Ecosystem Experiment. David W. Schindler et al. in *Proceedings of the National Academy of Sciences USA,* Vol. 105, No. 32, pages 11254–11258; August 12, 2008.

Phosphate Rock Statistics and Information. U.S. Geological Survey. Available at **http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock**

SCIENTIFIC AMERICAN

The ethical and policy ramifications of deploying science and technology in the service of society hold the same importance as the act of invention itself. Getting antiretroviral treatments to HIV/AIDS patients in sub-Saharan Africa. Ensuring that the world's largest chip manufacturer takes every possible step to reduce the company's environmental footprint. Lending the currency of one's celebrity (as well as cold, hard cash) to a global campaign to abolish smoking.

Leadership in these realms requires vision and imagination that transcends mere engineering ingenuity. This year's Scientific American 10 pays tribute to the exceptional foresight and accomplishment of a select group whose achievements, particularly during the past year, stand out from those of their peers. The 10 winners have demonstrated that establishing a public health program or running a green business requires more than administrative efficiency and good public relations. Bringing creativity to bear in overcoming institutional and bureaucratic impediments to adoption of not just new technology but innovative procedural methods is crucial for improving health care and the environment.

One winner helped to build an incubator for newborns that could be fashioned from car parts so that it could be easily repaired in rural areas of developing countries. Another realized that an innovative infrastructure for recharging and swapping out large batteries might offer a way to route around the technological obstacles that have held up commercial electric cars. Pure technological inspiration is also honored in the form of a practical means of taking a few skin cells from, say, a person's arm and converting them to the equivalent of embryonic stem cells.

This combination of leadership and inventiveness exhibited among the Scientific American winners for 2009 serves as a template for how we might consider tackling the most seemingly intractable problems of resource depletion, inadequate health care and desperate educational need.

—The Editors

10

COURTESY OF THE WHITE HOUSE (*Obama*)

Intel's first green building, a design center, is set to open this year in Haifa, Israel.

TODD BRADY

CORPORATE ENVIRONMENTAL MANAGER
Intel, SANTA CLARA, CALIF.

A chip company makes expansion of its environmental footprint a priority

A multibillion-dollar technology company such as Intel could choose many ways to go green. It could build more energy-efficient production plants or eliminate toxic chemicals from its products. It could minimize greenhouse gas emissions or recycle its waste. It could buy wind power and renewable energy credits. Or with the help of a passionate corporate environmental manager like Todd Brady, it could do all of the above.

Brady, who has been with Intel since 1995, has helped the company earn its reputation as a world corporate environmental leader. He played a large part in the development of Intel's first green building, due to open this year, which carries the esteemed Leadership in Energy and Environmental Design (LEED) certification. This development design center in Haifa, Israel, recycles waste heat captured from computers in the data center and uses it to warm the space. Three quarters of its occupied office space is lit completely by sunlight coming in through large windows.

Brady was also a driver in the company's bold decision to reduce energy consumption by 4 percent and greenhouse gas emissions by 30 percent by 2010. Since 2001 Intel has saved more than 500 million kilowatt-hours of energy, enough to power more than 50,000 homes.

It has also conserved nine billion gallons of freshwater, reduced its global-warming footprint by removing 50,000 automobiles from the road, and stopped using lead and halogen in its processors. And in 2008 the U.S. Environmental Protection Agency announced that Intel had become the single largest corporate purchaser of renewable energy certificates in the U.S.—thanks, again, to Brady's stewardship. *—Melinda Wenner*

COURTESY OF INTEL

SHAI AGASSI

FOUNDER AND CHIEF EXECUTIVE
Better Place, PALO ALTO, CALIF.

A wonderfully simple recharging scheme may ensure a future for electric vehicles

In our impatient economy, electric cars simply haven't been able to keep up. Sure the Tesla Roadster is fast and trendy, but a luxury price and a charge time of about three hours curb its appeal. Chevrolet's Volt, scheduled for 2010, though more accessible, can venture only 40 miles before petering out. Shai Agassi, an auto industry newcomer, thinks the prospect of a world without oil requires a more expansive vision. The former software executive is methodically assembling an entirely new automobile infrastructure: an electric recharge grid fueled by solar and wind energy. Drivers would buy miles on a subscription plan, then swap out discharged batteries for fresh ones at conveniently located exchange stations. In California, for instance, "switching stations" 30 miles apart on major freeways could cover the state. For a short-distance top off, workers or shoppers could park and plug into a metered charging spot. An operating system in vehicle-based computers would help drivers match destinations to their battery life and recharge options.

Agassi's start-up, Better Place, launched a pilot last year in Israel, where tax incentives should bump up interest and help support a plan for mass marketing by 2011. Venture capitalists have committed $200 million to the business; Denmark, Australia, Ontario, Hawaii and California also have signed on for their own charging networks. Renault-Nissan will supply electric cars for the deal. Eventually, Agassi anticipates, lithium-ion batteries will extend mileage, and standardized sizes will enable the network to serve multiple car models. By weaving technology, policy and practical road service together, Agassi's system could make electric cars a reality. *—Sally Lehrman*

Electric cars will get a boost from battery-switching stations.

WAFAA EL-SADR

CHIEF
Infectious Disease Division, Harlem Hospital Center, NEW YORK CITY

The physician leads a multipronged public health campaign to fight the scourge of HIV

A staggering third of all HIV/AIDS patients suffer from tuberculosis, and the infection ultimately kills half of those with both diseases. Wafaa El-Sadr has assumed a leadership role in a campaign intended to ensure that the numbers will soon start falling. El-Sadr, director of the Columbia University International Center for AIDS Care and Treatment Programs (ICAP), has recently initiated a partnership between ICAP and nearly 400 health care facilities in sub-Saharan Africa in an effort to curb the HIV/TB crisis. As of December 2008, these African centers had screened 106,000 HIV-infected people for TB and had developed a set of coordinated strategies both to treat TB and to prevent its transmission.

The Egyptian-born physician has focused on all aspects of the HIV pandemic, and her work won her an esteemed MacArthur Fellowship in 2008. After joining the Harlem Hospital Center in 1988 as chief of infectious diseases, El-Sadr pioneered a comprehensive, family-based model for HIV care that is now implemented around the world. She also led an initiative to minimize the risk of mother-to-child transmission of HIV that has helped thousands of women across eight countries.

El-Sadr has been involved in research that will ultimately guide doctors in determining the best course of HIV/AIDS therapy. From 2001 to 2006, she co-chaired the largest HIV treatment study ever conducted: Strategies for Management of Antiretroviral Therapy, or SMART. One of its main conclusions was that HIV patients live longer and healthier lives when they stay on antiretroviral therapy permanently. Now El-Sadr is working to ensure that ongoing treatments are possible: as of last year, ICAP supported one tenth of HIV/AIDS patients receiving antiretroviral treatment in sub-Saharan Africa. *—Melinda Wenner*

ROBERT J. LINHARDT

PROFESSOR OF BIOCATALYSIS AND METABOLIC ENGINEERING
Rensselaer Polytechnic Institute

A chemical sleuth unravels the cause of deaths from a tainted drug

When Americans began dying in January 2008 from the effects of contaminated heparin—a complex carbohydrate that has been a key component of medical blood thinners since the 1930s—the U.S. Food and Drug Administration asked Robert J. Linhardt, who is a chemist at the Rensselaer Polytechnic Institute, to help it identify the culprit. Linhardt not only succeeded, he also devised a solution that may one day prevent such scares from occurring again.

The problem was rooted in the burgeoning demand for blood thinners: the U.S. uses 300,000 doses of heparin a day to prevent blood clots during procedures such as heart-bypass surgeries and kidney dialysis. U.S. pharmaceutical companies mainly buy heparin that has been isolated from the intestines of pigs grown on American farms, but the nation uses more heparin than it can make, so drugmakers here also have to import it.

When heparin complications began surfacing in early 2008, the FDA fingered products imported from China's Changzhou SPL Company. At that point the FDA, along with an American firm that sold Changzhou's tainted product, asked Linhardt for help. Within weeks, Linhardt and his colleagues had painstakingly separated out the heparin's components and identified the source: oversulfated chondroitin sulfate (OSCS), a chemical based on a drug used to treat osteoarthritis. The OSCS may have been added to the heparin as a cheap filler, but it ultimately killed 81 Americans by causing inflammation and dangerous blood pressure drops.

Tracing the reason for the deaths wasn't good enough for Linhardt, though—he also wanted a solution. By August he and his colleagues had announced that they had synthesized a dose of pure heparin a million times larger than any lab-made dose before it. Their secret: using *Escherichia coli* bacteria as tiny chemical factories. And although the synthetic form is still a long way from hospital shelves, Linhardt's work represents a giant step toward a future in which heparin saves lives as it should—and never again takes them.

—Melinda Wenner

EUGENIE SCOTT

EXECUTIVE DIRECTOR
National Center for Science Education, OAKLAND, CALIF.

A champion for the teaching of evolution steps up her advocacy

Thomas Henry Huxley was the 19th-century biologist known as "Darwin's bulldog" for his defense of the great scientist's ideas. The 21st century has a counterpart in the woman who describes herself as "Darwin's golden retriever." Eugenie Scott has emerged as one of the most prominent advocates for keeping evolution an integral part of the curriculum in public schools in her role as head of the nonprofit National Center for Science Education (NCSE). Scott became executive director of NCSE in 1986, a year before the U.S. Supreme Court ruled it illegal to teach creation science in public schools in its *Edwards v. Aguillard* ruling.

Scott was a physical anthropologist at the University of Kentucky in 1980 when she became interested in so-called creationist science, which attempts to reconcile biology, geology and other disciplines with literalist interpretations of the Bible. She headed a grassroots movement in Lexington to prevent creationism from being taught in the public schools there.

In 2005 she served as a pro bono consultant in the landmark *Kitzmiller v. Dover* trial, in which Judge John Jones ruled that "intelligent design" was a form of creationism and was therefore unconstitutional to teach in public schools.

Last year Scott and the NCSE faced an uphill battle over the Academic Freedom Act in Florida, which allows educators to teach about "controversies" related to evolution. Similar legislation this year appeared to be stalled in the state legislature.

In March the Texas State Board of Education voted to drop the requirement that science classes consider the "strengths and weaknesses" of Darwin's theories, a demand born of the campaign to peddle creationism under another name. But instead of eliminating the problem, the board voted to include wording that students should "analyze and evaluate" the theories, despite a petition from the NCSE stating that while the words were different, the intent to discredit Darwin was the same. With the ever changing semantics of antievolutionists, Darwin's golden retriever will have plenty more chances to act as a loyal defender of teaching evolution in the schools.

—Kate Wilcox

COURTESY OF RENSSELAER POLYTECHNIC INSTITUTE (*Linhardt*); PETER DASILVA *New York Times* (*Scott*)

CHRIS HONDROS *Getty Images*

BILL GATES/MICHAEL BLOOMBERG

CO-CHAIR
Bill and Melinda Gates Foundation

MAYOR OF NEW YORK CITY

Celebrity heft propels a campaign to limit smoking

It is deadlier than malaria, AIDS and tuberculosis combined, felling more people annually than any other agent. And it is spreading with alarming speed, especially in developing countries. Microsoft co-founder Bill Gates teamed up last year with media magnate and politician Michael Bloomberg to battle killer tobacco with a $375-million global antismoking initiative.

The partnership builds on a $125-million international grants program Bloomberg started in 2006 to promote policies such as smoke-free public spaces, advertising bans, tax hikes and antismuggling measures. The new infusion ($250 million from Bloomberg and $125 million from the Bill and Melinda Gates Foundation) pays for campaigns to educate children and adults about tobacco's harms, to protect individuals against secondhand exposure and to help smokers quit. The initiative also will train tax officers and health officials to establish effective antismoking directives. And it will monitor global tobacco use and evaluate strategies for control. Partners include the World Health Organization, the Centers for Disease Control and Prevention, and the World Lung Foundation. Although the emphasis is on cigarette-hungry Bangladesh, China, India, Indonesia and Russia, Gates also hopes to tamp down Africa's still modest appetite.

Bloomberg, a former smoker, built a reputation for antismoking crusades during his two terms as New York City mayor. The attack on tobacco is new to the Gates Foundation, best known for its assault on infectious disease. Poor to middle-income countries currently spend a mere $20 million on antismoking campaigns—but collect $66 billion in cigarette taxes. With this injection of funds and a well-crafted initiative, Bloomberg and Gates may well shape the political will and policies needed to help the world kick its habit. —*Sally Lehrman*

A carburetor incorporated into an indoor cookstove cuts toxic gas emissions.

BRYAN WILLSON

PROFESSOR OF MECHANICAL ENGINEERING
Colorado State University

An engineer facilitates clean energy technology for the developing world

Somewhere close to half the world's population relies on outrageously inefficient, fuel-greedy indoor stoves to prepare daily meals. The cookers pump out noxious gases such as carbon monoxide and benzene, lethally poisoning as many as 1.6 million people every year. With careful design, a simple carburetor and an insulated chamber, Bryan Willson's team at the Engines and Energy Conversion Laboratory at Colorado State University have solved the problem. Now, for just $10 to $40, families in India and the Philippines can buy a sleek stove that cuts emissions by 80 percent, uses less fuel and even heats food faster.

Two-stroke engines—the kind used on tens of millions of motorcycle taxis in Africa, India and the Philippines—also blacken the air with a deadly cocktail. Willson's students created a bolt-on kit that converts these engines from carbureted to direct fuel injection, slashing tailpipe emissions equivalent to about 50 modern cars with each retrofit. Envirofit, a nonprofit spin-off of Willson's lab, sells the conversion kits in the Philippines for about $200. Granted, this is a huge investment for a taxi driver, but it is still affordable through a microloan program combined with a fat, 35 percent boost in fuel efficiency.

Willson, a mechanical engineer, has expanded his cramped, Fort Collins lab into a hothouse for clean energy inventions. But the innovation he inspires doesn't end there. By helping students and collaborators apply expertise in development economics and entrepreneurship, Willson makes sure that technical solutions reach those who need them. —*Sally Lehrman*

KRISTIAN OLSON

PROGRAM LEADER
Center for Integration of Medicine and Innovative Technology, BOSTON

Simple, low-cost resuscitators and incubators can save newborns in the developing world

A few years ago Kristian Olson's wife gave birth to triplets after a difficult labor. The 38-year-old pediatrician and internist realized that if his wife had gone through childbirth in many of the places where he spends a great deal of time, the infants would not have survived. That understanding made Olson an even more ardent champion of deploying simple and inexpensive technologies that will enable newborns to survive outside the protective shelter of high-tech medical centers.

One colleague told the *Boston Globe* that Olson is "The Man" when the topic turns to lifesaving technologies for the developing world. Last year Olson and the Center for Integration of Medicine and Innovative Technology (CIMIT)—a nonprofit consortium of Boston teaching hospitals and engineering schools—moved ahead with a program to demonstrate the effectiveness of $7 resuscitators, tubes through which a medical worker exhales into a newborn's mouth. The program started after the 2004 South Asian tsunami. Since then, about 500 midwives in Aceh, Indonesia, have been trained to use the technology.

Another project Olson continues to spearhead under CIMIT's Global Health Initiative is development of an incubator built from car parts. The idea, conceived of by a former CIMIT official, is simple: expertise and parts to fix medical equipment may be lacking in rural hospitals, but the know-how to fix cars is ubiquitous. Olson headed the team that built prototypes of the incubator, proving the feasibility of one of CIMIT's goals of bringing untraditional solutions to solving the problems of poor nations. —*Gary Stix*

Incubators made from car parts might one day replace the blankets used in this intensive care unit in Katmandu, Nepal.

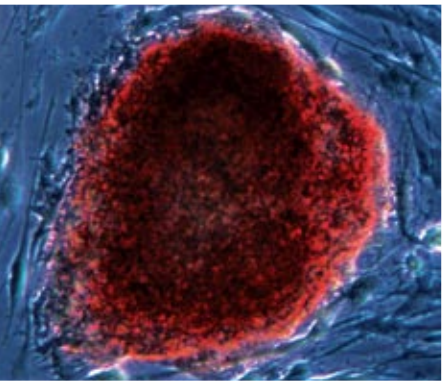
COURTESY OF ENVIROFIT (*cookstove*); COURTESY OF COLORADO STATE UNIVERSITY (*Willson*); CENTER FOR INTEGRATION OF MEDICINE AND INNOVATIVE TECHNOLOGY (*Olson*); COURTESY OF DESIGN THAT MATTERS (*incubators*)

ANDRAS NAGY

SENIOR INVESTIGATOR
Mount Sinai Hospital, TORONTO

A biologist discovers a practical method of making stem cells from mature cells

Federal funding for U.S. embryonic stem cell research may have the green light again, but the reversal does nothing to undermine the diligent and creative work of researchers who have, over the past eight years, developed possible alternatives. Among the most successful is Andras Nagy, a biologist at Mount Sinai Hospital in Toronto, who has developed a novel way to convert mature cells into the functional equivalent of embryonic stem cells.



Toronto researchers discovered a practical way to convert a mature skin cell into a stem cell (*above*).

Nagy's research has come up with perhaps the most practical method to date. In 2006 two laboratories independently turned adult skin cells into stem cells that were pluripotent—or had the ability to develop into many different types of cells—simply by turning on the activity of four genes. Problem is, the viruses used to introduce the active genes sometimes rendered the cells cancerous. In 2008 Japanese scientists announced that they had eliminated the need for viruses entirely, but their solution was horribly inefficient: when their experiments worked, they were lucky if 29 out of every million cells actually became stem cells.

In February, Nagy announced that he had a better solution. He and his colleagues had introduced the four necessary genes into mouse and human cells by way of a linear genetic construct called a transposon, which has the ability to efficiently insert itself into a cell's genome. As a bonus, genes inserted with a transposon can later be removed with the aid of an enzyme called a transposase—meaning they will not cause cancer or other untoward effects down the line.

Once Nagy added the four genes, many of the mature cells converted into stem cells—after 20 days the investigators identified up to 48 separate stem cell colonies. The cells remained pluripotent even after they removed the genes again. In effect, Nagy and his colleagues had, for the first time, created the equivalent of embryonic stem cells that were uncontroversially ethical, safe *and* efficient—a significant advance toward being able to use them in patients in a clinic. *—Melinda Wenner*

BARACK OBAMA

PRESIDENT OF THE U.S.

The new chief executive begins his term by initiating a radical shift in science policy

After eight long years in exile, scientists have been enthusiastically welcomed back into the White House. In the first few months of his administration, President Barack Obama acted with remarkable speed to place science at the center of policymaking on climate change, energy, health care and research funding. He wiped away science-averse policies and appointed outstanding scientific talent—including physicists Steven Chu and John Holdren, marine ecologist Jane Lubchenco, and biomedical experts Harold Varmus and Eric Lander—to top posts.

In March, President Obama lifted the ban on federal funding for embryonic stem cell research and asked the National Institutes of Health to devise new rules. With a pledge to listen to scientists, "especially when it's inconvenient," he simultaneously ordered the creation of policies that would protect scientific integrity and ensure transparency in policymaking.

That same month, international climate change delegates in Bonn applauded a pledge by Todd Stern, President Obama's special climate envoy, to "make up for lost time" and combine urgency, science and pragmatism in U.S. actions. Indeed, the president's budget called for $150 billion to fund research, development and technology for clean energy over 10 years, plus $43 billion in additional research and infrastructure funding and $20 billion in tax incentives already built into the economic stimulus plan.

When making the choice to award the president, we searched among less obvious candidates who were deserving of broader public recognition. But President Obama's accomplishments in a matter of weeks of taking office were so extraordinary that he could not be denied. The new president's actions have proved almost startling after the Bush administration, which was criticized for routine suppression of scientific knowledge for political purposes. But the impact of the Obama White House will likely reach far beyond such a facile comparison. The president's unprecedented emphasis on science and technology should propel basic research, innovation, and U.S. scientific and technological competitiveness for generations to come. *—Sally Lehrman*

COURTESY OF SID TABAK *Mount Sinai Hospital (Nagy)*; KNUT WOLTJEN *Mount Sinai Hospital (stem cell)*; CHIP SOMODEVILLA *Getty Images (Obama)*

The Taming of the

Cat

Genetic and archaeological findings hint that wildcats became house cats earlier—and in a different place—than previously thought

By Carlos A. Driscoll, Juliet Clutton-Brock, Andrew C. Kitchener and Stephen J. O'Brien

It is by turns aloof and affectionate, serene and savage, endearing and exasperating. Despite its mercurial nature, however, the house cat is the most popular pet in the world. A third of American households have feline members, and more than 600 million cats live among humans worldwide. Yet as familiar as these creatures are, a complete understanding of their origins has proved elusive. Whereas other once wild animals were domesticated for their milk, meat, wool or servile labor, cats contribute virtually nothing in the way of sustenance or work to human endeavor. How, then, did they become commonplace fixtures in our homes?

Scholars long believed that the ancient Egyptians were the first to keep cats as pets, starting around 3,600 years ago. But genetic and archaeological discoveries made over the past five years have revised this scenario—and have generated fresh insights into both the ancestry of the house cat and how its relationship with humans evolved.

Cat's Cradle

The question of where house cats first arose has been challenging to resolve for several reasons. Although a number of investigators suspected that all varieties descend from just one cat species—*Felis silvestris*, the wildcat—they could not be certain. In addition, that species is not confined to a small corner of the globe. It is represented by populations living throughout the Old World—from Scotland to South Africa and from Spain to Mongolia—and until recently scientists had no way

KEY CONCEPTS

- Unlike other domesticated creatures, the house cat contributes little to human survival. Researchers have therefore wondered how and why cats came to live among people.
- Experts traditionally thought that the Egyptians were the first to domesticate the cat, some 3,600 years ago.
- But recent genetic and archaeological discoveries indicate that cat domestication began in the Fertile Crescent, perhaps around 10,000 years ago, when agriculture was getting under way.
- The findings suggest that cats started making themselves at home around people to take advantage of the mice and food scraps found in their settlements.

—The Editors

> "He will kill mice and he will be kind to Babies when he is in the house, just as long as they do not pull his tail too hard. But when he has done that, and between times, and when the moon gets up and night comes, he is the Cat that walks by himself, and all places are alike to him. Then he goes out to the Wet Wild Woods or up the Wet Wild Trees or on the Wet Wild Roofs, waving his wild tail and walking by his wild lone."
>
> —Rudyard Kipling, "The Cat That Walked by Himself"

of determining unequivocally which of these wildcat populations gave rise to the tamer, so-called domestic kind. Indeed, as an alternative to the Egyptian origins hypothesis, some researchers had even proposed that cat domestication occurred in a number of different locations, with each domestication spawning a different breed. Confounding the issue was the fact that members of these wildcat groups are hard to tell apart from one another and from feral domesticated cats with so-called mackerel-tabby coats because all of them have the same pelage pattern of curved stripes and they interbreed freely with one another, further blurring population boundaries.

In 2000 one of us (Driscoll) set out to tackle the question by assembling DNA samples from some 979 wildcats and domestic cats in southern Africa, Azerbaijan, Kazakhstan, Mongolia and the Middle East. Because wildcats typically defend a single territory for life, he expected that the genetic composition of wildcat groups would vary across geography but remain stable over time, as has occurred in many other cat species. If regional indigenous groups of these animals could be distinguished from one another on the basis of their DNA and if the DNA of domestic cats more closely resembled that of one of the wildcat populations, then he would have clear evidence for where domestication began.

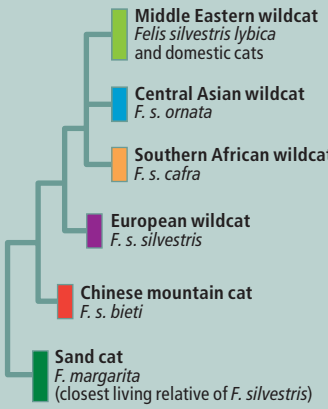
In the genetic analysis, published in 2007, Driscoll, another of us (O'Brien) and their colleagues focused on two kinds of DNA that molecular biologists traditionally examine to differentiate subgroups of mammal species: DNA from mitochondria, which is inherited exclusively from the mother, and short, repetitive sequences of nuclear DNA known as microsatellites. Using established computer routines, they assessed the ancestry of each of the 979 individuals sampled based on their genetic signatures. Specifically, they measured how similar each cat's DNA was to that of all the other cats and grouped the animals having similar DNA together. They then asked whether most of the animals in a group lived in the same region.

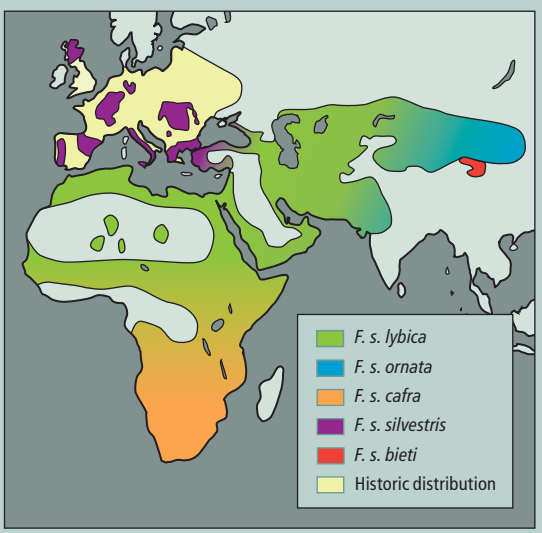
The results revealed five genetic clusters, or lineages, of wildcats. Four of these lineages corresponded neatly with four of the known subspecies of wildcat and dwelled in specific places: *F. silvestris silvestris* in Europe, *F. s. bieti* in China, *F. s. ornata* in Central Asia and *F. s. cafra* in southern Africa. The fifth lineage, however, included not only the fifth known subspecies of wildcat—*F. s. lybica* in the Middle East—but also the hundreds of domestic cats that were sampled, including purebred and mixed-breed felines from the U.S., the U.K. and Japan. In fact, genet-

[FINDINGS]

THE HOUSE CAT'S ANCESTOR

Researchers examined DNA belonging to nearly 1,000 wildcats and domestic cats from across the Old World to determine which subspecies of the wildcat, *Felis silvestris,* gave rise to the house cat. They found that the DNA clustered into five groups, based on similarity of sequence, and noted that the wildcats within each group came from the same region of the world (*map*). The domestic cats, however, grouped only with *F. silvestris lybica,* the Middle Eastern wildcat (*photograph*). This result established that all domestic cats are descended from *F. s. lybica* alone (*family tree*).





JANE BURTON Getty Images (preceding pages); TOM BRAKEFIELD Getty Images (this page); JEN CHRISTIANSEN (illustration)

ically, *F. s. lybica* wildcats collected in remote deserts of Israel, the United Arab Emirates and Saudi Arabia were virtually indistinguishable from domestic cats. That the domestic cats grouped with *F. s. lybica* alone among wildcats meant that domestic cats arose in a single locale, the Middle East, and not in other places where wildcats are common.

Once we had figured out where house cats came from, the next step was to ascertain when they had become domesticated. Geneticists can often estimate when a particular evolutionary event occurred by studying the quantity of random genetic mutations that accumulate at a steady rate over time. But this so-called molecular clock ticks a mite too slowly to precisely date events as recent as the past 10,000 years, the likely interval for cat domestication. To get a bead on when the taming of the cat began, we turned to the archaeological record. One recent find has proved especially informative in this regard.

In 2004 Jean-Denis Vigne of the National Museum of Natural History in Paris and his colleagues reported unearthing the earliest evidence suggestive of humans keeping cats as pets. The discovery comes from the Mediterranean island of Cyprus, where 9,500 years ago an adult human of unknown gender was laid to rest in a shallow grave. An assortment of items accompanied the body—stone tools, a lump of iron oxide, a handful of seashells and, in its own tiny grave just 40 centimeters away, an eight-month-old cat, its body oriented in the same westward direction as the human's.

Because cats are not native to most Mediterranean islands, we know that people must have brought them over by boat, probably from the adjacent Levantine coast. Together the transport of cats to the island and the burial of the human with a cat indicate that people had a special, intentional relationship with cats nearly 10,000 years ago in the Middle East. This locale is consistent with the geographic origin we arrived at through our genetic analyses. It appears, then, that cats were being tamed just as humankind was establishing the first settlements in the part of the Middle East known as the Fertile Crescent.

A Cat and Mouse Game?

With the geography and an approximate age of the initial phases of cat domestication established, we could begin to revisit the old question of why cats and humans ever developed a special relationship. Cats in general are unlikely candidates for domestication. The ancestors of most domesticated animals lived in herds or packs with clear dominance hierarchies. (Humans unwittingly took advantage of this structure by supplanting the alpha individual, thus facilitating control of entire cohesive groups.) These herd animals were already accustomed to living cheek by jowl, so provided that food and shelter were plentiful, they adapted easily to confinement.

Cats, in contrast, are solitary hunters that defend their home ranges fiercely from other cats of the same sex (the pride-living lions are the exception to this rule). Moreover, whereas most domesticates feed on widely available plant foods, cats are obligate carnivores, meaning they have a limited ability to digest anything but meat—a far rarer menu item. In fact, they have lost the ability to taste sweet carbohydrates altogether. And as to utility to humans, let us just say cats do not take instruction well. Such attributes suggest that whereas other domesticates were recruited from the wild by humans who bred them for specific tasks, cats most likely chose to live among humans because of opportunities they found for themselves.

Early settlements in the Fertile Crescent between 9,000 and 10,000 years ago, during the Neolithic period, created a completely new environment for any wild animals that were sufficiently flexible and inquisitive (or scared and hungry) to exploit it. The house mouse, *Mus musculus domesticus*, was one such creature. Ar-

EARLY DOMESTICATION: Traditionally the ancient Egyptians have been credited with domesticating the cat by roughly 3,600 years ago. But in 2004 archaeologists working on the Mediterranean island of Cyprus discovered a 9,500-year-old burial of an adult human and a cat (*circled in photograph, left, and map, below*). Because cats are not native to Cyprus, people must have brought them over by boat, probably from the nearby Levant. The find thus suggests that people in the Middle East began keeping cats as pets long before the Egyptians did.

SOURCE: "EARLY TAMING OF THE CAT IN CYPRUS," BY J.-D. VIGNE, J. GUILAINE, K. DEBUE, L. HAYE AND P. GÉRARD, IN *SCIENCE*, VOL. 304; APRIL 2004

[TIMELINE]

FROM WILD TO MILD

Researchers believe, based on archaeological and historic records, that the transformation of the Middle Eastern wildcat into a ubiquitous pet transpired over thousands of years.

◀ 10,500–9,500 YEARS AGO House mouse remains preserved with human stores of grain in Israel; origin of agriculture and of permanent human settlements creates opportunities for cats willing to get close enough to humans to hunt house mice

9,500 YEARS AGO Human and cat double burial on Mediterranean island of Cyprus; earliest evidence of special relationship between people and cats

◀ 3,700 YEARS AGO Ivory cat statuette sculpted in Israel; suggests cats were a common sight around human settlements in the Fertile Crescent

3,600 YEARS AGO Artists paint domesticated cats from Thebes, Egypt; oldest clear evidence of fully domesticated cat

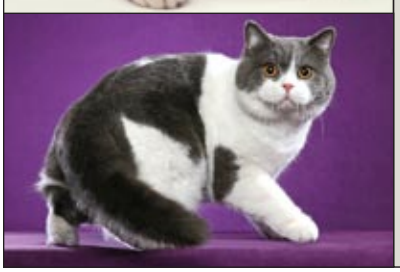
◀ 2,900 YEARS AGO Cats become "official deity" of Egypt in the form of the goddess Bastet; huge number of cats sacrificed and mummified in her sacred city indicates that Egyptians were breeding domestic cats

2,300 YEARS AGO The height of cat worship in Egypt; the Ptolemeic rulers maintain strict bans on the export of cats

2,000 YEARS AGO Cat remains preserved at the German site of Tofting in Schleswig and increasing references to cats in art and literature show that domestic cats were common throughout Europe

◀ 1350–1767 The *Tamara Maew* (or "Cat-Book Poems"), composed by Buddhist monks in Thailand, describes indigenous natural breeds, such as the Siamese, which arose largely through genetic drift, as opposed to human intervention

1800s Most of the modern breeds developed in the British Isles, according to writings of English natural history artist Harrison Weir



◀ 1871 Cat show at the Crystal Palace in London is first to include human-created breeds

2006 First hypoallergenic cat, created by Allerca

chaeologists have found remains of this rodent, which originated in the Indian subcontinent, among the first human stores of wild grain from Israel, which date to around 10,000 years ago. The house mice could not compete well with the local wild mice outside, but by moving into people's homes and silos, they thrived.

It is almost certainly the case that these house mice attracted cats. But the trash heaps on the outskirts of town were probably just as great a draw, providing year-round pickings for those felines resourceful enough to seek them out. Both these food sources would have encouraged cats to adapt to living with people; in the lingo of evolutionary biology, natural selection favored those cats that were able to cohabitate with humans and thereby gain access to the trash and mice.

Over time, wildcats more tolerant of living in human-dominated environments began to proliferate in villages throughout the Fertile Crescent. Selection in this new niche would have been principally for tameness, but competition among cats would also have continued to influence their evolution and limit how pliant they became. Because these proto–domestic cats were undoubtedly mostly left to fend for themselves, their hunting and scavenging skills remained sharp. Even today most domesticated cats are free agents that can easily survive independently of humans, as evinced by the plethora of feral cats in cities, towns and countrysides the world over.

Considering that small cats do little obvious harm, people probably did not mind their company. They might have even encouraged the cats to stick around when they saw them dispatching mice and snakes. Cats may have held other appeal, too. Some experts speculate that wildcats just so happened to possess features that might have preadapted them to developing a relationship with people. In particular, these cats have "cute" features—large eyes, a snub face and a high, round forehead, among others—that are known to elicit nurturing from humans. In all likelihood, then, some people took kittens home simply because they found them adorable and tamed them, giving cats a first foothold at the human hearth.

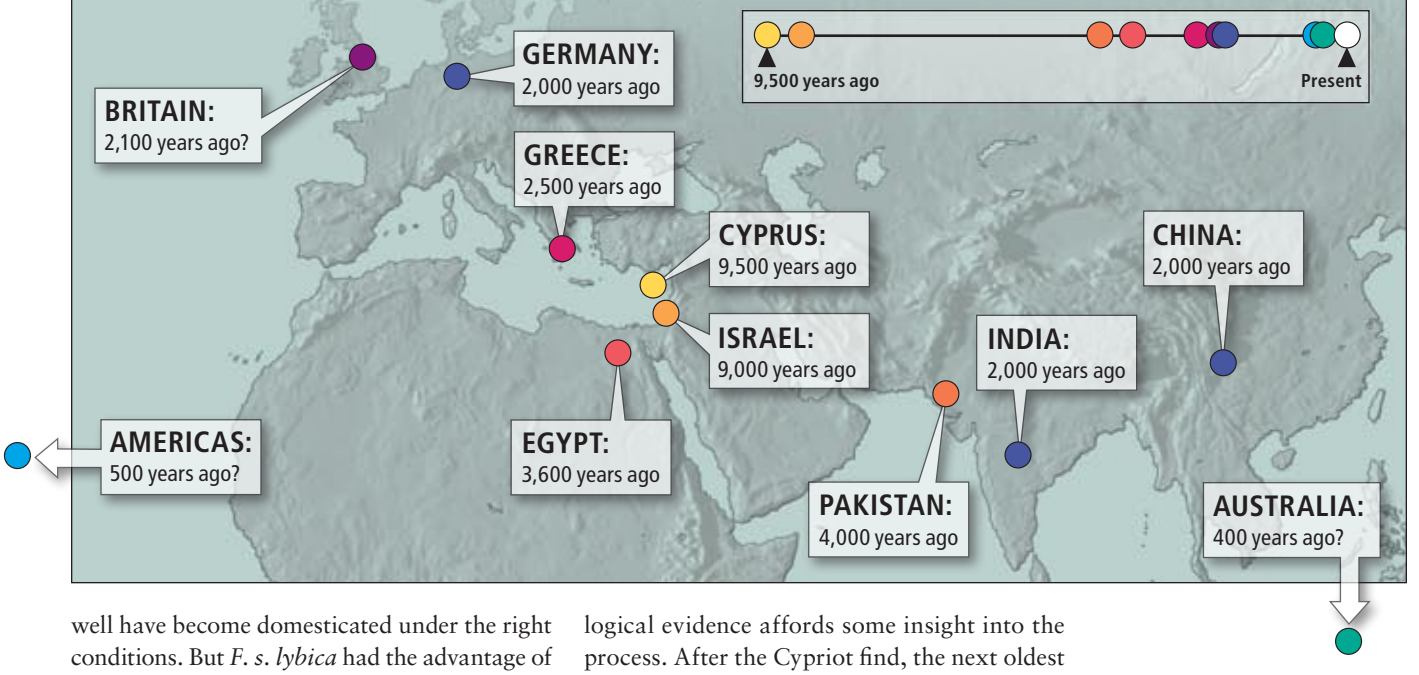
Why was *F. s. lybica* the only subspecies of wildcat to be domesticated? Anecdotal evidence suggests that certain other subspecies, such as the European wildcat and the Chinese mountain cat, are less tolerant of people. If so, this trait alone could have precluded their adoption into homes. The friendlier southern African and Central Asian wildcats, on the other hand, might very

STEPHEN DALTON *Photo Researchers, Inc. (mouse)*; THE ISRAEL MUSEUM, JERUSALEM *(statuette)*; THE BRITISH MUSEUM *(mummy)*; DAVE KING *Getty Images (Siamese)*; HELMI FLICK *(British Shorthair)*

[DISPERSAL]

HAVE CATS, WILL TRAVEL

As agriculture and permanent human settlements spread from the Fertile Crescent to the rest of the world, so, too, did domestic cats. The map below shows the earliest putative occurrences of house cats in regions around the globe.



well have become domesticated under the right conditions. But *F. s. lybica* had the advantage of a head start by virtue of its proximity to the first settlements. As agriculture spread out from the Fertile Crescent, so, too, did the tame scions of *F. s. lybica*, filling the same niche in each region they entered—and effectively shutting the door on local wildcat populations. Had domestic cats from the Near East never arrived in Africa or Asia, perhaps the indigenous wildcats in those regions would have been drawn to homes and villages as urban civilizations developed.

Rise of the Goddess

We do not know how long the transformation of the Middle Eastern wildcat into an affectionate home companion took. Animals can be domesticated quite rapidly under controlled conditions. In one famous experiment, begun in 1959, Russian scientists using highly selective breeding produced tame silver foxes from wild ones in just 40 years. But without doors or windowpanes, Neolithic farmers would have been hard-pressed to control the breeding of cats even if they wanted to. It seems reasonable to suggest that the lack of human influence on breeding and the probable intermixing of house cats and wildcats militated against rapid taming, causing the metamorphosis to occur over thousands of years.

Although the exact timeline of cat domestication remains uncertain, long-known archaeological evidence affords some insight into the process. After the Cypriot find, the next oldest hints of an association between humans and cats are a feline molar tooth from an archaeological deposit in Israel dating to roughly 9,000 years ago and another tooth from Pakistan dating to around 4,000 years ago.

Testament to full domestication comes from a much later period. A nearly 3,700-year-old ivory cat statuette from Israel suggests the cat was a common sight around homes and villages in the Fertile Crescent before its introduction to Egypt. This scenario makes sense, given that all the other domestic animals (except the donkey) and plants were introduced to the Nile Valley from the Fertile Crescent. But it is Egyptian paintings from the so-called New Kingdom period—Egypt's golden era, which began nearly 3,600 years ago—that provide the oldest known unmistakable depictions of full domestication. These paintings typically show cats poised under chairs, sometimes collared or tethered, and often eating from bowls or feeding on scraps. The abundance of these illustrations signifies that cats had become common members of Egyptian households by this time.

It is in large part as a result of evocative images such as these that scholars traditionally perceived ancient Egypt as the locus of cat domestication. Even the oldest Egyptian representations of wildcats are 5,000 to 6,000 years younger

[THE AUTHORS]

Carlos A. Driscoll is a member of the University of Oxford's Wildlife Conservation Research Unit and the Laboratory of Genomic Diversity at the National Cancer Institute (NCI). In 2007 he published the first DNA-based family tree of *Felis silvestris,* the species to which the domestic cat belongs. **Juliet Clutton-Brock**, founder of the International Council for Archaeozoology, is a pioneer in the study of domestication and early agriculture. **Andrew C. Kitchener** is principal curator of mammals and birds at National Museums Scotland, where he studies geographical variation and hybridization in mammals and birds. **Stephen J. O'Brien** is chief of the NCI's Laboratory of Genomic Diversity. He has studied the genetics of cheetahs, lions, orangutans, pandas, humpback whales and HIV. This is his fifth article for *Scientific American*.

JEN CHRISTIANSEN

SAVING THE SCOTTISH WILDCAT

As the northernmost representative of the European wildcat, the Scottish wildcat lives under environmental and climatic conditions unlike those experienced by any other wildcat. It is also critically endangered, thanks to interbreeding with feral domestic cats. According to the latest rough estimate, perhaps only 400 pure Scottish wildcats survive. But sorting the Scottish feline from hybrids and domestic cats is challenging because they all look so similar. To that end, the authors recently discovered a unique genetic signature of the Scottish wildcat that permits precise identification. This development will facilitate implementation of legal protection of this creature.

than the 9,500-year-old Cypriot burial, however. Although ancient Egyptian culture cannot claim initial domestication of the cat among its many achievements, it surely played a pivotal role in subsequently molding the domestication dynamic and spreading cats throughout the world. Indeed, the Egyptians took the love of cats to a whole new level. By 2,900 years ago the domestic cat had become the official deity of Egypt in the form of the goddess Bastet, and house cats were sacrificed, mummified and buried in great numbers at Bastet's sacred city, Bubastis. Measured by the ton, the sheer number of cat mummies found there indicates that Egyptians were not just harvesting feral or wild populations but, for the first time in history, were actively breeding domestic cats.

Egypt officially prohibited the export of their venerated cats for centuries. Nevertheless, by 2,500 years ago the animals had made their way to Greece, proving the inefficacy of export bans. Later, grain ships sailed directly from Alexandria to destinations throughout the Roman Empire, and cats are certain to have been onboard to keep the rats in check. Thus introduced, cats could have established colonies in port cities and then fanned out from there. By 2,000 years ago, when the Romans were expanding their empire, domestic cats were traveling with them and becoming common throughout Europe. Evidence for their spread comes from the German site of Tofting in Schleswig, which dates to between the 4th and 10th centuries, as well as increasing references to cats in art and literature from that period. (Oddly, domestic cats seem to have reached the British Isles before the Romans brought them over—a dispersal that researchers cannot yet explain.)

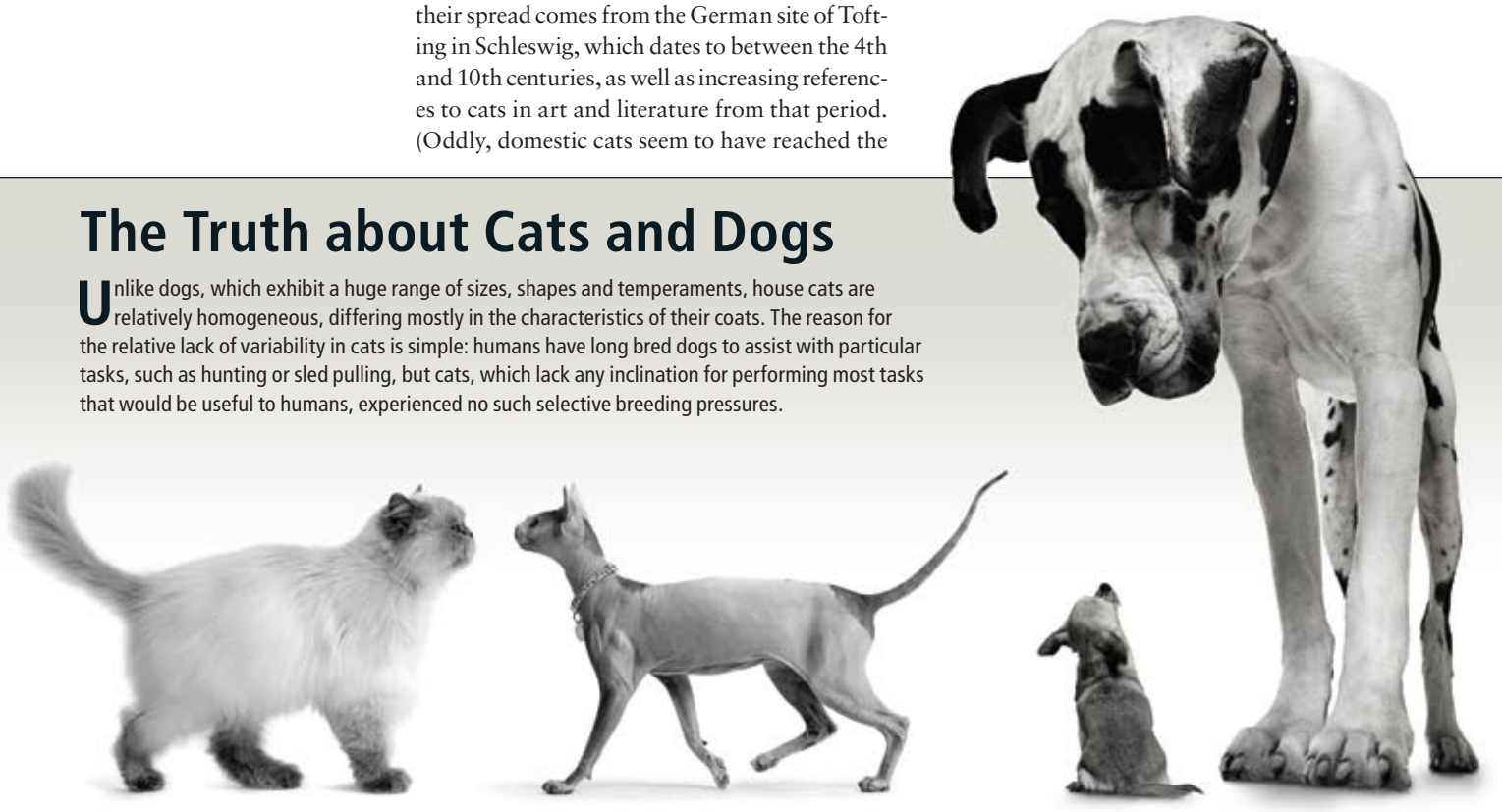
Meanwhile, on the opposite side of the globe, domestic cats had presumably spread to the Orient almost 2,000 years ago, along well-established trade routes between Greece and Rome and the Far East, reaching China by way of Mesopotamia and arriving in India via land and sea. Then something interesting happened. Because no native wildcats with which the newcomers could interbreed lived in the Far East, the Oriental domestic cats soon began evolving along their own trajectory. Small, isolated groups of Orientals domestics gradually acquired distinctive coat colors and other mutations through a process known as genetic drift, in which traits that are neither beneficial nor maladaptive become fixed in a population.

This drift led to the emergence of the Korat, the Siamese, the Birman and other "natural breeds," which were described by Thai Buddhist monks in a book called the *Tamara Maew* (meaning "Cat-Book Poems") that may date back to 1350. The putative antiquity of these breeds received support from the results of genetic studies announced last year, in which Marilyn Menotti-Raymond of the National Cancer Institute and Leslie Lyons of the University of

GANDEE VASAN *Getty Images (cats)*; TIM FLACH *Getty Images (dogs)*

The Truth about Cats and Dogs

Unlike dogs, which exhibit a huge range of sizes, shapes and temperaments, house cats are relatively homogeneous, differing mostly in the characteristics of their coats. The reason for the relative lack of variability in cats is simple: humans have long bred dogs to assist with particular tasks, such as hunting or sled pulling, but cats, which lack any inclination for performing most tasks that would be useful to humans, experienced no such selective breeding pressures.



California, Davis, found DNA differences between today's European and Oriental domestic cat breeds indicative of more than 700 years of independent cat breeding in Asia and Europe.

As to when house cats reached the Americas, little is known. Christopher Columbus and other seafarers of his day reportedly carried cats with them on transatlantic voyages. And voyagers onboard the *Mayflower* and residents of Jamestown are said to have brought cats with them to control vermin and to bring good luck. How house cats got to Australia is even murkier, although researchers presume that they arrived with European explorers in the 1600s. Our group at the U.S. National Institutes of Health is tackling the problem using DNA.

Breeding for Beauty

Although humans might have played some minor role in the development of the natural breeds in the Orient, concerted efforts to produce novel breeds did not begin until relatively recently. Even the Egyptians, who we know were breeding cats extensively, do not seem to have been selecting for visible traits, probably because distinctive variants had not yet arisen: in their paintings, both wildcats and house cats are depicted as having the same mackerel-tabby coat. Experts believe that most of the modern breeds were developed in the British Isles in the 19th century, based on the writings of English natural history artist Harrison Weir. And in 1871 the first proper fancy cat breeds—breeds created by humans to achieve a particular appearance—were displayed at a cat show held at the Crystal Palace in London (a Persian won, although the Siamese was a sensation).

Today the Cat Fancier's Association and the International Cat Association recognize nearly 60 breeds of domestic cat. Just a dozen or so genes account for the differences in coat color, fur length and texture, as well as other, subtler coat characteristics, such as shading and shimmer, among these breeds.

Thanks to the sequencing of the entire genome of an Abyssinian cat named Cinnamon in 2007, geneticists are rapidly identifying the mutations that produce such traits as tabby patterning, black, white and orange coloring, long hair and many others. Beyond differences in the pelage-related genes, however, the genetic variation between domestic cat breeds is very slight—comparable to that seen between adjacent human populations, such as the French and the Italians.

COURTESY OF KATHRIN STUCKI *A1 Savannahs*

STILL EVOLVING: The mating of house cats with exotic species of cats is revolutionizing domestic cat genetics. The photograph above depicts a Savannah, the result of crossing a domestic cat with a Serval.

The wide range of sizes, shapes and temperaments seen in dogs—consider the Chihuahua and Great Dane—is absent in cats. Felines show much less variety because, unlike dogs—which starting in prehistoric times were bred for such tasks as guarding, hunting and herding—wildcats were under no such selective breeding pressures. To enter our homes, they had only to evolve a people-friendly disposition.

So are today's cats truly domesticated? Well, yes—but perhaps only just. Although they satisfy the criterion of tolerating people, most domestic cats are feral and do not rely on people to feed them or to find them mates. And whereas other domesticates, like dogs, look quite distinct from their wild ancestors, the average domestic cat largely retains the wild body plan. It does exhibit a few morphological differences, however—namely, slightly shorter legs, a smaller brain and, as Charles Darwin noted, a longer intestine, which may have been an adaptation to scavenging kitchen scraps.

The house cat has not stopped evolving, though—far from it. Armed with artificial insemination and in vitro fertilization technology, cat breeders today are pushing domestic cat genetics into uncharted territory: they are hybridizing house cats with other felid species to create exotic new breeds. The Bengal and the Caracat, for example, resulted from crossing the house cat with the Asian leopard cat and the caracal, respectively. The domestic cat may thus be on the verge of an unprecedented and radical evolution into a multispecies composite whose future can only be imagined. ■

MORE TO EXPLORE

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Data in the Fast Lanes of RACETRACK MEMORY

A device that slides magnetic bits back and forth along nanowire "racetracks" could pack data in a three-dimensional microchip and may replace nearly all forms of conventional data storage

By Stuart S. P. Parkin

KEY CONCEPTS

- A radical new design for computer data storage called racetrack memory (RM) moves magnetic bits along nanoscopic "racetracks."
- RM would be nonvolatile—retaining its data when the power is turned off—but would not have the drawbacks of hard disk drives or present-day nonvolatile chips.
- Chips with horizontal racetracks could outcompete today's nonvolatile "flash" memory. Building forests of vertical racetracks on a silicon substrate would yield three-dimensional memory chips with data storage densities surpassing those of hard disk drives.
- RM is up against several other new kinds of memory under development.

—The Editors

The world today is very different from that of just a decade ago, thanks to our ability to readily access enormous quantities of information. Tools that we take for granted—social networks, Internet search engines, online maps with point-to-point directions, and online libraries of songs, movies, books and photographs—were unavailable just a few years ago. We owe the arrival of this information age to the rapid development of remarkable technologies in high-speed communications, data processing and—perhaps most important of all but least appreciated—digital data storage.

Each type of data storage has its Achilles' heel, however, which is why computers use several types for different purposes. Most digital data today, such as the information that makes up the Internet, resides in vast farms of magnetic hard disk drives (HDDs) and in the HDDs of individual computers. Yet these drives, with their rotating disks and moving read/write heads, are unreliable and slow. Loss of data because of so-called head crashes occurs relatively often. Regarding speed, it can take up to 10 milliseconds to read the first bit of some requested data. In computers, 10 milliseconds is an eon—a modern processor can perform 20 million operations in that time.

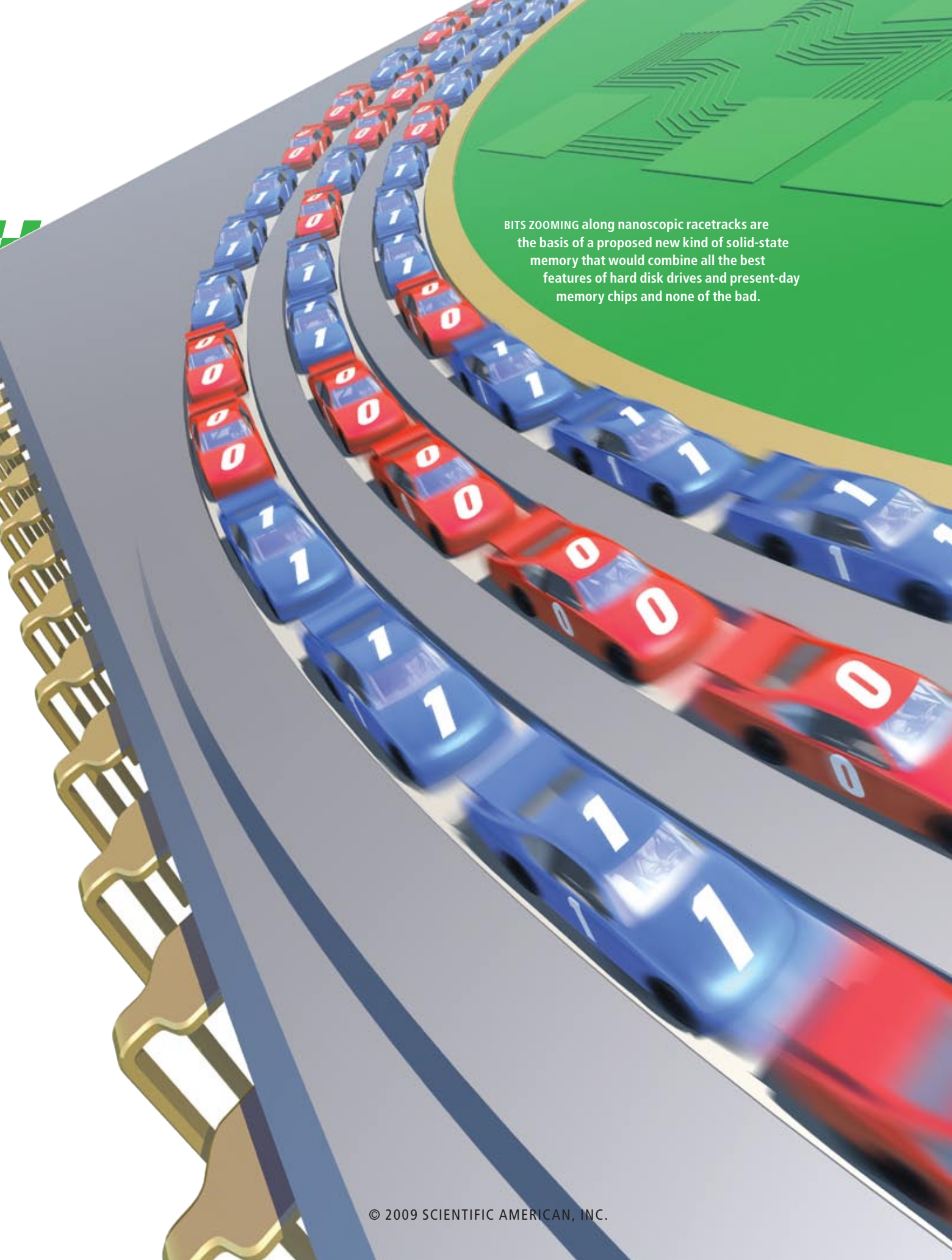
That is why computers use a second type of storage, solid-state memory, for their computational operations. Solid-state memories read and write data with great speed, enabling swift processing. High-performance versions, such as static and dynamic random-access memory (SRAM and DRAM, respectively), use the electronic state of transistors and capacitors to store data bits. These chips lose their data, however, when the computer powers down—or crashes.

A few computers use nonvolatile chips, which retain data when the power is off, as a solid-state drive in place of an HDD. The now ubiquitous smart cell phones and other handheld devices also use nonvolatile memory, but there is a trade-off between cost and performance. The cheapest nonvolatile memory is a kind called flash memory, which, among other uses, is the basis of the little flash drives that some people have hanging from their key rings. Flash memory, however, is slow and unreliable in comparison with other memory chips. Each time the high-voltage pulse (the "flash" of the name) writes a memory cell, the cell is damaged; it becomes unusable after only perhaps 10,000 writing operations. Nevertheless, because of its low cost, flash memory has become a dominant memory technology, particularly for applications in which the data will not be changed very often.

The computing world is thus crying out for a memory chip with high data density that is also cheap, fast, reliable and nonvolatile. With such a memory, computing devices would become much simpler and smaller, more reliable, faster and less energy-consuming. Research groups around the world are investigating several approaches to meet this demand, including systems based on new electronic components called memristors [*see box on page 81*] and others making use of spintronics, in which the spin, or magnetism, of electrons plays a key role [see "Spintronics," by David D. Awschalom, Michael E. Flatté and Nitin Samarth; SCIENTIFIC AMERICAN, June 2002].

The answer may lie in a new kind of spintronic chip called racetrack memory (RM), which I

GEORGE RETSECK

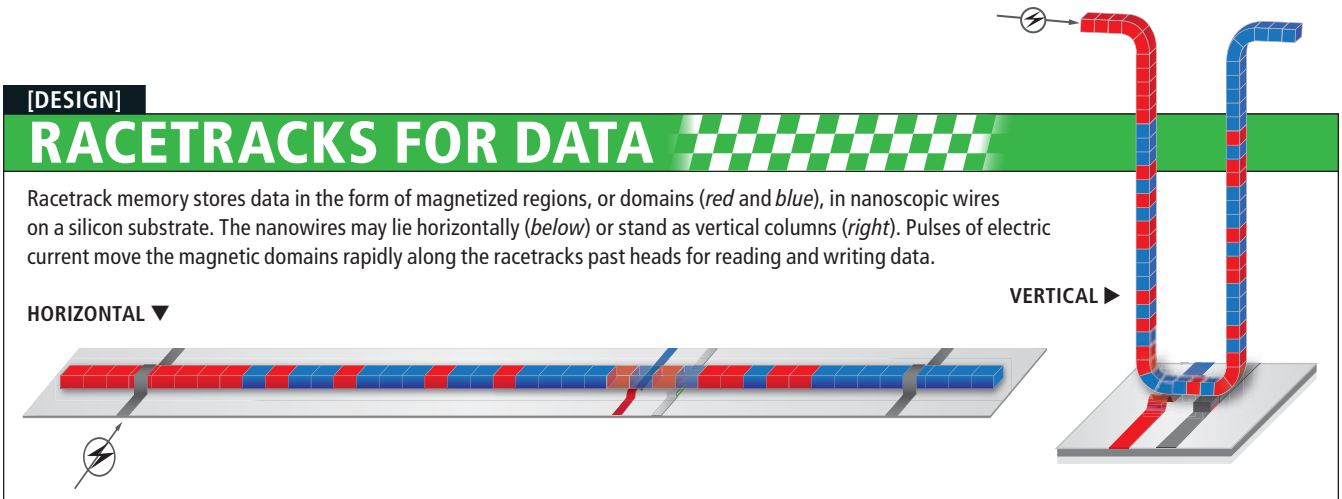


BITS ZOOMING along nanoscopic racetracks are the basis of a proposed new kind of solid-state memory that would combine all the best features of hard disk drives and present-day memory chips and none of the bad.

[DESIGN]

RACETRACKS FOR DATA

Racetrack memory stores data in the form of magnetized regions, or domains (*red* and *blue*), in nanoscopic wires on a silicon substrate. The nanowires may lie horizontally (*below*) or stand as vertical columns (*right*). Pulses of electric current move the magnetic domains rapidly along the racetracks past heads for reading and writing data.



A sensor (*gray*) reads the data by detecting the changing magnetization (*arrows*) traveling above it.

A strip containing two oppositely magnetized domains uses the domain wall that separates its two domains to write a data bit on the racetrack. As the domain wall crosses underneath the racetrack, magnetic fields (*yellow*) emanating from the domain wall set the magnetization direction in the racetrack's bit.

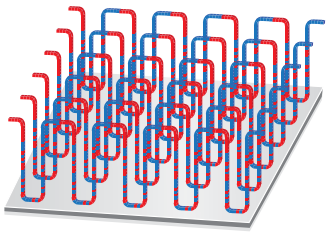
proposed in 2002. RM stores bits of data as magnetized regions on nanowires—the "racetracks." These magnetized regions are as nonvolatile and rewritable as those on an HDD, but the chip needs no moving parts larger than an electron to read and write bits, boosting speed and reliability. The bits themselves zoom along their racetrack, passing a read/write head at a fixed location beside the wire.

Furthermore, the wires may be constructed as vertical columns rising like a forest on a silicon chip. This design breaks free of the limitations inherent in two-dimensional data stores, such as HDDs and all memory chips sold at present, allowing very large data densities. I believe three-dimensional racetrack memory will be the right vehicle to keep information storage technology speeding along the fast lane into a future of data-intensive applications as yet unimagined.

Drawbacks of Disk Drives

The basic structure of an HDD has not changed since its inception in the 1950s, although the technology of individual components has altered enormously, in particular shrinking by many orders of magnitude. An HDD stores data as the directions of magnetization of tiny regions in an ultrathin layer of magnetic material coating the surface of a highly polished glass disk. The disk rotates at high speed (commonly 7,200 revolutions per minute in computers currently sold) under a recording head on a moving arm that reads and writes the magnetic bits.

In the early decades HDDs were refrigerator-size devices and the cost per stored bit was very high. The figure of merit for a disk technology is its areal density: the number of data bits reliably stored per unit area of the magnetic surface. At first areal densities of disk platters improved by only about 25 percent each year, but beginning in the late 1980s HDDs rapidly morphed into much more compact and capacious machines.



THREE-DIMENSIONAL memory chip consisting of arrays of vertical racetracks on silicon may achieve data densities greater than those of hard disk drives without requiring any mechanical moving parts.

An important milestone in this evolution was the development of read heads exploiting spintronics, or what I like to call spin-engineered materials. My research in the period of 1988 to 1991 into the fundamental properties of materials constructed of multiple magnetic nanolayers led to development of the spin-valve magnetoresistive sensor. This sensor detects tiny magnetic fields as a change in its resistance, and at the time of its invention it was the most sensitive detector of such fields at ambient temperatures.

The first use of spin-valve sensors in HDD read heads came in 1997 with IBM's Deskstar 16GP "Titan." Within five years HDD storage capacities had increased 1,000-fold, the rapidest advance in the half-century-long history of HDDs. Today the collective storage capacity of all HDDs manufactured in one month exceeds 200 exabytes, or 2×10^{20} bytes—enough to store all the extant analog data in the world, that is, all the data on paper, film and videotape.

The spin-valve sensor was the first spintronic nanodevice, and knowing some spintronics is essential to understanding how RM works. Spin is a fundamental quantum property of electrons. Imagine each electron as a tiny spinning ball of electric charge, with a magnetic field pointing along the axis of the spin. The spin axis of an

LUCY READING-IKKANDA

electron in an ambient magnetic field lines up either parallel or antiparallel to the field. It is said to have either "spin up" or "spin down," with respect to the local magnetic field.

When electrons travel through a magnetized metal, the spin-up electrons travel more easily, resulting in a spin-polarized current or spin current—one in which most of the moving electrons carry a specific spin. In contrast, an ordinary current, such as one traveling along copper wire, involves electrons whose spins point randomly in all directions. Permalloy, a strongly magnetic alloy of nickel and iron, can produce as much as 90 percent spin polarization in a current.

The spin-valve sensor consists of a nanosandwich, a layer of nonmagnetic metal between two magnetic layers. The first magnetic layer spin-polarizes the current in a specific direction. The second magnetic layer changes its magnetism back and forth to match the field coming from each passing magnetic domain representing a 0 or a 1 on a disk. When the two magnetic layers of the sensor are parallel, the spin-polarized current flows through relatively easily. When the layers are antiparallel, the polarized electrons are impeded. The changing resistance of the device is known as giant magnetoresistance, a phenomenon independently discovered in 1988 by the groups of Albert Fert of the University of Paris–South and Peter Grünberg of the Jülich Research Center in Germany. Giant magnetoresistance allows read heads to detect much weaker fields, which in turn allows magnetic domains on a disk to be much smaller and more tightly packed.

Yet the era of the spin-valve sensor has lasted no more than a decade. A newer spintronic technology known as magnetic tunnel junctions has already replaced it in the HDDs manufactured today. Magnetic tunnel junctions exploit an effect called tunneling magnetoresistance to achieve even greater sensitivity to small magnetic fields than spin-valve devices [see "Magnetic Field Nanosensors," by Stuart A. Solin; Scientific American, July 2004].

Although spintronic read heads have enabled vast increases in the storage capacity of HDDs and helped to bring the cost of storing data down to about 10 cents per gigabyte, the basic mechanical nature of an HDD's rotating disk and moving read head remains, leading to two major deficiencies. First, a head crash occurs when the recording head accidentally strikes the magnetic layer, thereby damaging it, and can result in loss of all data in the HDD. Second, it takes a lot of energy to spin a glass disk at 7,200 rpm, and even at such a pace, rotating the disk to the data of interest takes millions of times longer than accessing data from volatile memory. As a result, HDDs are very inefficient for many quite ordinary applications, such as recording transactions to bank accounts—each transaction may involve a very small amount of data, yet it takes time to rotate the disk and move the write head to the correct location, and backup copies must be made in case of a head crash.

Persistence of Memory

Researchers have devoted much time and effort in recent years toward developing types of nonvolatile memories that might combine the good features of HDDs and silicon chips while avoiding all the bad. In 1995, for example, my colleagues at IBM and I proposed building a spintronic memory based on magnetic tunnel junctions. Data are stored in the magnetic state of the magnetic tunnel junction and can be read using the tunneling magnetoresistance of the device. These magnetic random-access memories, or MRAMs, went on sale in 2006 from Freescale Semiconductor, a spin-off of Motorola.

Many other proposed memory devices involve a component whose resistance changes for one reason or another. All of them, however, require a transistor connected in series with every resistive memory element to access each selected bit. The transistor size largely determines the memories' cost. Despite tremendous advances, the cheapest solid-state memory, flash, remains 20 to 100 times as expensive per bit as HDD.

The trade-off in the cost and performance of HDDs and the various types of solid-state memories mean that it makes sense to build computers that use many different technologies for storing digital data. Consequently, volatile RAM holds data in active use by programs, and HDDs serve as temporary stores of excess data that will not fit in the RAM, as well as for long-term storage of files and programs for when the computer is turned off or crashes. Nonvolatile and read-only memories are also used for special purposes.

This assortment of technologies makes computers and related devices more complex and bulkier than they need be, as well as much more energy-consuming. A memory storage device that had the nonvolatility and the low cost of an HDD, along with the fast reading and writing and the high reliability of conventional solid-state memories, would be a game-changing technology. My RM design can be that device.

Each racetrack consists of a nanoscopic wire

[THE AUTHOR]

Stuart S. P. Parkin is an IBM Fellow and manager of the magnetoelectronics group at the IBM Almaden Research Center in San Jose, Calif., and a consulting professor in the department of applied physics at Stanford University. He is also director of the IBM-Stanford Spintronic Science and Applications Center. Work by Parkin and his IBM colleagues in the late 1980s and early 1990s was instrumental in transforming the then recently discovered phenomenon of giant magnetoresistance into a practical technology that spurred a great increase in the data storage densities of hard disk drives.

EXPERIMENTAL RACETRACK made of the highly magnetic alloy permalloy is 300 nanometers (nm) wide and 40 nm thick. The nanowires under the racetrack allow measurements of magnetic domain walls in the racetrack. This setup is one of hundreds of different racetrack structures on an IBM research chip named "Aqueduct."

COURTESY OF IBM (*Parkin* and *chip*)

Domain walls can move **150 nanometers** in a nanosecond, allowing access millions of times **faster than** hard disk drives.

made of a magnetic material such as permalloy. A racetrack stores bits as a series of magnetized domains along its length. The domains may point one way along the wire to represent 0s and the other way to represent 1s. Just as with an HDD, such domains retain their state when the power is off.

Unlike an HDD, however, the magnetic medium never has to move. Instead the bits themselves travel back and forth along their racetrack, passing a nanoscopic read head and write head along the way. Thus, the hundreds of bits in each racetrack require only a few transistors, instead of a transistor for every bit as in conventional solid-state memory designs.

This idea of moving magnetic data through a medium instead of moving the medium itself is in some respects an old one. Bubble memory, which had its heyday in the 1970s, also involved the motion of small magnetic domains (the "bubbles"), but disk drives and solid-state memories outcompeted it by relentlessly shrinking and becoming faster. The bubbles were moved by a complicated system of magnetic fields. RM uses a much simpler, spintronic motive force.

The key to moving magnetic domains is the domain wall that exists wherever two domains with different directions of magnetization meet. In RM nanowires, a domain wall exists anywhere that a 0 is next to a 1. The customary way to move domain walls involves applying a magnetic field. The magnetization in each domain actually comes about because the atoms in the domain have their individual magnetism aligned. In a sufficiently strong external field aligned with one of the domains, the antiparallel atoms at the domain wall tend to flip around to line up with the applied field—and so the position of the wall shifts. Unfortunately, this process does not move the data bits along the nanowire. Consider a 0 sitting between a pair of 1s, with the applied field pointing in the 1 direction. The two domain walls will move to increase the size of the 1 domains, eventually wiping out the 0 altogether.

The spintronic trick to moving the domain walls uniformly along the racetrack is as simple as sending an electric current along the nanowire. Again consider the 1-0-1 arrangement of domains. The electrons flowing through the first 1 domain will be spin-polarized with their own magnetism aligned in the 1 direction. As each electron crosses the 1-0 domain wall, its magnetism will tend to flip to the 0 direction. But the electron's magnetism is tied to its spin, which is a quantity of angular momentum. As with energy and ordinary momentum, angular momentum is a conserved quantity. For the electron to flip from 1 to 0, something else must flip from 0 to 1, and that something else is an atom just on the 0 side of the domain wall. As the spin-polarized electrons flow through the domain wall, they move the domain wall along the nanowire one atom at a time.

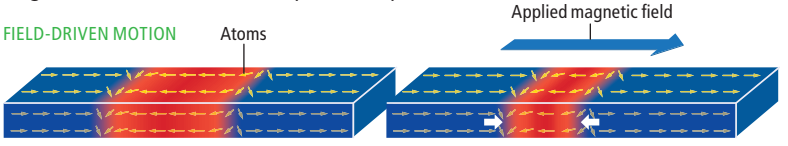
Now consider what happens when one of these same electrons arrives at the 0-1 domain and crosses it. The same reasoning shows that it flips from 0 back to 1, which flips an atom from 1 to 0, again moving the domain wall a tiny amount along the wire in the direction the electron is flowing. With both its domain walls moving along the wire in lockstep, the 0 bit itself travels without expanding or shrinking. So far my group has demonstrated in the lab that nanosecond-long pulses of spin-polarized current indeed cause a series of as many as six domain walls to move in lockstep along magnetic nanowires. The domain walls can move 150 nanometers in a nanosecond, allowing access times of nanoseconds, millions of times faster than HDDs and comparable to volatile memories.

The domain walls could easily drift out of po-

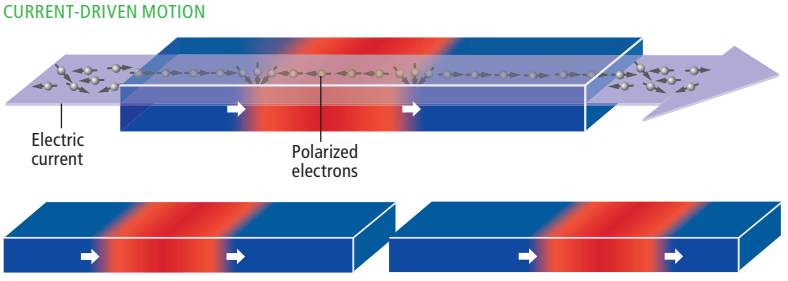
[PHYSICS]

USING SPIN TO MOVE BITS

The ability to use an electric current to move magnetic domains along a nanowire is essential to making racetrack memory practical (*bottom*). Older techniques using magnetic fields would be too complicated (*top*).



Magnetic domains representing 0s and 1s contain atoms whose intrinsic magnetism (*yellow arrows*) is aligned. The atoms' orientation changes at the domain walls. Applying a field pointing in, say, the 1 direction (*blue arrow*), causes domain wall atoms to turn to the 1 direction, which moves the domain walls (*white arrows*)—but in opposite directions, shrinking the 0 region. Moving the bits along the wire requires a more complicated magnetic field.



The electrons (*gray*) of a current in a racetrack become "spin polarized"—their spin and intrinsic magnetism align with the magnetization of the material. When these spin-polarized electrons cross from a 1 region to a 0, their orientations flip. Because spin is a form of angular momentum, which must be conserved, each electron that switches from 1 to 0 must flip an atom in the wire from 0 to 1. Thus, the spin-polarized current moves the 1-0 domain wall along the racetrack. The current moves the 0-1 domain walls in the same direction, so the data bits flow along the wire.

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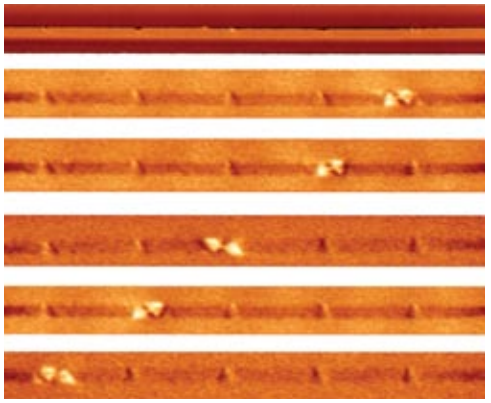
sition, however, perhaps propelled by small stray currents or magnetic fields or because the controlling pulses are not exactly the correct magnitude and duration. This hazard can be averted by building small notches in the racetrack's sides, spaced at the intended size of the bits. The domain walls tend to become pinned at these notches because they will have the smallest area and thus the least energy when sitting at a notch. Tiny stray currents will not suffice to move a domain wall away from a notch, and slightly imperfect control pulses will still move a wall from one notch to the next one, no more and no less.

A few different kinds of domain wall may occur. So-called transverse walls are relatively simple and much like the kind of wall you may be imagining based on my description above. Vortex walls, in contrast, have a complicated, swirling pattern of magnetization, including a little "core" in their center. A smaller current suffices to move a vortex wall because moving the core pulls the whole wall along. If the 0 and 1 domains are magnetized perpendicular to the racetrack instead of along it, only one relatively simple kind of domain wall occurs. In principle, this kind of magnetization should have advantages because the racetrack can be narrower and the domain walls should require less current to move.

With racetracks arranged as forests of vertical columns rising above the surface of a silicon wafer, the memory becomes three-dimensional, greatly increasing the density of data storage compared with the horizontal design. In contrast, both HDDs and silicon-based microelectronic memory (and logic) devices are fundamentally two-dimensional in nature, and many analysts predict the pace of their evolution to smaller sizes will run into fundamental physical problems in as little as a decade from now.



COURTESY OF IBM

MOVING DOMAIN WALL (*light bow-tie shape*) travels along a 300-nm-wide racetrack in controlled stages. Atomic force microscope image (*top strip*) shows notches in the side of the racetrack that pin a domain wall in place when no current is propelling it. A series of magnetic force microscope images (*other strips*) maps the magnetic field intensity, which is strongest at the domain wall. Researchers have demonstrated control of up to six domain walls at once.

My group has built some vertical racetracks, but we have not yet integrated devices on the same chips for writing or reading domain walls. Constructing robust vertical racetracks on silicon chips at a commercially viable cost may be a significant challenge. Most of my group's experiments are with nanowires placed horizontally on the silicon surface. The storage capacity of this mode of RM would be merely comparable to flash memory, though with significant advantages: the memory would be much faster than flash, would use less energy and would not wear out. We are currently working on a prototype that will exploit our ability to move half a dozen domain walls along each racetrack.

RM faces stiff competition from storage-class memories under development that use more traditional approaches [*see box above*]. Research groups are vying to turn their chosen approach into a superior commercially viable product. Stay tuned to see which technology crosses the finish line at a store near you. ■

Emerging Memories

Researchers are working on several emerging technologies to pursue storage-class memories with a more traditional design than that of racetrack memory—placing the bits in horizontal arrays on a silicon wafer. Achieving capacities comparable to vertical RM or hard disk drives would require stacks of these arrays.

RESISTIVE RANDOM-ACCESS MEMORY (RRAM) uses materials that can be switched between two or more distinct resistance states. Many companies are investigating metal oxide nanolayers switched by voltage pulses. Researchers generally think that the pulses' electric fields produce conducting filaments through the insulating oxide. HP Labs plans to release prototype chips this year based on "memristors," in which migrating oxygen atoms change the resistance.

PHASE-CHANGE RAM (PRAM) has memory elements made of chalcogenide glass, the same class of material as used in rewritable CDs and DVDs. The glass has a crystalline state with low resistance and an amorphous state with high resistance. A current pulse sets the state by heating the chalcogenide and then allowing it to cool either rapidly or slowly. In 2006 BAE Systems introduced a 512-kilobyte PRAM radiation-hardened for space applications. Numonyx, a spin-off of Intel Corporation and STMicroelectronics, began commercial sales of its 16-megabyte "Alverstone" chip in late 2008.

SPIN TORQUE TRANSFER RAM (STT-RAM) is a new kind of magnetic RAM (MRAM). MRAM stores data as the magnetization direction of each bit. Nanoscopic magnetic fields set the bits in conventional MRAM, but STT-RAM uses spin-polarized currents, enabling smaller and less energy-consuming bits. Companies developing STT-RAM include Ever-Spin, Grandis, Hynix, IBM, Samsung, TDK and Toshiba.

MORE TO EXPLORE

Magnetically Engineered Spintronic Sensors and Memory. Stuart Parkin, Xin Jiang, Christian Kaiser, Alex Panchula, Kevin Roche and Mahesh Samant in *Proceedings of the IEEE,* Vol. 91, No. 5, pages 661–680; May 2003.

Magnetic Domain-Wall Racetrack Memory. Stuart S. P. Parkin, Masamitsu Hayashi and Luc Thomas in *Science,* Vol. 320, pages 190–194; April 11, 2008.

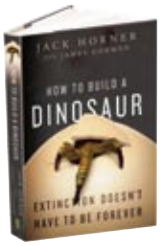
IBM-Stanford Spintronic Science and Applications Center Web site: **www.almaden.ibm.com/spinaps**

Dinochicken ▪ Acts of God ▪ Nature's Masterpiece

BY MICHELLE PRESS

HOW TO BUILD A DINOSAUR: EXTINCTION DOESN'T HAVE TO BE FOREVER

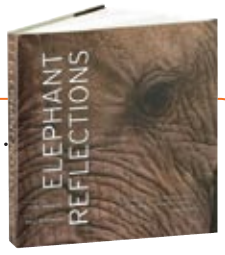
by Jack Horner and James Gorman. Dutton, 2009 ($25.95)



A more accurate title would be *How to Genetically Modify a Chicken.* But *How to Build a Dinosaur* is definitely catchier—and harmless. The subtitle is less sanguine. Extinction, certainly of really ancient creatures, is forever, as the authors themselves make clear.

But back to that chicken. Horner, a well-known paleontologist (his co-author is a writer for the *New York Times*), confides that he has kept a chicken skeleton at hand wherever he has worked, because it looks like a dinosaur. "Sometimes," he writes, "I look at it and turn it … and think, if I could just grow these bones a little different, tilt this one way, that another, I'd have a dinosaur." That skeleton started out as an embryo, he reasons, so why couldn't we biochemically nudge a chicken embryo this way and that, "until what hatched was not a chicken but a small dinosaur, with teeth, forearms with

EXCERPT

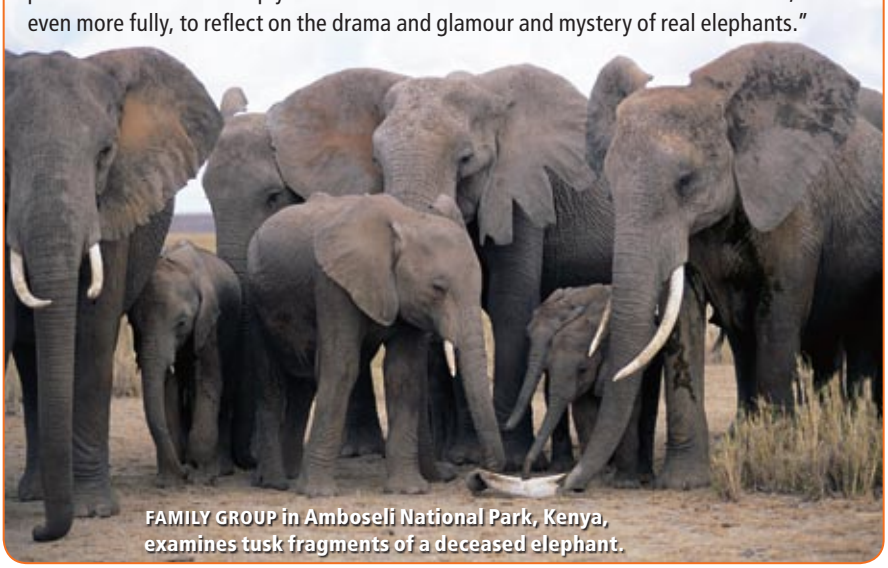


ELEPHANT REFLECTIONS

Photographs by Karl Ammann. Text by Dale Peterson. University of California Press, 2009 ($39.95)

This gorgeous book, which includes the natural history and conservation status of African elephants and recent surprising discoveries of field scientists, will convince you that the elephant is one of nature's greatest and most original works. As Peterson writes in his introduction:

"Good photography depends only partly on the artistic skill of the photographer. It also surely depends on the artistic value of the subject. We look at this collection of elephant reflections not simply to admire the talent and skill of Karl Ammann but also, and even more fully, to reflect on the drama and glamour and mystery of real elephants."



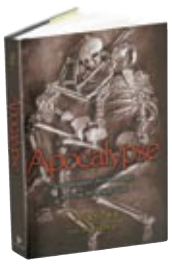
FAMILY GROUP in Amboseli National Park, Kenya, examines tusk fragments of a deceased elephant.

PHOTOGRAPH COPYRIGHT © 2009 BY KARL AMMANN *http://www.ucpress.edu/books/pages/10944.php*

For a slideshow of photographs from the book, go to **www.ScientificAmerican.com/elephant-reflections**

claws, and a tail?" The book describes how this might be done—someday.

APOCALYPSE: EARTHQUAKES, ARCHAEOLOGY, AND THE WRATH OF GOD
by Amos Nur, with Dawn Burgess. Princeton University Press, 2008 ($26.95)



The outsider may be surprised to learn that earth scientists and archaeologists disagree strongly about what caused the destruction of ancient civilizations. Archaeologists hold that human events—war in particular—crushed these societies; earth scientists lean toward natural causes—earthquakes in particular. Stanford University geophysicist Nur offers detailed evidence for the controversial earthquake theory. Troy, Jericho, Knossos, Mycenae, Armageddon, Teotihuacán and Petra, he argues, were all located along fault lines or in regions prone to earthquakes. He corroborates this scientific evidence with written records from the Bible, the *Iliad* and other documents that describe events that could have been earthquakes.

NOTABLE BOOKS: SCIENCE AND LITERATURE

1 **Sex in an Age of Technological Reproduction: *ICSI* and *Taboos***
by Carl Djerassi. University of Wisconsin Press, 2008 ($50; paperbound, $24.95)
Written by one of the inventors of oral contraceptives, these two plays dramatize the social transformations and controversies created by advances in reproductive technology.

2 **Quantum Lyrics: Poems**
by A. Van Jordan. W. W. Norton, 2009 (paperbound, $13.95)
Physicists—most often Einstein—as well as physics itself inhabit these poems.

3 **Sum: Forty Tales from the Afterlives**
by David Eagleman. Pantheon, 2009 ($20)
A neuroscientist presents in novelistic vignettes a variety of possibilities for the world that comes after death.

Q *What causes **albinism**? Are there any **treatments** for it?*

Raymond Boissy, a dermatology professor at the University of Cincinnati College of Medicine, explains (as told to Coco Ballantyne):

Albinism is a genetic disease causing partial or complete loss of pigmentation, or coloring, in the skin, eyes and hair. It arises from mutations affecting cells, called melanocytes, that produce the pigment melanin, which gives color to those body parts. In individuals with albinism, genetic alterations interfere with the melanocytes' production of pigment or their ability to distribute it to keratinocytes, the major cell type of the skin's outer layer.

The most common forms of albinism are oculocutaneous type 1 (OCA1) and type 2 (OCA2). Oculocutaneous means the disease affects the eyes ("oculo") and skin ("cutaneous"). People with OCA1 have mutations in a gene called *TYR* that is responsible for production of the enzyme tyrosinase, used by cells to convert the amino acid tyrosine into pigment. OCA2, the most common form in Africa, results from a mutation in the *OCA2* gene, which encodes the P protein—a protein whose role is not totally clear. This mutation is probably the oldest one causing albinism and, putatively, originated during humankind's development in Africa.

Most people with OCA1 have white skin, white hair and pigmentless eyes. The iris, the colored part of the eye encircling the pupil, is pale, whereas the pupil itself may appear red. This redness results from light reflecting off blood vessels in the retina, the light-sensitive layer of tissue lining the back of the eyeball. Pupils ordinarily appear black because pigment molecules in the retina absorb light and prevent it from bouncing back out. People with OCA2 can make a small amount of pigment and thus may have somewhat less pronounced visual symptoms.

Individuals with albinism are often legally blind. Without melanin during the embryonic stage, the neuronal tracts leading from the eye to the visual cortex of the brain develop aberrantly, resulting in diminished depth perception. And in the absence of pigment in the eye, retinal photoreceptors can become overstimulated and send confusing messages to the brain, which often also produce a nystagmus, or fluttering of the eyes.

A dearth of skin pigment leaves people more susceptible to nonmelanoma skin cancers such as squamous cell carcinoma and basal cell carcinoma. Normally functioning melanocytes distribute pigment to keratinocytes to shield the nucleus and the DNA inside from the sun's ultraviolet radiation. People with albinism may also experience premature skin aging, because UV-blocking melanin helps to prevent wrinkling and the loss of the skin's elasticity.

Researchers such as geneticist Richard King of the University of Minnesota and cell biologist Vitali Alexeev of Thomas Jefferson University are working on gene therapies or drugs that would fix albinism-causing mutations. Scientists have had some success in correcting patches of depigmented skin and hair in mice, but they are a long way from translating this research to humans.

ALBINO GORILLA, Barcelona zoo

CESAR RANGEL *AFP/Getty Images*

Q *Why do **two things** I like to eat sometimes **taste so bad** when eaten together?*

—R. Lange, Houston

Biosciences professor **Tim Jacob,** who studies smell and taste at Cardiff University in Wales, mixes up an answer:

Among the five tastes, salty, sweet and umami (meaty or savory) are appetitive, driving us toward essential nutrients, whereas bitter and sour are aversive, alerting us to potentially harmful substances. Mixing the aversive with the appetitive sends conflicting information to the brain, and confusion is what the senses are trying to avoid as they supply you with useful, lifesaving information. This mixed signal is why you reject food that has gone off. You do not want to eat a blend of the good and the bad.

Yet consider the phrase "sugaring the pill": pills are medicine and as such are poisonous in large quantities. They thus taste bitter but can be made more palatable by a camouflaging sugar coating. Similarly, coffee can be improved for people who are sensitive to bitterness by masking its sharpness with cream or sugar.

As adults, we can override these warnings and acquire tastes for coffee, olives or strong cheese. But you will confound your senses if you mix a formerly aversive taste with an appetitive one. (Care for some pickles and cocoa?) There can be delight in the confusion, however: sweet and sour is a popular choice in Chinese cuisine. ■

HAVE A QUESTION?... *Send it to experts@SciAm.com or go to* **www.ScientificAmerican.com/asktheexperts**

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