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1 BILLION PEOPLE
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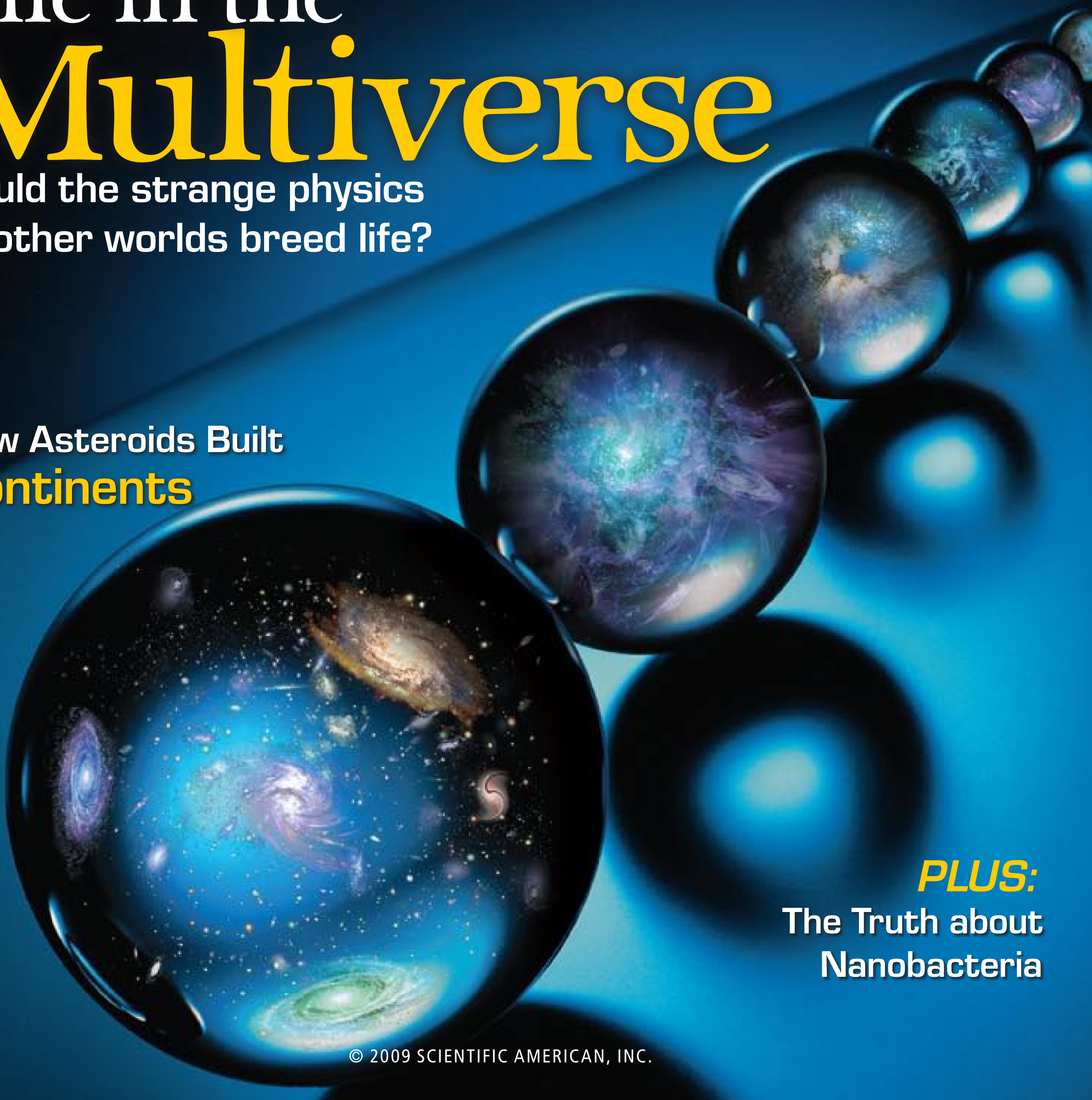
Life in the Multiverse

Could the strange physics of other worlds breed life?

How Asteroids Built Continents



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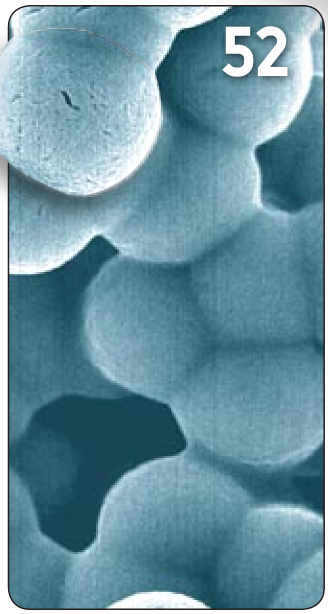

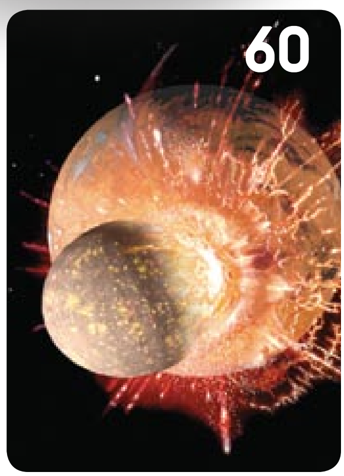

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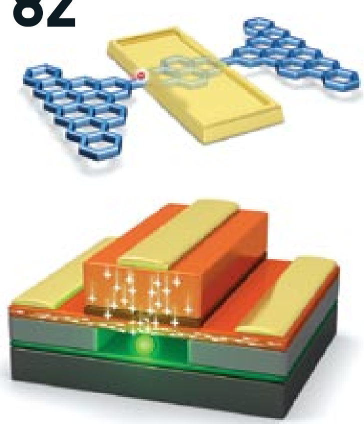

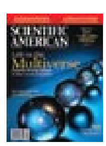

ON THE COVER

Prevailing theory holds that multiple universes could pop out of a primordial vacuum within a wider expanse—the multiverse. Photography by Kazuo Kawai, Getty Images; galaxies by Jean-Francois Podevin.


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Pictured: Antonio Spagnoli & Janai Grayson, Toyota Team Members
Toyota Highlander, built in Princeton, Indiana*

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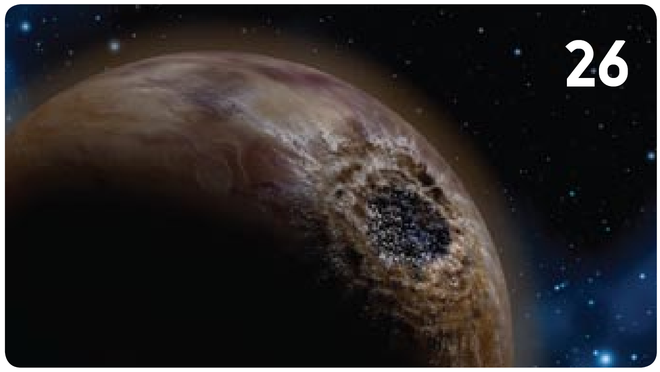
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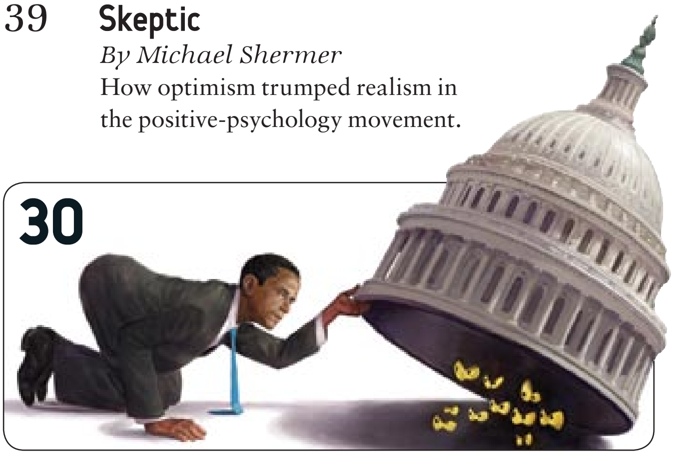
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Life Quest

After more than 40 years that included five long-running TV series (even an animated version) and a string of movies, the writers of the latest *Star Trek* blockbuster in theaters decided to move to a new universe—one that has created fresh opportunities for stories and the chance to modernize and update the franchise. In the movie last summer Kirk, Spock and the rest of the gang were back. But a critical change—a time-jumping, revenge-seeking madman who caused the death of Kirk's father and then destroyed the planet Vulcan—shattered the well-trod timeline of events that longtime fans have come to know so well.

Many *Star Trek* fans, old and new, like the new, parallel universe, which is intriguingly darker and gives beloved characters and the too-good-to-be-interesting Starfleet a helpful kick-start for future movies. One thing that struck me, however, was how similar the two universes actually were, aside from the cataclysms that brought forth the new timeline. They had the same starring roles (albeit with new, younger actors) and revolved around the same key worlds, the same Federation of Planets, and so on.

In science, as opposed to science fiction, parallel universes aren't necessarily so parallel. Beyond simple changes in character development, alternative universes may have wholly different laws of physics. Nevertheless, a number of them could prove to be congenial to life, which so far seems to be so rare in our own reality. According to prevailing cosmological theory, our universe spawned from a microscopic region of a primordial vacuum in a burst of exponential expansion called inflation; the vacuum may produce other universes as well. In numerous other universes, theorists long held, the laws of physics may not permit the formation of matter or galaxies as we know them—leaving our home unique.

But recent studies by Alejandro Jenkins and Gilad Perez, authors of our cover story, "Looking for Life in the Multiverse," show that some other universes may not be so inhospitable after all. "We have found examples of alternative values of the fundamental constants, and thus of alternative sets of physical laws, that might still lead to very interesting words and perhaps to life," they write. In other words, scientists get a "disaster" for life if their models vary just one "constant" of nature, but if they vary more than one they can find values that are compatible with the formation of complex structures and perhaps intelligent life. What would these universes be like? Turn to page 42 to find out.

Many of us are captivated by the search for other beings in the vast cosmos beyond Earth. So it is ironic that we sometimes place such a paltry value on life that already exists on our own planet. Seven horrific tropical diseases, mostly caused by parasitic worms, ruin the lives and health of a billion impoverished people around the world by making them chronically sick, yet these ailments get less attention and money than HIV/AIDS, malaria and tuberculosis. In his feature article starting on page 90, Peter Jay Hotez presents "A Plan to Defeat Neglected Tropical Diseases." Surely there is a way to provide the necessary drugs—which can cost just 50 cents per person—so that all people can thrive.

MARIETTE DiCHRISTINA
acting editor in chief

ETHAN HILL (*DiChristina*); KAZUO KAWAI (*sphere photography*); JEAN-FRANCOIS PODEVIN (*galaxies in spheres*)

Letters to the Editor

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Letters may be edited for length and clarity. We regret that we cannot answer each one. Post a comment on any article instantly at www.ScientificAmerican.com/sciammag

The First Computer ■ Fights over Fossils

SEPTEMBER 2009

> **"The first person to build and operate an electronic digital computer was a physics professor."**
> —*John Hauptman*
> IOWA STATE UNIVERSITY

■ Patent Lead

In "Origin of Computing," Martin Campbell-Kelly writes that the first digital computer was J. Presper Eckert and John W. Mauchly's ENIAC, finished in 1945 as part of the war effort. But the first person to build and operate an electronic digital computer was a physics professor, as noted in "Dr. Atanasoff's Computer," published in the August 1988 *Scientific American*. John Vincent Atanasoff's first computer was a 12-bit, two-word machine running at 60-hertz wall-plug frequency and could add and subtract binary numbers stored in a logic unit built with seven triode tubes. This was 1937. There was no war, no Pearl Harbor, just a theoretical physicist trying to solve problems in quantum mechanics with his students at Iowa State College in Ames, Iowa.

John Hauptman
Department of Physics
Iowa State University

In one of the longest cases—lasting almost five years—in the history of the U.S. federal courts, *Honeywell v. Sperry Rand*, Judge Earl R. Larson concluded in the 1973 verdict that Eckert and Mauchly's patent for the ENIAC was invalid. Judge Larson declared that Eckert and Mauchly "did not themselves first invent the automatic electronic digital computer but instead derived that subject matter from one Dr. John Vincent Atanasoff."

Edward B. Watters
Newberg, Ore.

CAMPBELL-KELLY REPLIES: *Computer historians are cautious about assigning priorities to inventors. I did not state that Eckert and Mauchly invented the electronic computer but rather that they invented a particular computer, the ENIAC. I also said that "computing entered the electronic age with the ENIAC," which is true in the sense of a practical computing instrument of fairly broad application.*

There were several electronic computing developments during World War II, both preceding and contemporaneous with the ENIAC, of which the Atanasoff machine was one—others included the NCR code-breaking machines, the Zuse Z4 computer in Germany, and the Colossus code-breaking computer in the U.K. In a short article I could not acknowledge them all. Atanasoff's machine was a little-known computer that was restricted to a narrow class of problems, was not programmable and was never fully functional.

Atanasoff discontinued development in 1942, and his work was virtually unknown until 1971, when Honeywell brought the suit against Sperry Rand to invalidate the ENIAC patent. During the trial it was revealed that Mauchly had visited Atanasoff and had seen his computer in June 1941. What he learned from this visit cannot be known, but the design of the ENIAC bore no resemblance to the Atanasoff computer. Mauchly himself claimed that he took away "no ideas whatsoever." Although the judge gave priority of invention to Atanasoff, this was a legal judgment that surprised many historians.

■ Fossils for All

Your editorial "Fossils for All" [Perspectives] singled me out as the example of "how science suffers by hoarding." This disrespects dozens of Middle Awash project scientists from 19 different countries

© Jim Lopes, 2008. Used under license from Shutterstock, Inc.

who have worked on these fossils for years. We have shared our results by publishing 6,400 journal, book and monograph pages. Most recently, we have communicated project discoveries to the scientific community via the most extensive special issue of *Science* since *Apollo 11* (www.sciencemag.org/ardipithecus). We reached the public with a two-hour television documentary (dsc.discovery.com/tv/ardipithecus/ardipithecus.html).

How and why did the *Scientific American* editorial miss that story? It closely repeats allegations made in the 2009 trade book *Lucy's Legacy*, co-authored by Donald C. Johanson and Kate Wong (the latter is a member of *Scientific American*'s board of editors). It is of particular concern that Wong—who covers paleoanthropology for *Scientific American*—now claims to have done "most of the legwork on this particular editorial." Journalistic standards were abandoned, as I was never consulted during Wong's "legwork" or even afforded an opportunity to rebut the allegations. Nor does the editorial mention that these allegations were long ago shown to be baseless by multiple investigations (even though the complainants succeeded in persuading the National Science Foundation to impose a burdensome and inappropriate "data-sharing" requirement now detrimental to sustained paleoanthropological fieldwork).

The second focus of the editorial was the marketing of the original Lucy fossil for an American audience. It left unmentioned the fact that Ethiopian paleoanthropologists were uniformly opposed to the export and display of this original fossil. The Middle Awash project operates in full compliance with Ethiopian antiquities laws and regulations—policies of a sovereign nation that does not need to be lectured about "open-access practices" or "doing the right thing," particularly when these are so often designed to benefit non-Ethiopian institutions and their inhabitants.

Tim White
Human Evolution Research Center
University of California, Berkeley

SEPTEMBER'S Perspectives column argued for wider access to fossils for researchers.

ILLUSTRATION BY MATT COLLINS

MARIETTE DICHRISTINA, ACTING EDITOR IN CHIEF, REPLIES: *We hold White's work in high regard, but the editorial was published more than a month before the* Science *special issue. It mentioned that critics of limited access to specimens commonly point to the length of time it has taken for the complete evaluation of* Ardipithecus ramidus*; in including that information, the board simply cited the most frequently given example for this issue. Further, the editorial immediately acknowledged counterarguments—noting the reasons for limiting access. And although the essay called for limits in exclusivity for such access, it did not make any pronouncements on what is appropriate nor make any judgment about White's work in particular.*

The editorial board collaborates as a group on selecting the topic, reporting it and creating drafts of the text. Kate Wong's having done "most of the legwork" is journalist's lingo for "most of the reporting." In other words, the editor who covers anthropology was primarily responsible for the fact-gathering for this essay, just as the editor who covers the energy beat would be responsible for information-gathering for an essay on related policies. But the essay as a whole is a group effort.

ERRATA In "Origin of Computing," Martin Campbell-Kelly writes that in 1790 "Napoleon Bonaparte decided that the republic required a new set of maps." Napoleon was not ruling France at the time.

In "Cooking," Melinda Wenner writes that our ancestors "must have first enjoyed the smell of a good roast 1.9 billion years ago." The word "billion" should have been "million."

In "The Pill," Christine Soares notes that in clinical trials John Rock and Gregory Pincus injected 50 women with synthetic progestins. The drug was administered orally.

In "The Web," Michael Moyer says that the acronym "URL" stands for "Universal Resource Locator;" instead it stands for "Uniform Resource Locator."

In "Cancer," Christine Soares states that Galen lived in the second century B.C. In fact, he lived in the second century A.D.

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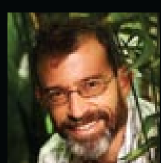

Sensational Press ▪ Stylish Cars ▪ Lotus Eaters

Compiled by Daniel C. Schlenoff

JANUARY 1960

ASTOUNDING TALES—"The press of the Soviet Union has been astounding its readers with accounts of a 'revolution' in science and a 'miracle' of technology. Nikolai A. Kozyrev, an astrophysicist, was said to have wrought the revolution, with his hypothesis that the passage of time is the source of cosmic energy. The miracle was the harnessing of a 'concentration of energy.' Speaking for the Presidium of the U.S.S.R. Academy of Sciences, three distinguished physicists joined in a public rebuke to the press for 'cheap sensationalism' and for placing its pages 'at the disposal of absolutely incompetent people.' They declared: 'We are not against bold hypotheses, provided they are given substantiation.' However, 'This is not a case of the concentration of energy but of the concentration of amazing ignorance.'"

JANUARY 1910

WAVE VS. SHIP—"Was it a last despairing protest of Old Ocean, when he lifted his giant hand in the blackness of night on January 10, and smote the Cunard liner 'Lusitania' a blow which racked and splintered her lofty bridge and pilot house, 75 feet above the sea, and crushed down her forecastle deck and decks beneath, giving them a permanent depression of several inches? When the mass of the wave struck the breastworks and pilot house, every one of the stout wooden storm windows was burst in, the woodwork being stripped clean to the sashes—and this, be it remembered, at an elevation of 75 feet above the normal sea level. We are inclined to agree with her captain in his belief that many smaller and less stoutly built ships which have disappeared utterly at sea, may have been sent to the bottom by the crushing in of their decks under so-called 'tidal waves' of these dimensions."

[NOTE: The *Lusitania* survived the rogue wave but was torpedoed and sunk by a German U-boat five years later.]

THE PERFECT CAR—"Convincing evidence that the automobile of today is as far perfected as the materials of construction and mechanical ingenuity will allow, is afforded by the fact that the cars shown in the two annual exhibitions this year exhibit no novelties of a radical character as compared with the cars of the preceding year. The present flood tide of prosperity in the automobile industry is due to the fact that people of moderate means, who have been waiting until a thoroughly serviceable car embodying the latest improvements was placed on the market at a low price, are now being accommodated [*see illustration*]."

THE AUTOMOBILE goes from transportation to lifestyle, 1910

JANUARY 1860

FIELDS AND FERTILIZER—"A very valuable letter has lately been written by Professor Liebig, the eminent chemist at Munich, in Bavaria: 'In consequence of the farmer restoring with guano and bones but a small portion of the very same elements of seeds and of fodder which had been withdrawn from his fields by centuries of cultivation, their products are wonderfully increased. Experiments with special reference to this end, in six different parts of the kingdom of Saxony, showed how enormously the corn and flesh production of Europe has been increased by the yearly importation of 100,000 tons of guano.'"

DR. LIVINGSTONE—"The celebrated African traveler Dr. Livingstone relates by letter from the Zambesi: 'The luxuriant valley of the Shire River is marshy and abounding in lagoons, in which grow great quantities of the lotus plant. The people were busy collecting the tubers, which when boiled or roasted, resembled chestnuts. They are thus real Lotophagi, such as are mentioned by Herodotus. Another part of the valley abounded in elephants. Herd upon herd appeared as far as the eye could reach; and noble animals they were. We sometimes chased them in our little steamer. The upper part of the valley is well peopled, and many of the hills are cultivated high up. But never having seen Europeans before, they looked on us with great suspicion. They watched us constantly, well armed with bows and poisoned arrows, ready to repel any attack, but no incivility was offered.'"

SCIENTIFIC AMERICAN, VOL. CII, NO. 3; JANUARY 15, 1910


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Energy & Environment

Climate Numerology

Trying to find a "safe" level for atmospheric carbon dioxide BY DAVID BIELLO

LAST DECEMBER WORLD LEADERS MET IN COPENHAGEN TO ADD more hot air to the climate debate. That is because although the impacts humanity would like to avoid—fire, flood and drought, for starters—are pretty clear, the right strategy to halt global warming is not. Despite decades of effort, scientists do not know what "number"—in terms of temperature or concentrations of greenhouse gases in the atmosphere—constitutes a danger.

When it comes to defining the climate's sensitivity to forcings such as rising atmospheric carbon dioxide levels, "we don't know much more than we did in 1975," says climatologist Stephen Schneider of Stanford University, who first defined the term "climate sensitivity" in the 1970s. "What we know is if you add watts per square meter to the system, it's going to warm up."

Greenhouse gases add those watts by acting as a blanket, trapping the sun's heat. They have warmed the earth by roughly 0.75 degree Celsius over the past century. Scientists can measure how much energy greenhouse gases now add (roughly three watts per square meter), but what eludes precise definition is how much other factors play a role—the response of clouds to warming, the cooling role of aerosols, the heat and gas absorbed by oceans, human transformation of the landscape, even the natural variability of solar strength. "We may have to wait 20 or 30 years before the data set in the 21st century is good enough to pin down sensitivity," says climate modeler Gavin Schmidt of the NASA Goddard Institute for Space Studies.

Despite all these variables, scientists have noted for more than a century that doubling preindustrial concentrations of CO_2 in the atmosphere from 280 parts per million (ppm) would likely result in global average temperatures roughly three degrees C warmer.

But how much heating and added CO_2 are safe for human civilization remains a judgment call. European politicians have agreed that global average temperatures should not rise more than two degrees C above preindustrial levels by 2100, which equals a greenhouse gas concentration of roughly 450 ppm. "We're at 387 now, and we're going up at 2 ppm per year," says geochemist Wallace Broecker of Columbia University. "That means 450 is only 30 years away. We'd be lucky if we could stop at 550."

Goddard's James Hansen argues that atmospheric concentrations must be brought back to 350 ppm or lower—quickly. "Two degrees Celsius [of warming] is a guaranteed disaster," he says, noting the accelerating impacts that have manifested in recent years. "If you want some of these things to stop changing—for example, the melting of Arctic sea ice—what you would need to do is restore the planet's energy balance."

Other scientists, such as physicist Myles Allen of the University of Oxford, examine the problem from the opposite side: How much more CO_2 can the atmosphere safely hold? To keep warming below two degrees C, humanity can afford to put one trillion metric tons of CO_2 in the atmosphere by 2050, according to Allen and his team—and humans have already emitted half that. Put another way, only one quarter of remaining known coal, oil and natural gas deposits can be burned. "To solve the problem, we need to eliminate net emissions of CO_2 entirely," Allen says. "Emissions need to fall by 2 to 2.5 percent per year from now on."

Climate scientist Jon Foley of the University of Minnesota, who is part of a team that defined safe limits for 10 planetary systems, including climate, argues for erring on the side of caution. He observes that "conservation of mass tells us if we only want the bathtub so high either we turn down the faucet a lot or make sure the drain is bigger. An 80 percent reduction [in CO_2 by 2050] is about the only path we go down to achieve that kind of stabilization."

The National Academy of Sciences, for its part, has convened an expert panel to deliver a verdict on the appropriate "stabilization targets" for the nation, a report expected to be delivered later this year. Of course, perspectives on what constitutes a danger may vary depending on whether one resides in Florida or Minnesota, let alone the U.S. or the Maldives.

Keeping atmospheric concentrations of greenhouse gases below 550 ppm, let alone going back to 350 ppm or less, will require not only a massive shift in society—from industry to diet—but, most likely, new technologies, such as capturing CO_2 directly from the air. "Air capture can close the gap," argues physicist Klaus Lackner, also at Columbia, who is looking for funds to build such a device.

JAMES L. STANFIELD *Getty Images*

GAS UNCAPPED: Because heat-trapping industrial gases spewed today will warm the earth for decades, researchers aren't sure how much of such emissions the planet can take and remain ecologically healthy.

Closing that gap is crucial because the best data—observations over the past century or so—show that the climate is sensitive to human activity. "Thresholds of irreversible change are out there—we don't know where," Schneider notes. "What we do know is the more warming that's out there, the more dangerous it gets."

Medicine & Health

Renewed Hope

Despite questions, AIDS vaccine trial in Thailand spreads optimism BY KATHERINE HARMON

THE LONG SEARCH FOR AN AIDS VACCINE HAS PRODUCED countless false starts and repeated failed trials, casting once bright hopes into shadows of disenchantment. The now familiar swings appeared in high relief last fall, with news of the most recent, phase III trial in Thailand. Initial fanfare for a protective outcome gave way to disappointment after reanalysis showed that the protection could be attributed only to chance. But rather than dashing all hopes for an AIDS vaccine, the trial has heartened some researchers, who see new clues in the battle against the fatal illness.

Costing $105 million and enrolling more than 16,000 subjects, the Thai clinical trial was the largest AIDS vaccine test to date. It began in 2003, and early results released last September showed a slim but statistically sound benefit from the vaccine (a series of inoculations with drugs known as ALVAC-HIV and AIDSVAX B/E). But in October the full report, with various statistical analyses, was released in a Paris meeting to greater skepticism. Specifically, 74 people who had received the placebo became infected with HIV in the trial period, compared with the 51 people who became infected after receiving the vaccine, which makes for a protective effect of 31.2 percent. By including, however, the seven people who turned out to have had HIV at the start of the trial (two in the placebo group and five in the vaccine group), the effectiveness drops to 26.4 percent.

"There are still a huge number of uncertainties surrounding this trial," says Dennis Burton, an immunologist at the Scripps Research Institute in La Jolla, Calif. The subjects were in low- and moderate-risk groups, such as heterosexuals in monogamous relationships, rather than higher-risk groups such as intravenous drug users. "The numbers involved are small," he adds, noting that statistically the protective effects could be the result of mere chance.

SMALL VICTORIES: **The massive Thai AIDS trial has raised optimism, even though the vaccines had only slight—if any—protective value.**

Still, many researchers are convinced that the trial has provided plenty of data to run with. "This contributes more evidence that an AIDS vaccine may be possible," says Jerome Kim of the Walter Reed Army Institute of Research and co-author of the Thai trial study (which appeared in the *New England Journal of Medicine* in October). "We've taken a very small step," Kim says. "It's not a home run, but it opens the door to future work." Vaccine proponents also point to the lessons learned from the failed Merck STEP trial. That vaccine test, halted in 2007, got only as far as phase II, but even so it did not leave researchers back at square one. It suggested, he notes, how some HIV strains could be blocked from infecting cells and offered data that could help in the interpretation of the Thai results. And a new analysis of the STEP trial, published last November in *Proceedings of the National Academy of Sciences USA*, provides a warning that the very vectors (adenoviruses, which are also employed in other vaccine development work) used to distribute the inactive HIV strains can actually make the immune system more vulnerable to infection by recruiting susceptible T cells to mucous membranes, where they are more likely to be infected during sexual activity.

Finding a vaccine has become an increasingly urgent undertaking. Despite advances in therapies, HIV/AIDS is still incurable. Some 7,000 people worldwide contract HIV every day, and in the U.S. about 66,000 new cases are reported every year. Preventing people from getting the virus would save millions of lives as well as greatly reduce health care costs associated with treatment. A vaccine is "really the only optimal method of control for this dreadful pandemic," says Raphael Dolin of the Beth Israel Deaconess Medical Center in Boston, who also wrote an editorial accompanying the October paper.

Vaccines work by priming the immune system to recognize the target pathogen and attack it when detected. To fend off HIV, researchers introduced one vaccine (ALVAC) to induce a T cell response—thereby alerting the immune system—and another (AIDSVAX) later to spur an antibody response. In a previous phase III trial in intravenous drug users, AIDSVAX did not work. ALVAC, made by Sanofi Pasteur, had not been tested alone.

Using these two drugs together raised eyebrows in the vaccine community. Burton, along with 21 other researchers, co-authored a 2004 paper in *Science* criticizing the choice to proceed to phase III with two vaccines that had never demonstrated any effectiveness alone. The trial collaborators, however, based their decision on previous research that a combined approach can boost helper T cell response better than a single vaccine.

Despite his earlier doubts, Burton has been inspired by the trial results. "I feel more optimistic than I have in some time," he says. Researchers are embarking on a host of new experiments to put the Thai findings to work. Volunteers from the trial will now be examined for immune responses—particularly neutralizing antibodies as well as cellular immunity in T cells—and some will get subsequent booster shots to see if protection can be sustained. In the lab, researchers will try to re-create the Thai results in monkeys to validate a new animal model using multiple low doses. Other recent research has shown that the number of antibodies needed to provide protection is lower than previously believed, possibly making a vaccine easier to create.

Indeed, entirely new and promising candidates are now in animal trials, including those by the U.S. military to address subtypes A, C and E (rather than the Thai subtype B). Other organizations—including the International AIDS Vaccine Initiative (IAVI), the Karolinska Institute and the Swiss nonprofit EuroVacc—and manufacturers also have other vaccines in the works. "The science is really moving," says Seth Berkley, an epidemiologist at Columbia University's Mailman School of Public Health and also president and founder of IAVI. All those confronting the epidemic hope that the momentum leads to a payoff sooner rather than later.

Back into the Folds

Interest returns in using fetal cells to repair damaged brains BY M. A. WOODBURY

President Franklin D. Roosevelt admonished in a 1932 commencement address that "it is common sense to take a method and try it. If it fails, admit it frankly and try another." FDR had the revival of a depressed U.S. economy in mind, but scientists experimenting with treating brain disorders with fetal cell transplants have taken his aphorism to heart. New methods are transforming past failures, and the results seem far more promising this go-round.

Fetal cell therapy began in earnest in the mid-1980s, among

AP PHOTO

researchers hoping to treat Parkinson's disease. These patients have trouble controlling their movements partly because their brains lack the neurotransmitter dopamine. The hope was that tissue from fetal midbrains placed into patients' brains would turn into dopamine-making cells. Shortly after the turn of the century, however, the work foundered when a subset of transplant patients developed disabling movement disorders termed runaway dyskinesias.

But amid the setbacks was the fact that some subjects—especially those who were younger and less afflicted—did well with the fetal cells. "The question is, How do we reconcile all these disparate strands and problems with these trials and move the field forward?" says Roger Barker, a neurologist at the University of Cambridge who is meta-analyzing prior transplant data in hopes of devising a better trial. One possible explanation for the mixed findings is contamination: transplant tissue containing serotonin-secreting neurons could have muddied the results.

Although fetal cells may need support from other, nearby cells in a tissue transplant, Barker concedes that the field is moving to transplanting pure stem cells, rather than tissue. He and others are particularly heartened by safety results last year of the first fetal neural stem cell trial approved by the U.S. Food and Drug Administration. The phase I trial enrolled children born with Batten disease, a fatal neurodegenerative illness in which genetic mutations render patients unable to produce enzymes needed to clear cellular waste.

In the trial, six children had up to one billion fetal neural stem cells injected into the ventricles of the brain or into white matter tracts. None exhibited ill effects, and an autopsy of one child who died from the natural course of the disease indicated that the transplanted cells had grafted nicely into the brain.

CHRISTOPHER FURLONG *Getty Images*

BOXING LEGEND Muhammad Ali, shown here last August, considered treating his Parkinson's disease with fetal tissue in 1987. New work has restored interest in the cells.

This result is a big advance in the field, says Robert Steiner of the Oregon Health and Science University who was a principal investigator on the trial. "This is a much more sophisticated approach to doing neural cell transplants by actually purifying and only using fetal neural cells rather than the mix of cells used in the earlier trials," he notes.

Achieving high degrees of purity—that is, assuring that the vast majority of cells being transplanted are only neural stem cells—requires careful separation of cells. StemCells in Palo Alto, Calif., which produced the cells for the trial, employed a technique that labels fetal neural stem cells with a fluorescent tag. That makes them easy to see and sort from other cells. With the technique, the firm says that at least 90 percent of their proprietary cells are neural stem cells—a critical benchmark for FDA approval in clinical trials.

The success of the safety trial has given the FDA confidence to green-light a second trial, this time for children with Pelizaeus-Merzbacher disease (PMD), a genetic disorder that compromises the creation of myelin, a fatty substance that sheaths the axons of nerves. The trial will inject neural stem cells into the brains of four children with PMD and use magnetic resonance imaging to track new myelin formation. Preclinical trials in animal models of PMD have demonstrated that the cells can differentiate into myelin-forming cells called oligodendrocytes and successfully create myelin sheaths, but they have yet to prove they can restore function.

Cells that are more developed might lead to functional results. Steven Goldman of the University of Rochester isolated neural stem cells of fetal origin that had differentiated into the progenitor cells of oligodendrocytes. When injected into mouse models of PMD, the precursor cells improved the health of afflicted rodents, which also lived a normal life span.

Scientists debate the best method of obtaining the cells. Rather than sorting primary cells in various stages of differentiation, for instance, Geron in Menlo Park, Calif., can induce the appropriate precursor cells from human embryonic stem cells. (Geron received FDA approval to use the cells for trials last year.) But in the end, only clinical trials can determine the best strategies. "Because now we have better ways of identifying the potentially regenerative cells in the fetal populations, we can probably perform more powerful and better targeted studies than before," remarks Charles ffrench-Constant, an expert in regenerative neuroscience at the University of Edinburgh. Certainly for advocates, fetal cell transplantations are emerging from their dark days and moving into a reenergized spotlight.

M. A. Woodbury is a science and medical writer based in New York City.

Technology

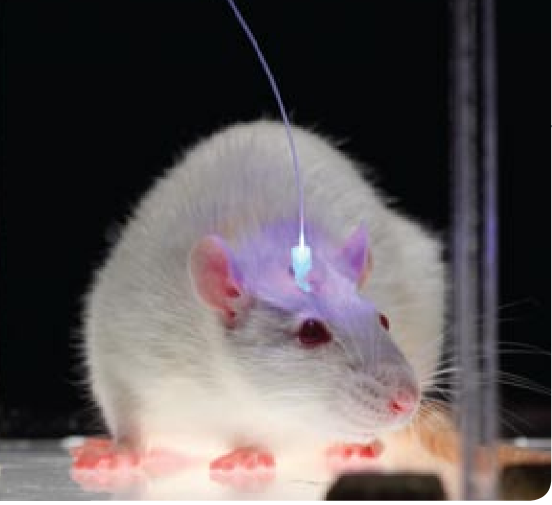
A Light in the Brain

Optogenetics emerges as a potent tool to study the brain's inner workings

BY GARY STIX

In 1979 Francis Crick, famed codiscoverer of DNA's structure, published an article in *Scientific American* that set out a wish list of techniques needed to fundamentally improve understanding of the way the brain processes information. High on his wish list was a method of gaining control over specific classes of neurons while, he wrote, "leaving the others more or less unaltered."

Over the past few years Crick's vision for targeting neurons has begun to materialize thanks to a sophisticated combination of fiber optics and genetic engineering. The advent of what is known as optogenetics has even captured popular attention be-



MIND CONTROL: Blue light piped into the brain of a genetically engineered rat turns on a set of neurons.

COURTESY OF JOHN CARNETT, VIVIANA GRADINARU, MURTAZA MOGRU AND KARL DEISSEROTH *Stanford University*

cause of its ability to alter animal behavior—one research group demonstrated how light piped into a mouse's brain can drive it to turn endlessly in circles. Such feats have inspired much public comment, including a joke made by comedian Jay Leno in 2006 about the prospect for an optogenetically controlled fly pestering George W. Bush.

Controlling a subordinate or a spouse with a souped-up laser pointer may be essential for science-fiction dystopia and late-night humor, but in reality optogenetics has emerged as the most important new technology for providing insight into the numbingly complex circuitry of the mammalian brain. It has already furnished clues as to how neural miswiring underlies neurological and mental disorders, including Parkinson's disease and schizophrenia.

A seminal event that sparked widespread neuroscience interest came in 2005, when Karl Deisseroth and his colleagues at Stanford University and at the Max Planck Institute for Biophysics in Frankfurt demonstrated how a virus could be used to deliver a light-sensitive gene called *channelrhodopsin-2* into specific sets of mammalian neurons. Once equipped with the gene (taken from pond algae), the neurons fired when exposed to light pulses. A box on Crick's list could be checked off: this experiment and ones that were soon to follow showed how it would be possible to trigger or extinguish selected neurons, and not their neighbors, in just a few milliseconds, the speed at which they normally fire. Hundreds of laboratories worldwide have since adopted Deisseroth's technique.

A 38-year-old psychiatrist by training who still sees patients once a week, Deisseroth entered the field of bioengineering because of his frustration over the inadequate tools available to research and treat mental illness and neurodegenerative disorders. "I have conducted many brain-stimulation treatments in psychiatry that suffered greatly from a lack of precision. You can stimulate certain cells that you want to target, but you also stimulate all of the wrong cells as well," he says. Instead of just observing the effects from a drug or an implanted electrode, optogenetics brings researchers closer to the fundamental causes of a behavior.

Since 2005 Deisseroth's laboratory—at times in collaboration with leading neuroscience groups—has assembled a powerful tool kit based on *channelrhodopsin-2* and other so-called opsins. By adjusting the opening or closing of channels in cell membranes, opsins can switch neurons on or turn them off. Molecular legerdemain can also manipulate just a subset of one type of neuron or control a circuit between groups of selected neurons in, say, the limbic system and others in the cortex. Deisseroth has also refined methods for delivering the opsin genes, typically by inserting into a virus both opsin genes and DNA to turn on those genes.

To activate the opsins, Deisseroth's lab has attached laser diodes to tiny fiber-optic cables that reach the brain's innermost structures. Along with the optical fibers, electrodes are implanted that record when neurons fire. "In the past year what's happened is that these techniques have gone from being something interesting and useful in limited applications to something generalizable to any cell or question in biology," Deisseroth says.

Most compelling, however, are experiments that have demonstrated the relevance of optogenetics to both basic science and medicine. At the Society for Neuroscience meeting in Chicago last October, Michael Häusser of University College London reported on an optogenetics experiment that showed how 100 neurons could trigger a memory stored in a much larger ensemble of about 100,000 neurons, suggesting how the technique may be used to understand memory formation.

Last spring Deisseroth's group published an optogenetics study that helped to elucidate the workings of deep-brain stimulation, which uses electrodes implanted deep in the brain to alleviate the abnormal movements of Parkinson's disease. The experiment called into question the leading theory of how the technology works—activation of an area called the subthalamic nucleus. Instead the electrodes appear to exert their effects on nerve fibers that reach the subthalamic nucleus from the motor cortex and perhaps other areas. The finding has already led to a better understanding of how to deploy deep-brain electrodes. Given its fine-tuned specificity, optoelectronics might eventually replace deep-brain stimulation.

Although optogenetic control of human behavior may be years away, Deisseroth comments that the longer-range implications of the technology must be considered: "I'm not writing ethics papers, but I think about these issues every day, what it might mean to gain understanding and control over what is a desire, what is a need, what is hope."

Sound Approach

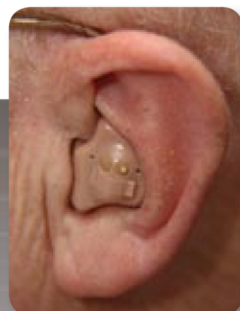
Loopy idea brings in speech loud and clear BY LARRY GREENEMEIER

Standard hearing aids capture sound via a microphone and then send an amplified version to an earpiece. They work well in relatively quiet, intimate settings, but in public spaces filled with background noise, most users find them of little use. A simple technology that sidesteps the problem, long available in Europe, has finally begun entering the U.S. market. Advocates hope that with the success of pilot projects, the hearing impaired will be able to find public address announcements and other kinds of speech more intelligible.

The technology is an induction-loop system (known as a hearing loop), whereby electromagnetic waves produced by a microphone, public address system or telephone receiver induce an analogous current in the loop. The loop can broadcast the signals directly to a hearing aid equipped with an appropriate detector—specifically, a tiny copper telecoil wire, which picks up the signal (also via induction) and then sends it for amplification and transmission out of the earpiece. (Hearing loops can also broadcast signals to cochlear implants, which are surgically implanted devices that directly stimulate the auditory nerve.)

Telecoils work somewhat like Wi-Fi for hearing aids, enabling them to serve as customized, wireless loudspeakers, says David Myers, a psychology professor at Hope College and a strong advocate for the devices. Makers of hearing aids are increasingly equipping their devices with telecoils, whose original use was to boost telephone sounds. More than 60 percent of hearing aids come with telecoils, up from 37 percent in 2001, according to a survey report in the April 2008 *Journal of Hearing.*

Still, Myers notes, although about 36 million Americans suffer from hearing loss, the loop technology has not been as widely embraced in the U.S. as it has been in other regions of the world, particularly in northern Europe. Myers, who himself has impaired hearing, first became aware of the technology more than a decade ago while worshipping in Scotland's Iona Abbey, where the building's poor acoustics prevented him from clearly hearing the service. At his wife's prompting, Myers switched on his hearing aid's "T" (for telecoil) setting to see what would happen. "The sudden clarity was overwhelming," he adds, "an experience that I have since had in countless other British venues, from auditoriums to cathedrals to the backseats of London and Edinburgh taxis."



HEARING AIDS with an embedded "T" switch (for telecoil) can pick up clearer sound in the Gerald R. Ford International Airport in Grand Rapids, Mich., which has an induction-loop system (identified by blue signs).

COURTESY OF LOU SCHAKEL *Hope College Public Relations (ear)*; COURTESY OF HOPE COLLEGE PUBLIC RELATIONS *(airport)*

Since then, Myers and others have worked to introduce the technology to the U.S., which has lagged in adopting the hearing loops because the technology is not a requirement for public venues, Myers says. Since its 2004 revision, the Americans with Disabilities Act (ADA) has required public venues to offer assistive-listening systems. But rather than installing hearing loops, a venue can offer FM or infrared systems, which require users to borrow equipment.

The ADA's position is that no single approach works for every person and every venue; infrared systems, for instance, are less effective in sunlight than the FM approach but are generally more private. "Differences in [confidentiality], interference, cost, installation requirements and operability make it impossible to simply use one type of [assistive-listening system] in every place," ADA guidelines state.

Myers disagrees, pointing out that many individuals with hearing loss are self-conscious about asking for an ear-

phone setup. And some are averse to using earphones previously worn by others. Installed hearing loops would enable people to use their own devices discreetly.

For fans of hearing loops, progress is being made, if slowly. Janice Schacter, chair and founder of the advocacy group Hearing Access Program, has succeeded with transportation systems. In September, New York City's Taxi & Limousine Commission approved hearing loops for cabbies who want to install it in their vehicles, a decision that came after a 13-month pilot program with 15 taxis set up with Schacter's help. Hearing-loop technology could exist at up to 642 information booths in the New York subway system, Schacter says, who worked with the city to launch the initial pilot test at the Wall Street station.

Warp-Speed Algebra

New quantum algorithm can solve monster-size equations

BY DAVIDE CASTELVECCHI

QUANTUM COMPUTERS CAN DO WONdrous things: too bad they do not exist yet. That has not stopped physicists from devising new algorithms for the devices, which can calculate a lot faster than ordinary computers—in fact, exponentially faster, in quite a literal sense. Once quantum computers do become available, the algorithms could become a key part of applications that require number crunching, from engineering to video games.

The latest quantum algorithm is generating excitement among physicists. It tackles linear equations: expressions such as $3x + 2y = 7$ and typically written with unknowns on one side and constants on the other. Many high schoolers learn the trite mechanics of solving systems of such equations by eliminating one unknown at a time. Speed becomes crucial when systems contain billions of variables and billions of equations, which are not unusual in modern applications such as simulations of weather and other physical phenomena. Efficient algorithms can solve large, "N by N" systems (systems having N linear equations and N unknowns) by computer. Still, calculation time grows at least as fast as N does: if N gets 1,000 times larger, the problem will take at least 1,000 times longer to solve, often more.

The quantum algorithm now proposed by Aram W. Harrow of the University of Bristol in England and Avinatan Hassidim and Seth Lloyd of the Massachusetts Institute of Technology takes a clever shortcut. It can return the most relevant information about the solution without fully calculating the solution itself, thus trading off the amount of data it produces for speed. (For example, in the case of weather prediction it could return the average temperature over a town rather than the temperatures predicted city block by city block.)

Like all quantum algorithms, their method, described in the October 9 *Physical Review Letters,* encodes all the relevant information about the system into quantum bits. Contrary to ordinary, or "classical," bits, quantum bits can exist both as 0 and 1 simultaneously—or, as physicists say, in a superposition of states. The algorithm transforms the bits into a state that essentially encodes a superposition of all possible solutions of the system, meaning for all possible values of the constants on the right hand sides of the equations. From this "universal solution," one can then extract the relevant information about particular solutions without calculating them fully.

The gain in speed is enormous: the time required to produce the universal solution grows only with the number of digits in N. Thus, if N gets 1,000 times larger, the algorithm takes three times as long (because three digits are added to N), as opposed to 1,000 times as long. Even writing down the result for all the variables would involve 1,000 times more steps in the classical case. "It takes exponentially less time to solve the problem than to read the so-

lution," Lloyd says only half-jokingly.

"Every single quantum algorithm that shows a clear speedup when compared with its classical analogue is still a big deal," says Artur Ekert of the National University of Singapore. Only a handful of quantum algorithms can boast that achievement—such as those invented in the 1990s for factoring large numbers into primes or for searching databases.

So far only experimental quantum computers exist, containing only a few bits. But a small demonstration of the new algorithm should be feasible in the not too distant future, says Martin Plenio of the University of Ulm in Germany. "It will be many years, though, before a quantum computer of a sufficient size can be built to solve a problem that cannot be attacked on classical devices," he adds.

Some applications could be possible sooner, Lloyd says, if they exploit the intrinsically quantum nature of photons. He proposes, for example, that the algorithm could be embodied in a "superimaging device" that would remove optical distortions in a telescope. Each photon measured by the telescope would play the role of the constant terms of the equation, and the distortions would correspond to a linear system of equations. Finding the solutions would mean reversing the distortions, thus improving image quality.

Research & Discovery

Machismo Mayhem

Why you felt less manly after voting John McCain for president BY CHARLES Q. CHOI

With its winners and losers, politics is a lot like sports. Now biologists have the testosterone—or lack thereof—to prove it. Specifically, they have found that male voters who back a losing candidate experience a drop in the hormone.

Immediately before and after the 2008 U.S. presidential election result, neuroscientists from Duke University and the University of Michigan at Ann Arbor collected the saliva of 163 college-age participants to determine the amount of testosterone in their systems. Male voters for winner Barack Obama had stable levels of testosterone, but the hormone rapidly declined in males who cast ballots for losers John McCain and Robert Barr. Female voters showed no significant testosterone changes after victory or defeat of their candidate.

Past research has shown that winning and losing in sports matches and other competitions affect testosterone levels in men. The new findings, published online October 21 by *PLoS ONE*, reveal that politics can influence testosterone in men "just as if they directly engaged head to head in a contest for dominance," says Kevin LaBar of Duke, the study's senior researcher.

McCAIN SUPPORTERS in Phoenix react to the bad news in the 2008 presidential election. Research suggests that the men experienced a testosterone drop.

In separate work, anthropologist Coren Apicella of Harvard University and her colleagues obtained similar results with a smaller group, findings they will publish this year. "It's an exciting time for people who study political behavior, where biological factors have largely been ignored," she notes. "Political scientists are starting to recognize the role of biology, and more and more research is showing there may be some reciprocal interactions between how elections make one feel and how feelings can affect political behavior."

Testosterone is linked to aggression, risk taking and responses to threats. Bumps and drops in testosterone levels after competition can help both winners and losers in all species, explains Steven Stanton, the Duke study's lead author. Victors may get motivated to pursue further gains, whereas also-rans are encouraged to back down so as not to press onward and potentially get injured. Indeed, in the Duke study, McCain and Barr voters reported feeling significantly more controlled, submissive, unhappy and unpleasant after the loss than the Obama supporters did.

The team conjectures that because the shift in the hierarchy of dominance in the nation after a presidential election is stable for at least four years, the stress of having one's political party lose executive control could plausibly lead to continued testosterone suppression in males. But "it's hard to know how long-lasting these effects might be," LaBar remarks, considering that many factors influence testosterone levels.

LaBar and his team, though, are shifting gears. "We're now going to try and explore this in spectator sports," he says. "Sports competitions are not like the political process, where you can have a direct influence on the outcome, but obviously avid sports fans are highly invested personally in the outcome of a game."

Charles Q. Choi is a frequent contributor.

MARK WILSON *Getty Images*

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A Large Lump of Coal

Other Earths may be made of graphite and diamond BY GEORGE MUSSER

Astronomy is the science of the exotic, but the thing that astronomers most want to find is the familiar: another planet like Earth, a hospitable face in a hostile cosmos. The Kepler spacecraft, which was launched last March, is their best instrument yet for discovering Earth-like planets around sunlike stars, as opposed to the giant planets that have been planet finders' main harvest so far. Many predict that 2010 will be the year of exo-Earths. But if the giant planets, which looked nothing like what astronomers had expected, are any indication, those Earths may not be so reassuringly familiar either.

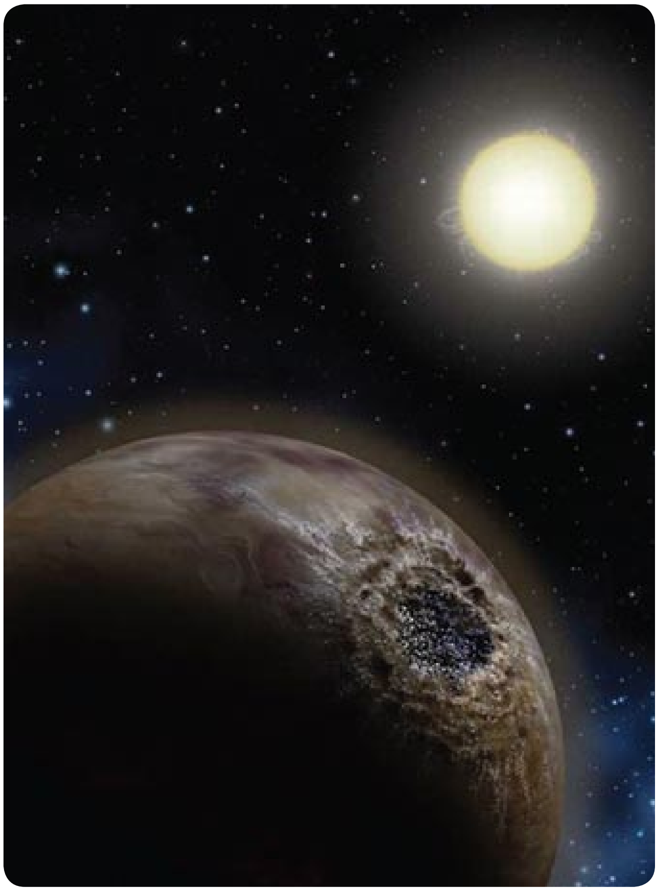
It has dawned on theorists in recent years that other Earth-mass planets may be enormous water droplets, balls of nitrogen or lumps of iron. Name your favorite element or compound, and someone has imagined a planet made of it. The spectrum of possibilities depends largely on the ratio of carbon to oxygen. After hydrogen and helium, these are the most common elements in the universe, and in an embryonic planetary system they pair off to create carbon monoxide. The element that is in slight excess ends up dominating the planet's chemistry.

In our solar system, oxygen dominates. Although we tend to think of our planet as defined by carbon, the basis of life, the element is actually a fairly minor constituent. The terrestrial planets are made of silicate minerals, which are oxygen-rich. The outer solar system abounds in another oxygen-rich compound, water.

A new study shows in detail how carbon lost out. Jade Bond of the University of Arizona and the Planetary Science Institute (PSI), Dante Lauretta of Arizona and David O'Brien of PSI have simulated how chemical elements got distributed around the solar system as it formed. They find that carbon remained in a gaseous state within the protoplanetary disk and was eventually blown out into deep space; the embryonic Earth wound up with none at all. The carbon in our bodies must have been delivered later, by asteroids and comets that formed under conditions that allowed them to incorporate the element.

Had the carbon-oxygen balance tilted the other way, Earth would have turned out very differently, as Marc Kuchner, then at Princeton University, and Sara Seager, then at the Carnegie Institution of Washington, argued in 2005. It would consist not of silicates but of carbon-based compounds such as silicon carbide and, indeed, pure carbon itself. The crust would be mainly graphite, and a few kilometers underground the pressures would be high enough to form a rigid shell of diamond and other crystals. Instead of water ice, the planet would have carbon monoxide or methane ice; instead of liquid water, it might have oceans of tar.

The galaxy could be filled with such worlds. According to an observational survey Bond cites, the average planet host star has a higher carbon-to-oxygen ratio than the sun does, and her team's simulations predict that the most enriched systems give birth to carbon planets. "Some of these compositions differ greatly from solar and as a result produce terrestrial planets with vastly different compositions," Bond says.



LYNETTE COOK

EARTH-LIKE PLANETS around other stars may be composed not of stone but of carbon, with a graphite crust, diamond interior and tar oceans.

To be sure, other surveys have found that the sun is indistinguishable from the average star in its class. The Kepler spacecraft may help settle the question, because even the limited amount of information it can glean about planets—their mass and radius—is enough to tell their general composition.

Carbon Earths might be especially prevalent in more bizarre settings, such as the environs of white dwarfs and neutron stars. Regions of the galaxy that are rich in heavy elements generally, such as the galactic center, have higher carbon-to-oxygen ratios. As time passes and stars continue to manufacture heavy elements, the balance everywhere will tilt in favor of carbon.

These and other astronomical discoveries turn the tables on our notions of the familiar and unfamiliar. Most of the galaxy is dark matter; most suns are dimmer and redder than our sun; and now, it seems, other Earths may not be especially Earth-like. If anything departs from the norm and deserves to be called exotic, it is us.

What's the fastest way to learn a language?

ACT LIKE A BABY.

It's not the advice you'd expect. Learning a new language seems formidable, as we recall from years of combat with grammar and translations in school. Yet infants begin at birth. They communicate at eighteen months and speak the language fluently before they go to school. And they never battle translations or grammar explanations along the way.

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Third, children learn through play, whether it's the arm-waving balancing act that announces their first step or the spluttering preamble to their first words. All the conversational chatter skittering through young children's play with parents and playmates—"...what's this..." "...clap, clap your hands..." "...my ball..."—helps children develop language skills that connect them to the world.

Adults possess this same powerful language-learning ability that orchestrated our language success as children. Sadly, our clashes with vocabulary drills and grammar explanations force us to conclude it's hopeless. We simply don't have "the language learning gene."

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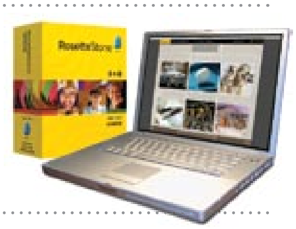

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Big Need for a Little Testing

The EPA must act swiftly to evaluate the possible health risks of nanotechnology

BY THE EDITORS

A decade ago the great worry about nanotechnology was that it could quite literally destroy the planet. As Sun Microsystems co-founder Bill Joy warned in his essay "Why the Future Doesn't Need Us," self-assembling nanobots could potentially spread out of our control. (Mis-)programmed to replicate ad infinitum, these subsentient bots would spread across the landscape as a gray goo of devastation, consuming the earth and every unlucky creature who called it home.

Nowadays we can only wish that our planet-dooming scenarios were so far-fetched. Our existential worries revolve around the all too immediate problems of global warming and disease, and nanotechnology—incorporated into improved solar panels, wind turbines or drug delivery mechanisms—could, if anything, emerge as an important tool to fight these threats.

Yet like any new technology, nanomaterials carry with them potential both for good and for harm. The most salient worries concern not a gray goo apocalypse but rather the more prosaic and likely possibility that some of these novel materials may turn out to be hazardous to our health or the environment. Because ordinary materials display unique properties at the nanoscale, the nanometer-size bits of a seemingly benign material might turn out to be noxious. As John D. Young and Jan Martel report in "The Rise and Fall of Nanobacteria," starting on page 52, even naturally occurring nanoparticulates can have an deleterious effect on the human body. If natural nanoparticulates can harm us, we would be wise to carefully consider the possible actions of engineered nanomaterials. The size of nanoparticles also means that they can more readily escape into the environment and infiltrate deep into internal organs such as the lungs and liver. Adding to the concern, each nanomaterial is unique. Although researchers have conducted a number of studies on the health risks of individual materials, this scattershot approach cannot provide a comprehensive picture of the hazards—quantitative data on what materials, in what concentrations, affect the body over what timescales.

In response to this uncertainty, the U.S. Environmental Protection Agency recently announced a grand research strategy to study the health and environmental effects of nanomaterials, a welcome step that many have been advocating for years. We hope that the program will help build a robust database that will give policy makers and the public the facts needed to understand the possible health risks that specific nanomaterials might create. And although it would be unwise to rush careful research efforts, speed is paramount. According to the Project on Emerging Nanotechnologies, more than 1,000 consumer products containing nanomaterials are available in the U.S., a number that is quickly growing.

We also emphasize speed because of the EPA's alarming recent history with a similar research program. In 1996 Congress directed the EPA to conduct a comprehensive screening program for endocrine disruptors in the environment. These chemicals interfere with the body's hormonal system and can lead to abnormal development of the sex organs, infertility and cancer. Although the U.S. has banned the production of known endocrine disruptors such as PCBs and DDT, other common chemicals—most notably bisphenol A (BPA) and some pesticides—may also affect the body's endocrine system.

Even for a government agency, the EPA's response to the congressional directive was woefully indolent. Instead of quickly beginning to study the thousands of suspected endocrine disruptors that may exist in the nation's drinking water, the EPA spent the next decade building a labyrinth of committees and subcommittees to evaluate what materials might be worthy of study and the methodologies that should be used to study them. By 2002—six years after the program began—the EPA got so far as to devise the selection process it planned to use to choose the first 50 to 100 chemicals that would eventually be subject to analysis. In 2007 the agency published a draft list of those chemicals. In April 2009 it finalized the list. And triumphantly, in late October, 13 years after the program began, the EPA announced that it would begin research.

The country cannot afford a repeat of this farce—and not just because of the public health concerns. With so many nanomaterials already on the market and such little public awareness of nanotechnology, one safety scare might convince consumers that *all* nanotechnology is dangerous. (Witness Europe's attitude toward genetic modification for an example of how a culture can turn against an entire class of innovation.) In addition, without clear scientific and regulatory guidance, many companies are hesitant to invest in nanotechnology R&D, fearing the exposure to legal action that could result if one day a technology is deemed dangerous. Procter & Gamble, for example, is not pursuing nanotechnology because of the long-term risk of litigation.

This uncertainty is putting people's health at risk and choking innovation. And with all the threats the planet faces, we need all the little bits of innovation we can get. ■

ILLUSTRATION BY MATT COLLINS

The Need for Open Process

The Obama administration must reform how policies are made, not just the policies themselves

BY JEFFREY D. SACHS

When President Barack Obama promised change, he put two kinds on the agenda. The first was substantive change: reforms to key sectors of the economy, such as health care, climate change, financial markets and arms procurement. The second was process change: improvements to how public policies are shaped and how decisions over public funding are made. Against the odds, the Obama administration is making some progress on the first—but at the sacrifice of the second.

The important health care legislation inching its way through Congress as this column goes to press will help expand the number of Americans covered by health care insurance and will limit some of the abuses by the private insurance industry in denying coverage and reimbursements to the public. Similarly, climate change legislation is also moving forward, with the chance that a permit system will begin to limit the emissions of greenhouse gases and start the lengthy shift of the U.S. economy to lower-emissions technologies.

Yet how this modest progress is being achieved is alarming. The Obama administration has not put forward one coherent plan as a detailed policy proposal. Every major piece of public policy has been turned over to the backrooms of Congress, emerging through the lobby-infested bargaining process among vested and regional interests. There was no overarching plan for the economic stimulus; no clear plan for health care reform; no defined strategy for climate change control; and so forth. If there were plans behind the scenes, they were never presented to the public as such.

This approach, it is often said, reflects the "learning" from the failures of the Clinton administration's attempt to reform health care and control climate change. This time, the logic goes, the administration will leave no easy targets in the form of detailed policy proposals that can be shot down. It will let the negotiations among interest groups take place first and deftly guide a compromise piece of legislation to adoption. This is the logic of politics as the art of the possible.

By refusing to put forward clear plans, the administration is creating gaping and unnecessary weaknesses in public policy. First, and most important, the bad parts of legislation are not shot down. For example, Congress has never even considered the advantages of a straightforward carbon tax over the messier cap-and-trade system because there has been little occasion for serious policy planning.

Second, backroom negotiations are of course an invitation to vast, shady transfers of wealth. Carbon permits worth hundreds of billions of dollars were allocated to vested interests in private dealings without any public awareness, debate or participation. Similar deals in health care, financial reform and the stimulus bill have left the public struggling to understand the real winners and losers from various legislative actions.

Moreover, the administration has repeatedly lost the opportunity to convey important information to the American people. Only one third of the U.S. public believes that man-made climate change is even real. The public has absolutely no idea about the modest costs and high benefits of bringing emissions under control. It suffers similarly hopeless confusion about health care, the stimulus package, financial reform and other policy initiatives.

The complex, crucial issues we face require both expert inputs and public understanding. On each major issue of public policy, the administration should first put forward a white paper explaining why it is calling for a policy initiative, what it will cost, what benefits it will bring and how it will work. Legislative proposals should be shaped around these strategy documents. Independent expert groups should be invited to draft responses.

Most important, lobbying needs to be scorned rather than promoted. If given a chance, the public would back the Obama administration in facing down these narrow interests, the very interests that have contributed so much to our financial meltdowns, overpriced health care, clunker automobiles and energy insecurity. Scientists, engineers and public policy specialists can help craft real solutions, and an enlightened and trusted public would help put those solutions into place above the opposition of narrow interests. ■

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

An extended version of this essay is available at **www.ScientificAmerican.com/jan2010**

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

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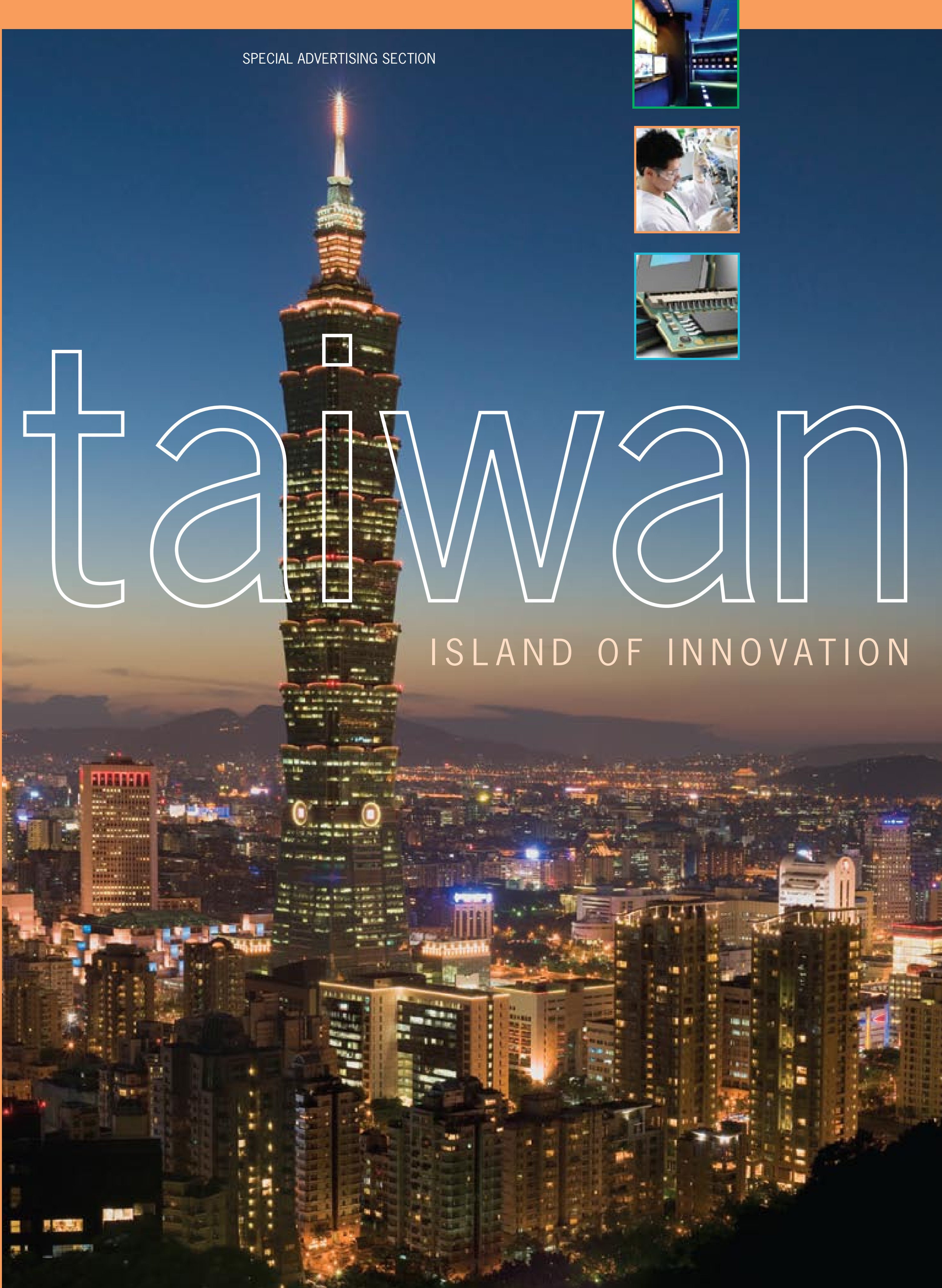
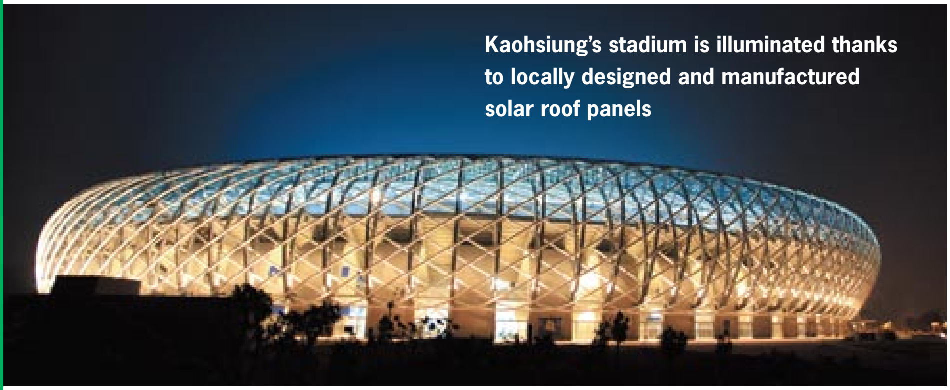
ISLAND OF INNOVATION



Academia and Research Are the Key to Taiwan's Success



Kaohsiung's stadium is illuminated thanks to locally designed and manufactured solar roof panels

Long known as a worldwide center for manufacturing of semiconductors and components, Taiwan is rapidly emerging as a strategic center in Asia for advanced technologies, engineering and design in diverse fields from cloud computing to biotechnology, medical devices and solar energy solutions. The country's ongoing shift from being a manufacturing center to a knowledge-based economy centered on education and innovation is remarkable.

Driving Taiwan's transformation is a web of key academic and research institutions that work together with industry to promote applied solutions that play to existing strengths and work to build up new ones. A network of science-based industrial and software parks – each with their own specialization – has also been built across the country to attract talent and facilitate growth. This unique environment and the opportunities it generates are the subject of this survey on Taiwan.

Today's Taiwan is also at the center of the world's most dynamic region for growth. Taiwanese companies have long been active in mainland China, constituting by some estimates nearly half of all Chinese electronics manufacturing. During the past year, President Ma Ying-Jeou has promoted an official thaw in relations, sponsoring a series of Bridge Building initiatives that will allow Taiwan to end its regional isolation and to fully benefit from China's emergence as the world's most important economy.

The National Science Council, an Executive body responsible for coordinating policy as well as funding fundamental and applied research, has identified a number of key areas for growth in the next decade. These include specific initiatives in biotechnology, genomics and nanotechnology. Renewable energy, including solar and wind power, is also a core priority for a country which relies on imports for 99% of current needs. Readers of this report will note how the focus on these areas seamlessly carries over to the initiatives and programs of individual universities and research institutes profiled.

A LEADING ROLE FOR INDUSTRY

Private industry is also playing a key role in transforming Taiwan from a supplier of components to a center of expertise in engineering and design. "Western manufacturers used to come to us with blueprints and ask us if we could produce components for them," says one Taiwanese electronics executive. "Now they ask us to design entire devices." The result is a range of new products "Made and Designed in Taiwan" including netbooks, e-readers, and LED lighting.

Taiwanese companies such as Acer for computers, HTC for touch-screen cell phones and D-Link for networking technology are now well-known consumer brands around the world. Just as important, however, are lesser-known but equally innovative companies: AUO, the world's 3rd largest producer of LCD monitors, is set to unleash a new generation of e-readers. Delta, a components manufacturer focused on power-saving technologies, produced inexpensive solar panels that turned the roof of the Kaohsiung stadium – host of the 2009 World Games – into a Green engineering marvel.

Taipei's annual Computex show, long considered an essential trade fair for ICT component procurement, is now a world-wide stage for new product and technology launches with celebrity-style appearances by senior executives from Microsoft, Intel and HP. The June 2010 30th anniversary show is expected to draw an audience of over 100,000 visitors and exhibitors, including a large contingent from mainland China.

Biotech is a growing priority for academia and industry

On the cover: Taipei 101, East Asia's tallest building

ITRI – Taiwan's Technology Innovation Engine

Taiwan's Industrial Technology Research Institute is a not-for-profit R&D organization engaging in applied research and industrial service. Founded in 1973, ITRI guided Taiwan's evolution from a low-tech manufacturer to a high-tech powerhouse. Today, ITRI is helping Taiwan move into the knowledge economy era, adding value for existing industries while building new ones from the ground up.

With almost 6,000 research and management staff, each year ITRI is granted about 1,000 patents and transfers hundreds of technologies to industry to spread economic benefits to society. In addition to its headquarters in Hsinchu, ITRI opened a branch campus in southern Taiwan four years ago and has international offices in Silicon Valley, Tokyo, Berlin and Moscow.

ITRI has aggressively researched and developed countless next-generation technologies, including WIMAX wireless broadband, solar cells, RFID, light electric vehicles, flexible displays, 3-D ICs and Telecare technologies. ITRI's Flexible Electronics Pilot Lab and Nanotechnology Lab provide international-level research platforms where R&D can be conducted jointly with partners. The Institute has also seen significant growth in intellectual property business and new ventures in recent years and is devoted to creating a model that would make Taiwan manufacturing even more competitive in the international market.

Reflecting on ITRI's successful formula, president Johnsee Lee says the Institute relies on three key principles: Working closely with the private sector to set direction (ITRI receives no government subsidies), taking risks at the exploratory level to assure that creativity can happen, and expanding international cooperation in a widening range of areas.

ITRI has been a path breaker linking major global companies with Taiwan through research partnerships and patent licensing agreements. Major corporate relationships include Corning, Sarnoff Laboratories, IBM and Telcordia. During the past year ITRI has also been a key player in the government's Bridge Building project to increase cooperation and communication with mainland China, taking the lead role in representing Taiwan at the Conference on Cross-strait Cooperation and Exchange in the Photovoltaics Industry.

As Taiwan moves beyond its core ICT industry base and becomes a more advanced economy, ITRI is identifying the next stage of industries and applications for the Island's economic success. Many of these revolve around the needs of the 21st Century economy and society.

"We have built a Creativity Lab to focus on applying Taiwan's core semiconductor strengths to address changing lifestyles," says Lee, citing the importance of new products to keep an aging population active and independent. "Medical devices are a particularly good example of combining Taiwan's strength in electronics with the boom in world health care."

One of Lee's goals is to make sure that Taiwan builds momentum and leadership in the rapidly growing field of Cloud Computing. Not only does he believe the technology will ultimately provide added security for computer users, he also hopes it will lead to a host of new devices and applications. "Cloud Computing is an amazing opportunity for Taiwan to create a real home-grown software industry because it creates a level playing field," he says.

"Going international is one of our top priorities for the next five years," says Lee. "In a global world we cannot limit ourselves to working with Taiwanese companies. We invite all major companies to partner with us."

ITRI has received numerous international awards for its innovative technologies. Awards received in 2009 include:

- **R&D 100 Awards for ITRI's STOBA Lithium Battery**
- ***The Wall Street Journal*'s 2009 Technology Innovation Awards for ITRI's FleXpeaker**
- **iF Design Award for ITRI's Fluid Driven Lighting System**
- **Red Dot Design Award for ITRI's Flexio Radio**

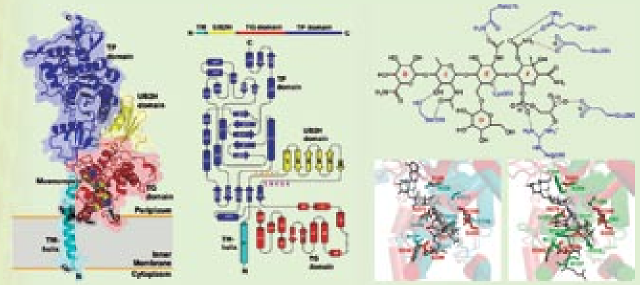
Academia Sinica, Taiwan

www.sinica.edu.tw

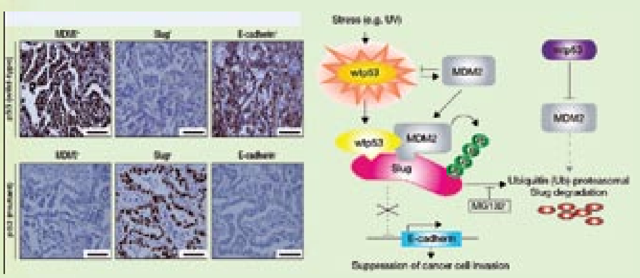
Chi-Huey Wong
President

Academia Sinica, the most preeminent academic institution in Taiwan, was founded in 1928 to pursue research excellence. It undertakes the mission to conduct cutting-edge research in sciences and the humanities, nurture academic talents and issue policy advisories. It has 24 institutes and 7 research centers that are organized into three divisions: Mathematics and Physical Sciences, Life Sciences, and Humanities and Social Sciences. At present, there are about 800 principal investigators, 700 postdocs, and more than 1000 Ph.D. students, supported by an annual budget over US$400 million. Among its 246 academicians, there are 6 Nobel laureates.

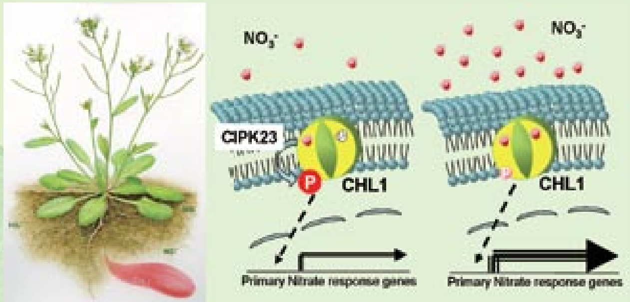
Recent Achievements



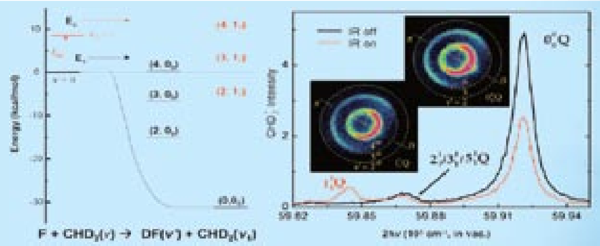
■ Crystal Structure of the Membrane-Bound Bifunctional Transglycosylase PBP1b from *Escherichia Coli* (*Proc. Natl. Acad. Sci. USA* (2009), 106, 8824)



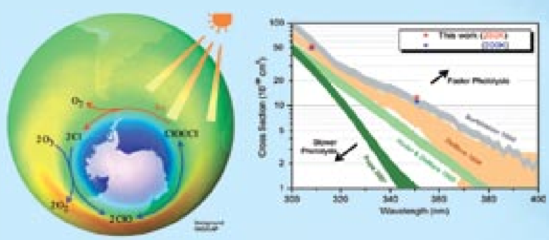
■ p53 Controls Cancer Cell Invasion by Inducing the MDM2-Mediated Degradation of Slug (*Nature Cell Biology* (2009), 11, 694)



■ Nitrate Sensor CHL1, Regulated by Protein Kinase CIPK23, Detects a Wide Range of Soil Nitrate Concentrations (*Cell* (2009), 138, 1184)



■ CH Stretching Excitation in the Early Barrier F + CHD3 Reaction Inhibits CH Bond Cleavage (*Science* (2009), 325, 303)



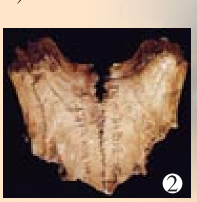
■ UV Absorption Cross Sections of ClOOCl are Consistent with Ozone Degradation Models (*Science* (2009), 324, 781)

■ Bayesian Coalitional Rationalizability (*Journal of Economic Theory* (2009), 144, 248)

■ Colony Bureaucrat in the Taiwan Governor-General Kenjiro Den Times and Taiwan Rule Mainly on the Den's Diary (*Study of Bureaucracy of the Japanese* (Kyoto: Japan, 2008), 163)

■ Operators for the Adjudication of Conflicting Claims? (*Journal of Economic Theory* (2008), 143, 177)

■ Imperfect Durability and the Coase Conjecture (*The Rand Journal of Economics* (2008), 39, 1)



■ ❶ Niu Fang-ting

■ ❷ Inscribed Deer Skull

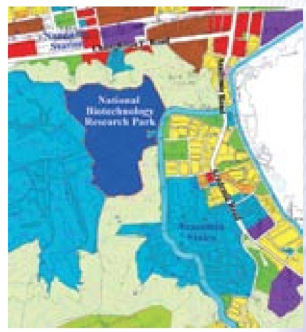
中央研究院

As Taiwan's national academy of sciences, Academia Sinica shoulders the responsibility of studying key national issues and reporting on them to the government for policy-making. Two recent reports on energy and health care have been issued and are well received. Academia Sinica has also helped enact the Taiwan Biotech and New Pharmaceutical Development Act which, similar to the 1980 Bayh-Dole Act in the US, is expected to assist Taiwan to upgrade further by entering the knowledge-based biotech industry, in addition to the well-established high-tech sector.

Taiwan's biotech research strength is in early-stage discoveries. Academia Sinica is making great efforts to help translate its research results into commercial opportunity and consistently seeking to protect intellectual property and facilitate technology transfers. In terms of the number of biotech patents issued by the United States, Taiwan is now ranked number 13 in the world and one-third of the patents are from Academia Sinica. It is hoped that Taiwan will have at least 5% of the world biotech market within 10 years.

Academia Sinica is making advances in the recruitment of top researchers, the improvement of research environment, integration of areas of study, and sharing of intellectual wealth with society. Academia Sinica has seen an increase in the hiring of top-notch foreign researchers while trying to create a more globalized environment to better facilitate their integration in our society. It has also seen a rapid growth in research productivity. The number of citations per paper has increased to 9.15, exceeding many leading universities and institutions in the region.

In terms of talent cultivation and training, Academia Sinica has collaborated with local universities on University Degree Program (for local students) and Taiwan International Graduate Program (TIGP, for international and local students, with all-English teaching and research environment). These joint Ph.D. Programs, focused on interdisciplinary studies, will help strengthen graduate education in Taiwan and attract a growing number of students who can become internationally competitive.



To integrate its existing resources and expand research facilities and space, Academia Sinica is now working on an ambitious campus expansion project. It would get 62 acres of land from the government, merging with its present 94 acres of campus. That area is planned to house a National Biotechnology Research Park, including facilities for biology, translational medicine, and international studies, plus an incubation center for biotechnology and additional housing units. This biotech park, enjoying an advantage of easy transportation (where the MRT, Taiwan Railway and the Taiwan High-Speed Rail meet), will not only lead cutting-edge research in biology but offer better chances for international venture capital and companies looking for business partners in the greater Chinese community including China and Hong Kong.

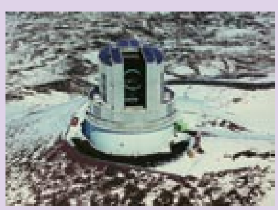
In the future, Academia Sinica will continue its proud academic tradition of pursuing excellence in research while working with other academic institutions around the world to create a better future for mankind.

State-of-the-Art Facilities

■ The Ultra High-throughput Compound Screening System

■ Mass Spectrometer

■ National High-field NMR Facility at AS



■ Subaru Telescope

■ The Yuan Tseh Lee Array for Microwave Background Anisotropy (AMiBA) on Mauna Loa, Hawaii

National Cheng Kung University – An Academic Leader

National Cheng Kung University, located in the culture-rich southern city of Tainan, is one of Taiwan's top two research-oriented universities and a leader in promoting the academic and industrial cooperation that is a cornerstone of Taiwan's knowledge-based economy. With more than 1,200 faculty members and 20,000 students, the university has a strong emphasis in scientific research, including dedicated colleges for Sciences, Engineering, Electrical Engineering & Computer Science, Planning & Design, Medicine, Bioscience & Biotechnology.

Since its founding in 1931, NCKU has achieved remarkable success in globalization. Not only has an English-speaking environment been built to attract hundreds of international students, but formal academic ties have also been established with many world-renowned universities and institutes. NCKU also provides international dual-degree programs with other prestigious universities, mainly in the US, and has had the benefit of appointing major international scholars, including 2004 Nobel Laureate Dr. Aaron Ciechanover, as visiting professors.

Contributing to the University's increasingly global outlook is President Dr. Michael M.C. Lai, an internationally well-known and respected virologist with a PhD. in molecular biology from the University of California, Berkeley. An author of more than 300 papers, Dr. Lai served as a Vice President of Academia Sinica and a Distinguished Professor at the University of Southern California. He returned to Taiwan from California in 2003 to head up the national SARS research team. Currently Dr. Lai serves as a member of the Science and Technology Advisory Group of the Executive Yuan, a position with important influence over government science policy.

"Enhancing the internationalization of our University is one of the foremost goals of NCKU," says Dr. Lai. "Not only do we promote robust academic exchanges and research collaborations with major universities in the world, but also we actively build an English-speaking environment to accommodate hundreds of international students and scholars."

"Currently there are 1,200 degree-seeking international students on the campus."
—Dr. Michael M.C. Lai, President

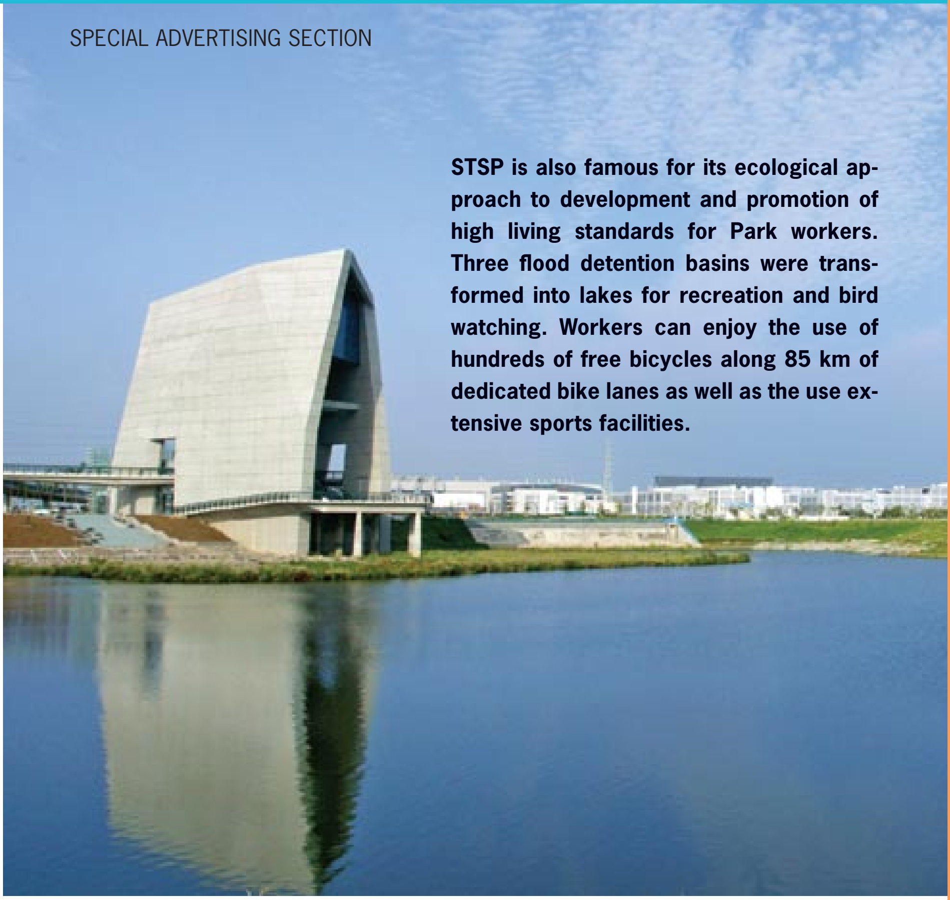
NCKU also hosts many advanced national-scale research centers and laboratories to support the teaching and research environment, including test plants for aviation technology and building material experiment groups, the National Chip Implementation Center, Asia's largest hydraulics laboratory, and a dedicated research center and lab for the study of Nanotechnology.

In addition to its global ties, however, NCKU remains dedicated to supporting the growth of its home region of southern Taiwan. The University enjoys a close relationship with the Southern Taiwan Science Park that is comparable to the ties between Stanford, UC Berkeley and California's Silicon Valley. Through these efforts, the south is emerging as a leader in biotechnology, photovoltaics and solar energy, among other areas.

"NCKU has a well-earned reputation of educating the best citizens for the society," says Dr. Lai. "We will continue this tradition to educate future leaders with strong humanistic and professional grounding and global vision. We will also promote interdisciplinary research to benefit the society and help solve the global problems facing the mankind."

NCKU's strength in research output is evident in its #2 ranking in Taiwan for overall academic articles from faculty members cited in the SCI and SSCI indexes, surpassed only by National Taiwan University (NTU), as the data derived from the Essential Science Indicators (ESI) database of Thomson Reuters demonstrate. According to this database, NCKU ranks #37 worldwide in engineering and #52 worldwide in material sciences in 2009. Additionally, NCKU ranks #30 worldwide and #1 nationwide in engineering whereas NTU ranks #32 worldwide and #2 nationwide according to the 2009 Performance Ranking of Scientific Papers for World Universities conducted by the Higher Education Evaluation & Accreditation Council of Taiwan (HEEACT). Based upon a new methodology developed by Elsevier to identify multidisciplinary research leadership, NCKU ranks #19 worldwide, the best of all Taiwan's leading universities, in alternative energy research papers produced in distinctive competency.

Southern Taiwan Science Park – The Next Wave of High Tech



STSP is also famous for its ecological approach to development and promotion of high living standards for Park workers. Three flood detention basins were transformed into lakes for recreation and bird watching. Workers can enjoy the use of hundreds of free bicycles along 85 km of dedicated bike lanes as well as the use extensive sports facilities.

In just fifteen short years since its construction was approved by Taiwan's legislature in 1995, The Southern Taiwan Science Park has emerged as Taiwan's leading showcase for new technologies. The STSP, now comprised of campuses in the cities of Tainan and Kaohsiung, is a world-leading center for the production of TFT-LCD flat panel displays and has a strong presence from Taiwan's integrated circuit industries. Future growth, however, will come from new industrial clusters focused on biotechnology, green/renewable energy, and medical devices, among others.

"When I arrived at the STSP, there was nothing but sugar cane fields," says Park Director General Chen Chun Wei. "Today we have over 248 companies in the Park generating over $16 billion in revenue."

Chen says the key to the Park's success is a well-developed infrastructure and an administration that provides one-stop service to investors so that everything from construction management to business registration, transportation and logistics is readily available. The STSP's network of relationships with 30 leading universities and research centers in southern Taiwan (some of which are located within the Park itself) makes it a model for the kind of industry, academic and government partnerships that have been so crucial to the development of technology-based industry in Taiwan.

From the beginning, the STSP has relied on the core strengths of Taiwan's ICT sector and leading companies such as TSMC, UMC and Chi Mei. Foreign suppliers, especially from the US (Corning) and Japan (Yaskawa, Daifuku) followed. But the goal was to use those strengths to build the next generation of technology success. The Precision Industry cluster, for example, attracted major international companies to service the first generation companies, and boosted local competitiveness but then laid the groundwork for successful ventures in green energy, particularly solar panels.

While a number of the major LCD players now manufacture solar panels, STSP also hosts important start-up ventures in Tainan that are promoting newer green technologies. Typical among them is Auria Solar, a pioneer in using Micromorph thin film technology that was able to start up end-to-end production of PV panels in record time. "I was told it would take over one year to get to full production," says Auria CEO Chi Yao-Tsai, "but thanks to innovative use of technology, the efficiency of the Park and the presence of a well-trained talent pool we hit full capacity within four months."

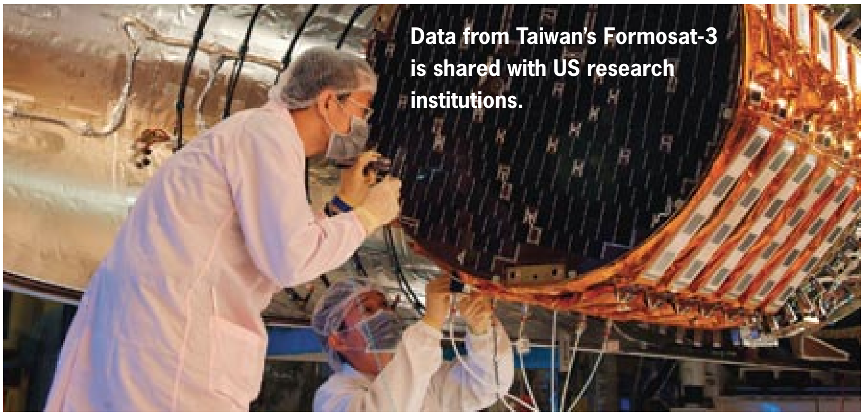
The Kaohsiung campus hosts a Metal Industries Research and Development Center and has built a cooperative network comprised of leading regional university hospitals and private sector companies to explore and create medical-related ventures. New industries in the zone are expected to include artificial implants and surgery tools, medical instruments and equipment and high functional robots and medical assistive devices.

STSP Kaohsiung is also a center for development of WiMAX broadband technology. A new lab building of the Telecommunications Technology Center will facilitate product certification for WiMAX developers, reducing costs dramatically.

Perhaps the STSP's most ambitious goal is for biotechnology development. The Administration has set aside about 100 acres in Tainan along the adjacent High Speed Rail line specifically for biotech manufacturers. Supporting facilities include ready-to-lease space in a Biotech Standard Factory, the National Laboratory Animal Center, a greenhouse, and the Academia Sinica's Biotechnology Experimental Center in Southern Taiwan.

As the Park enters its fifteenth year in 2010 it not only counts success by the number of companies and economic turnover but also through its positive contribution to the development of Southern Taiwan in terms of new jobs and sustainable, ecologically sound growth. STSP is truly living up to its mission of "creating the most suitable environment for the development of tenant enterprises and bringing hope to people in Southern Taiwan."

Taiwan-U.S. Science Cooperation: A Range of Opportunities



Data from Taiwan's Formosat-3 is shared with US research institutions.

Photo courtesy Orbital Sciences Corporation

There is a long history of strong ties between the scientific communities in Taiwan and the United States. Thousands of Taiwanese students have studied in the US. Many have remained and serve on the faculties of prestigious universities or work at leading companies. Those who have returned have contributed enormously to the development of Taiwan's universities as well as to the growth of Taiwan's enormous science and technology industries.

As noted elsewhere in this survey, formal ties currently link Taiwan's major universities and academic institutions with their US counterparts. Additionally, the Industrial Technology Research Institute (ITRI) maintains an office in California's Silicon Valley to increase contacts with US companies looking to work with Taiwanese researchers and to license Taiwan's growing list of patents.

Promoting US-Taiwan science cooperation is a full-time job for the four US outreach offices of Taiwan's National Science Council. Through the efforts of the NSC, there are increasing opportunities for exchange, research and investment being developed. These activities provide a unique way for American researchers and companies to establish ties with Taiwan's growing science and technology sector and vice-versa.

The offices serve as US liaisons for the unique network of science parks that the NSC has developed across the island which are already home to hundreds of US companies.

At the US Federal Government level, Taiwan's NSC now maintains formal relationships with the National Science Foundation, National Institutes of Health, National Institute of Standards Technology, the Environmental Protection Agency and the Department of Health and Human Services, among others.

"In all cases, the mission is to promote science and technology cooperation between Taiwan and the U.S." says Dr. Hsin-Hsiung Chang, NSC representative and Director of the Science and Technology Division at the Taiwan Economic and Cultural Representative Office in the United States located in Washington DC.

On a practical level, the NSC ties with leading government agencies have led to a number of important programs including free sharing of data from Taiwan's "FORMOSAT-3" satellite for meteorological use as well as a program for joint seismic research on the ocean floor off Taiwan with Columbia University's Lamont Doherty Observatory. A U.S-Taiwan International Workshop in Bio-inspired Sensing and Bio-Inspired Actuation for Civil and Mechanical Systems was held in Taipei last April, resulting in a detailed research agenda and agreement to co-sponsor training for students on biological systems and bio-inspired engineering design.

Since 2000, Taiwan's National Science Council and U.S. National Science Foundation have also together spearheaded the Summer Institute in Taiwan program under the NSF's East Asia and Pacific Summer Institute program, providing logistic and scholarship support for US graduate students to study and research in Taiwan in their chosen fields.

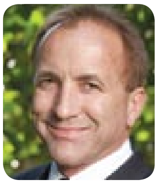
AGENDA 2010: JOINT NATURAL DISASTERS WORKSHOP

Recent natural catastrophes like the Chi-Chi Earthquake (Taiwan 1999), Hurricane Katrina (New Orleans 2005) and Typhoon Morakot (Taiwan 2009) are somber reminders that the US and Taiwan share common interest in improving the state of knowledge in understanding, predicting and mitigating natural hazards. The NSF and NSC have a proud history of co-sponsoring trans-Pacific research and education that advances capabilities to respond to natural hazards. However, both nations face increasingly alarming levels of risk due to growing urban populations vulnerable to such events. In response, the NSF and NSC are launching a bold new US-Taiwan collaborative research program. In May 2010, the "International Workshop in Mega-Cities and Mega-Disasters" will be held at the National Taiwan University in order to identify new research agendas in predicting natural hazards, developing interconnected infrastructure systems resilient to major hazard events, and improving government and non-government responses after natural catastrophes have occurred.

Kool-Aid Psychology

How optimism trumped realism in the positive-psychology movement

BY MICHAEL SHERMER

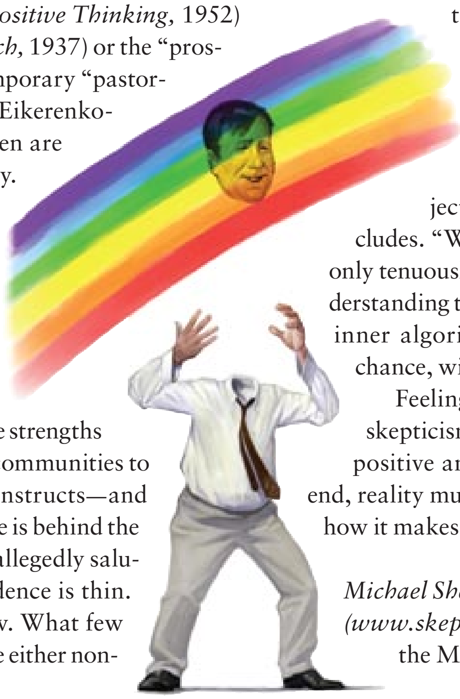


I am, by nature, an optimist. I almost always think things will turn out well, and even when they break I am confident that I can fix them. My optimism, however, has not always served me well. Twice I have been hit by cars while cycling—full-on, through-the-windshield impacts that were entirely the result of my blissful attitude that the street corners I had successfully negotiated hundreds of times before would not suddenly materialize an automobile in my path. Such high-impact, unpredictable and rare events are what author Nassim Nicholas Taleb calls "black swans." Given enough time, no upward sloping trend line is immune from dramatic collapse.

A bike crash as a black swan is, in fact, an apt metaphor for what the investigative journalist and natural-born skeptic Barbara Ehrenreich believes happened to America as a result of the positive-thinking movement. In her engaging and tightly reasoned book *Bright-Sided* (Metropolitan Books, 2009), she shows how the positive-psychology movement was born in the halcyon days of the 1990s when the economy was soaring, housing prices were skyrocketing, and positive-thinking gurus were cashing in on the motivation business. Academic psychologists, armed with a veneer of scientific jargon, wanted in on the action.

The shallow bafflegab of such positive-thinking pioneers as Norman Vincent Peale (*The Power of Positive Thinking,* 1952) and Napoleon Hill (*Think and Grow Rich,* 1937) or the "prosperity gospel" preachings of such contemporary "pastorpreneurs" as Frederick "Reverend Ike" Eikerenkoetter, Robert H. Schuller and Joel Osteen are predictably data-light and anecdote-heavy. But one expects better of respected experimental psychologists such as Martin E. P. Seligman, who almost single-handedly launched the positive-psychology movement in academia that is, according to the Positive Psychology Center Web page (www.ppc.sas.upenn.edu), "the scientific study of the strengths and virtues that enable individuals and communities to thrive." Ehrenreich systematically deconstructs—and then demolishes—what little science there is behind the positive-psychology movement and the allegedly salubrious effects of positive thinking. Evidence is thin. Statistical significance levels are narrow. What few robust findings there are often prove to be either nonreplicable or contradicted by later research. And correlations (between, say, happiness and health) are not causations. Seligman and his colleagues drank the positive-thinking Kool-Aid, Ehrenreich shows, but she provides the antidote.

Take Seligman's "happiness equation" (physics envy lives!): H = S + C + V (Happiness = your Set range + the Circumstances of your life + the factors under your Voluntary control). As Ehrenreich notes, "if you're going to add these things up you will have to have the same units [of measurement] for H (happy thoughts per day?) as for V, S, and C." When she confronted Seligman with this problem in an interview, "his face twisted into a scowl, and he told me that I didn't understand 'beta weighting' and should go home and Google it." She did, "finding that 'beta weights' are the coefficients of the 'predictors' in a regression equation used to find statistical correlations between variables. But Seligman had presented his formula as an ordinary equation, like $E = mc^2$, not as an oversimplified regression analysis, leaving himself open to literal-minded questions like: How do we know H is a simple sum of the variables, rather than some more complicated relationship, possibly involving 'second order' effects such as … C times V?" We don't know, thereby rendering the equation nothing more than a slogan gussied up in math.



Isn't positive thinking better than negative thinking? All other things being equal, sure, but the alternative to being either an optimist or a pessimist is to be a realist. "Human intellectual progress, such as it has been, results from our long struggle to see things 'as they are,' or in the most universally comprehensible way, and not as projections of our own emotions," Ehrenreich concludes. "What we call the Enlightenment and hold on to only tenuously, by our fingernails, is the slow-dawning understanding that the world is unfolding according to its own inner algorithms of cause and effect, probability and chance, without any regard for human feelings."

Feelings matter, of course, but the first principle of skepticism is not to fool ourselves, and feelings—both positive and negative—too often trump reason. In the end, reality must take precedence over fantasy, regardless of how it makes us feel. ■

Michael Shermer is publisher of Skeptic *magazine (www.skeptic.com) and author of* The Mind of the Market.

PHOTOGRAPH BY BRAD SWONETZ; ILLUSTRATION BY MATT COLLINS

The Doomsday Clock Still Ticks

As long as opportunities and excuses for nuclear aggression persist, the world will never be safe from annihilation

BY LAWRENCE M. KRAUSS

Early last October the Nobel Prize committee announced that it was awarding Barack Obama the Peace Prize for his "vision of and work for a world without nuclear weapons." At the same time, in counterpoint to that news, it was reported that the director of India's 1998 nuclear testing program had called for new tests. That move provoked fears of escalation, in case it motivated Pakistan and China to recommence testing and made it even harder for the U.S. to ratify the Comprehensive Nuclear Test Ban Treaty (CTBT). Although some 150 countries have ratified the treaty, neither the U.S., China nor India has yet done so.

The chair of India's Atomic Energy Commission has stated that his nation does not need to carry out any more tests; one can only hope that India's policy makers agree and that by the time this essay appears, the world will not yet have taken one more step toward the brink.

Such news underscores that nuclear weapons and nuclear proliferation won't be going away soon. On January 13 and 14 the *Bulletin of the Atomic Scientists* is hosting in New York City its first annual Doomsday Clock Symposium, where a decision regarding the setting of the minute hand on its famous Doomsday Clock will be made. The clock has served for nearly 65 years as an international symbol of the level of risk that the world faces from nuclear weapons and, more recently, from all potentially globally destructive technologies.

In the interests of full disclosure, I should mention that I am co-chair, along with physicist Leon Lederman, of the board of sponsors of the *Bulletin,* a group formed by Albert Einstein in 1946, with J. Robert Oppenheimer as its chair. But my purpose here is not to promote the *Bulletin* itself but rather what it stands for.

No issue carries more importance to the long-term health and security of humanity than the effort to reduce and, perhaps one day, rid the world of nuclear weapons. The U.S. can and should take a leading role in this effort, but until recently, President Obama's verbiage aside, our actions have done far too little to encourage this goal, and quite frankly we have too often discouraged it.

We live in a dangerous world, and actions by countries such as Iran and North Korea need to be monitored carefully, but the response should be commensurate with the threat.

President Obama was correct to end the planned installation of a missile defense system in Poland, not merely because Iran does not possess ICBMs capable of carrying nuclear warheads but because the proposed missile defense system, a mirror of the flawed one currently installed in the U.S., does not work and never has. Commissioning an unworkable defense against a nonexistent threat, especially when such a system in Eastern Europe clearly increased other international tensions with Russia, made no strategic sense. The mobile short-range missile defense system proposed as an alternative is more likely to function against any actual threat from Iran.

Still, President Obama's hopes for a nuclear-free world cannot be met if we continue to act as if the U.S. should have an unfettered monopoly on such weapons. How can we expect other countries to show restraint when we have not yet ratified the CTBT, even though we can verify compliance effectively and our own nuclear arsenal does not need testing? How can we hope for a safer world when the U.S. and Russia have between them more than 10,000 nuclear weapons, with perhaps 1,000 still on trigger alert, despite the absence of any credible, justifying threat?

We have lived in a world where nuclear weapons have not been used against a civilian population in more than 60 years. I am not optimistic that this nuclear truce will last another 60. But until we honestly recognize the threat and minimize the opportunity and motivation for governments or terrorist organizations to carry out such an act, we continue to increase the odds that it will one day happen. As Einstein said 65 years ago, after the explosion of the first nuclear weapon, "Everything has changed, save the way we think." We need to take his words to heart now more than ever. ■

Lawrence M. Krauss, a theoretical physicist, commentator and book author, is Foundation Professor and director of the Origins Initiative at Arizona State University (http://krauss.faculty.asu.edu).

PHOTOGRAPH BY JOHN BOSWELL; ILLUSTRATION BY MATT COLLINS

SLIM FILMS

Looking for Life in the MULTIVERSE

Universes with different physical laws might still be habitable

BY ALEJANDRO JENKINS AND GILAD PEREZ

KEY CONCEPTS

- Multiple other universes—each with its own laws of physics—may have emerged from the same primordial vacuum that gave rise to ours.
- Assuming they exist, many of those universes may contain intricate structures and perhaps even some forms of life.
- These findings suggest that our universe may not be as "finely tuned" for the emergence of life as previously thought.

—The Editors

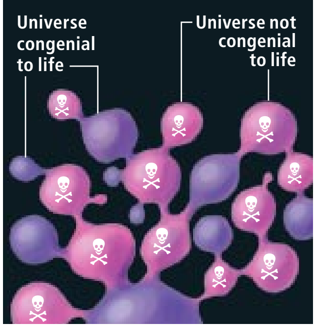
The typical Hollywood action hero skirts death for a living. Time and again, scores of bad guys shoot at him from multiple directions but miss by a hair. Cars explode just a fraction of a second too late for the fireball to catch him before he finds cover. And friends come to the rescue just before a villain's knife slits his throat. If any one of those things happened just a little differently, the hero would be *hasta la vista, baby*. Yet even if we have not seen the movie before, something tells us that he will make it to the end in one piece.

In some respects, the story of our universe resembles a Hollywood action movie. Several physicists have argued that a slight change to one of the laws of physics would cause some disaster that would disrupt the normal evolution of the universe and make our existence impossible. For example, if the strong nuclear force that binds together atomic nuclei had been slightly stronger or weaker, stars would have forged very little of the carbon and other elements that seem necessary to form planets, let alone life. If the proton were just 0.2 percent heavier than it is, all primordial hydrogen would have decayed almost immediately into neutrons, and no atoms would have formed. The list goes on.

The laws of physics—and in particular the constants of nature that enter into those laws, such as the strengths of the fundamental forces—might therefore seem finely tuned to make our existence possible. Short of invoking a supernatural explanation, which would be by definition outside the scope of science, a number of physicists and cosmologists began in the 1970s to try solving the puzzle by hypothesizing that our universe is just one of many existing universes, each with its own laws. According to this "anthropic" reasoning, we might just occupy the rare universe where the right conditions happen to have come together to make life possible.

WHAT IS THE MULTIVERSE?

Alternative universes have now become a legitimate field of study, in part because they may actually exist. According to the prevailing cosmological theory, our universe was spawned from a microscopic region of a primordial vacuum by a burst of exponential expansion called inflation. But the vacuum may continually spawn other universes as well. Each universe might have its own physical laws; some would be hospitable to life, some not.



Amazingly, the prevailing theory in modern cosmology, which emerged in the 1980s, suggests that such "parallel universes" may really exist—in fact, that a multitude of universes would incessantly pop out of a primordial vacuum the way ours did in the big bang. Our universe would be but one of many pocket universes within a wider expanse called the multiverse. In the overwhelming majority of those universes, the laws of physics might not allow the formation of matter as we know it or of galaxies, stars, planets and life. But given the sheer number of possibilities, nature would have had a good chance to get the "right" set of laws at least once.

Our recent studies, however, suggest that some of these other universes—assuming they exist—may not be so inhospitable after all. Remarkably, we have found examples of alternative values of the fundamental constants, and thus of alternative sets of physical laws, that might still lead to very interesting worlds and perhaps to life. The basic idea is to change one aspect of the laws of nature and then make compensatory changes to other aspects.

Our work did not address the most serious fine-tuning problem in theoretical physics: the smallness of the "cosmological constant," thanks to which our universe neither recollapsed into nothingness a fraction of a second after the big bang, nor was ripped part by an exponentially accelerating expansion. Nevertheless, the examples of alternative, potentially habitable universes raise interesting questions and motivate further research into how unique our own universe might be.

The Weakless Way of Life

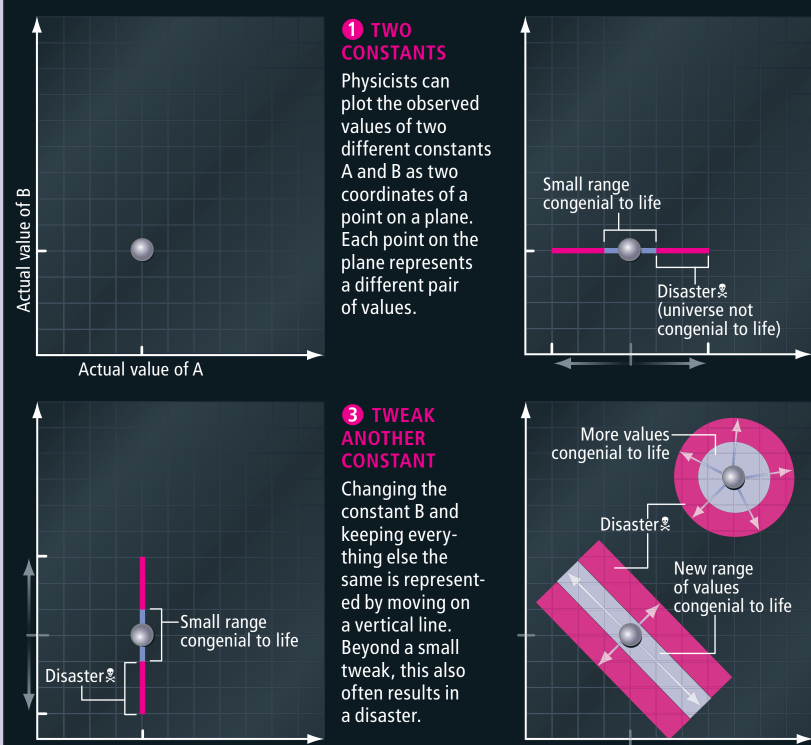
The conventional way scientists find out if one particular constant of nature is finely tuned or not is to turn that "constant" into an adjustable parameter and tweak it while leaving all other constants unaltered. Based on their newly modified laws of physics, the scientists then "play the movie" of the universe—they do calculations, what-if scenarios or computer simulations—to see what disaster occurs first. But there is no reason why one should tweak only one parameter at a time. That situation resembles trying to drive a car by varying only your latitude or only your longitude, but not both: unless you are traveling on a grid, you are destined to run off the road. Instead one can tweak multiple parameters at once.

To search for alternative sets of laws that still give rise to complex structures capable of sustain-

[THE BASIC IDEA]

HOW TO FIND HOSPITABLE UNIVERSES

Many features in the laws of nature appear to be finely tuned: a small change to any one of the constants that appear in physics equations typically leads to a "disaster." For example, atoms cannot form, or matter gets dispersed in space so thinly that it cannot condense into galaxies, stars or planets. Changing two constants at a time, however, can sometimes lead to sets of possible values that are compatible with the formation of complex structures and perhaps even some forms of intelligent life. Changing three or more constants widens the range of possibilities even more.



1 TWO CONSTANTS Physicists can plot the observed values of two different constants A and B as two coordinates of a point on a plane. Each point on the plane represents a different pair of values.

2 TWEAK ONE CONSTANT Changing the constant A (while keeping everything else the same) is represented by moving on a horizontal line. Going beyond a tiny change usually results in a disaster, and the universe would be unsuitable for life.

3 TWEAK ANOTHER CONSTANT Changing the constant B and keeping everything else the same is represented by moving on a vertical line. Beyond a small tweak, this also often results in a disaster.

4 CHANGE BOTH CONSTANTS The ability to change both A and B at once—for example, moving along a diagonal—can lead to new sets of values congenial to life. Farther away from the known values could also lie other "islands" of congenial values.

LUCY READING-IKKANDA (*multiverse and charts*) ing life, one of us (Perez) and his collaborators did not make just small tweaks to the known laws of physics: they completely eliminated one of the four known fundamental forces of nature.

By their very name, the fundamental forces sound like indispensable features of any self-respecting universe. Without the strong nuclear force to bind quarks into protons and neutrons and those into atomic nuclei, matter as we know it would not exist. Without the electromagnetic force, there would be no light; there would also be no atoms and no chemical bonds. Without gravity, there would be no force to coalesce matter into galaxies, stars and planets.

The fourth force, the weak nuclear force, has a subtler presence in our everyday life but still has played a major role in the history of our universe. Among other things, the weak force enables the reactions that turn neutrons into protons, and vice versa. In the first instants of the big bang, after quarks (among the first forms of matter to appear) had united in groups of three to form protons and neutrons, collectively called baryons, groups of four protons were then able to fuse together and become helium 4 nuclei, made of two protons and two neutrons. This so-called big bang nucleosynthesis took place a few seconds into the life of our universe, when it was already cold enough for baryons to form but still hot enough for the baryons to undergo nuclear fusion. Big bang nucleosynthesis produced the hydrogen and helium that would later form stars, where nuclear fusion and other processes would forge virtually all other naturally occurring elements. And to this day, the fusion of four protons to make helium 4 continues inside our sun, where it produces most of the energy that we receive from it.

Without the weak nuclear force, then, it seems unlikely that a universe could contain anything resembling complex chemistry, let alone life. Yet in 2006 Perez's team discovered a set of physical laws that relied on only the other three forces of nature and still led to a congenial universe.

Eliminating the weak nuclear force required several modifications to the so-called Standard Model of particle physics, the theory that describes all forces except gravity. The team showed that the tweaks could be done in such a way that the behavior of the other three forces—and other crucial parameters such as the masses of the quarks—would be the same as in our world. We should stress that this choice was a conservative one, intended to facilitate the calculation of how the universe would unfold. It is quite possible that a wide range of other "weakless" universes exist that are habitable but look nothing like our own.

In the weakless universe, the usual fusing of protons to form helium would be impossible, because it requires that two of the protons convert into neutrons. But other pathways could exist for the creation of the elements. For example, our universe contains overwhelmingly more matter than antimatter, but a small adjustment to the parameter that controls this asymmetry is enough to ensure that the big bang nucleosynthesis would leave behind a substantial amount of deuterium nuclei. Deuterium, also known as hydrogen 2, is the isotope of hydrogen whose nucleus contains a neutron in addition to the usual proton. Stars could then shine by fusing a proton and a deuterium nucleus to make a helium 3 (two protons and one neutron) nucleus.

Such weakless stars would be colder and smaller than the stars in our own universe. According to computer simulations by astrophysicist Adam Burrows of Princeton University, they could burn for about seven billion years—about the current age of our sun—and radiate energy at a rate that would be a few percent of that of the sun.

Next Generation

Just like stars in our universe, weakless stars could synthesize elements as heavy as iron through further nuclear fusion. But the typical reactions that in our stars lead to elements beyond iron would be compromised, primarily because few neutrons would be available for nuclei to capture to become heavier isotopes, the first step in the formation of heavier elements. Small amounts of heavy elements, up to strontium, might still be synthesized inside weakless stars by other mechanisms.

In our universe, supernova explosions disperse the newly synthesized elements into space, and synthesize more of the elements themselves. Supernovae can be of several types: in the weakless universe, the supernova explosions caused by collapsing ultramassive stars would fail, because it is the emission of neutrinos, produced via the weak-force interactions, that transmits energy out of a star's core so as to sustain the shock wave that is causing the explosion. But a different type of supernova—the thermonuclear explosion of a star triggered by accretion, rather than by gravitational collapse—would still take place. Thus, elements could be dispersed into interstellar space, where they could seed new stars and planets.

OTHER NOTIONS OF "PARALLEL UNIVERSES"

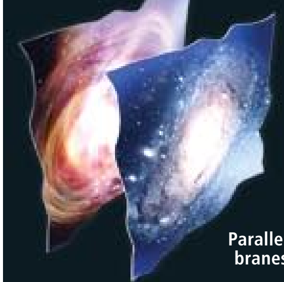
Physicists and cosmologists—and often science-fiction writers—talk of parallel universes in several different contexts: at least three notions exist distinct from the multiverse described in this article.

▼ HUBBLE BUBBLE

Our universe is probably much larger than the part we can observe, our "Hubble bubble." If it is infinite in size, then infinitely many separate Hubble bubbles (centered on observers in remote galaxies) must exist. Some could be identical to ours, with another you reading this exact article.

▼ BRANES

If space has more than three dimensions, our universe could be one of many three-dimensional membranes, or "branes," in a wider multidimensional space. These "parallel universes" can affect one another and even collide.



Parallel branes

▼ THE MANY-WORLDS HYPOTHESIS

In quantum physics, the same object can exist in multiple states—as in the famous cat that is simultaneously dead and alive—and only external prodding will force it to settle into one state. Some physicists believe that all possible states continue to exist, each in a separate, "branched out" version of the universe.

Schrödinger's cat

NASA (*deep space in "Hubble bubble"*); LUCY READING-IKKANDA (*branes and cat*)

[SCENARIO 1: THE WEAKLESS UNIVERSE]

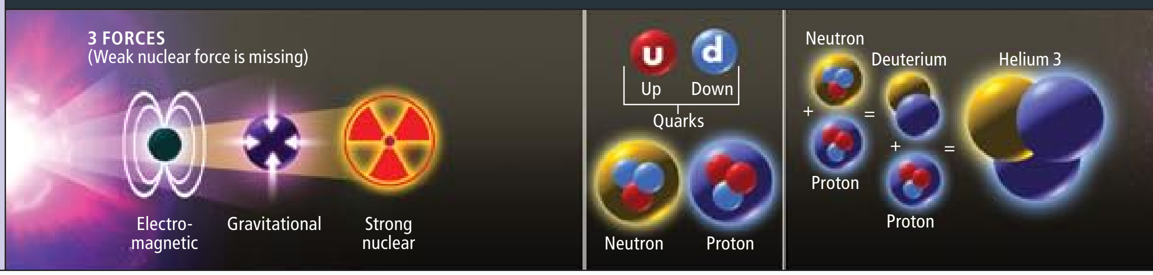
SHORT HISTORY OF AN ALTERNATIVE UNIVERSE

A universe with three fundamental forces, instead of the usual four, could still look surprisingly familiar. Here is how to find out.

- Remove the weak nuclear force by modifying several “constants” in the Standard Model of particle physics.
- Keep the other three forces exactly as they are in our universe.
- Modify other parameters to facilitate nuclear fusion in stars.

The result is a world with complex structure that could support life-forms similar to those on Earth.

OUR UNIVERSE	▲ Elementary particles and four fundamental forces appear. At the universe’s extreme temperature, the weak force prevents matter from having mass.	Cooling makes the weak force actually weak, so matter particles can acquire mass.	▲ Up and down quarks combine into protons (hydrogen nuclei) and neutrons.	▲ Some protons fuse into helium 4 nuclei. This reaction relies on the weak nuclear force to transform protons into neutrons, electrons and antineutrinos.
	10^{-40} SECOND	10^{-12} SECOND	10^{-6} SECOND	1 SECOND–3 MINUTES
ALTERNATIVE UNIVERSE	▼ Fewer elementary particles appear, but matter particles already have mass.		▼ Up and down quarks combine into protons and neutrons.	▼ Some protons and neutrons fuse into deuterium and then into helium 3 nuclei. Protons cannot transform into neutrons.



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Given the relative coldness of the weakless stars, a weakless Earth-like body would have to be about six times closer to its sun to stay as warm as our own Earth. To the inhabitants of such a planet, the sun would look much bigger. Weakless Earths would be significantly different from our own Earth in other ways. In our world, plate tectonics and volcanic activity are powered by the radioactive decay of uranium and thorium deep within Earth. Without these heavy elements, a typical weakless Earth might have a comparatively boring and featureless geology—except if gravitational processes provided an alternative source of heating, as happens on some moons of Saturn and Jupiter.

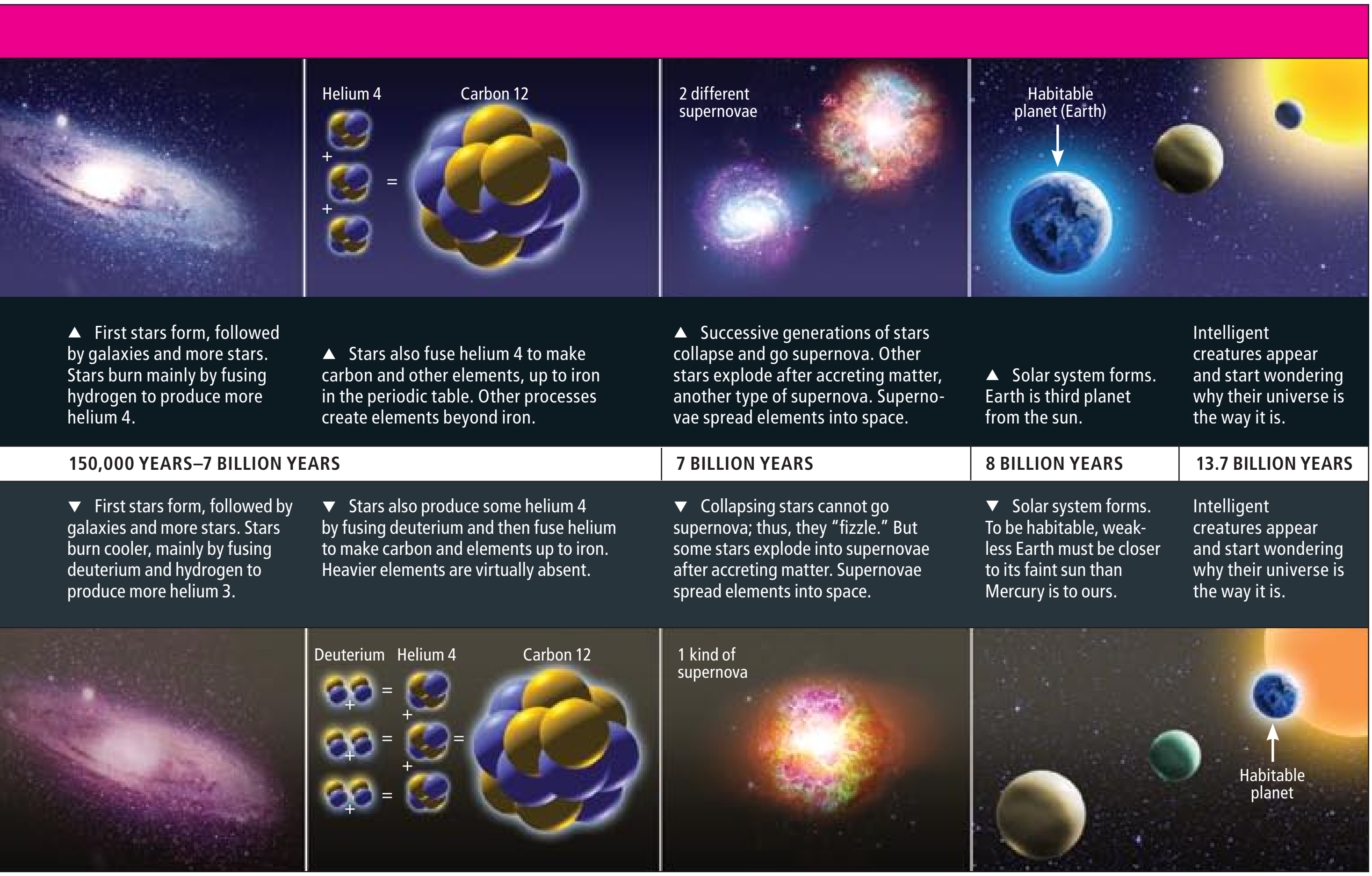
Chemistry, on the other hand, would be very similar to that of our world. One difference would be that the periodic table would stop at iron, except for extremely small traces of other elements. But this limitation should not prevent life-forms similar to the ones we know from evolving. Thus, even a universe with just three fundamental forces could be congenial to life.

Another approach, pursued by the other of us (Jenkins) and his collaborators, searches for alternative sets of laws by making smaller tweaks to the Standard Model than in the case of the weakless universe, though still involving multiple parameters at once. In 2008 the group studied to what extent the masses of the three lightest of the six quarks—called the up, down and strange quarks—may vary without making organic chemistry impossible. Changing the quark masses will inevitably affect which baryons and which atomic nuclei can exist without decaying quickly. In turn, the different assortment of atomic nuclei will affect chemistry.

We may need to learn more about other universes to understand our true place in the multiverse.

Quarky Chemistry

It seems plausible that intelligent life (if it is not very different from us) requires some form of organic chemistry, which is by definition the chemistry that involves carbon. The chemical properties of carbon follow from the fact that its nucleus has an electric charge of 6, so that six electrons orbit in a neutral carbon atom. These properties allow carbon to form an immense variety of complex molecules. (The suggestion often made by science-fiction writers that life could instead be based on silicon—



the next element in carbon's group in the periodic table—is questionable: no silicon-based molecules of any significant degree of complexity are known to exist.) Furthermore, for complex organic molecules to form, elements with the chemistry of hydrogen (charge 1) and oxygen (charge 8) need to be present. To see if they could maintain organic chemistry, then, the team had to calculate whether nuclei of charge 1, 6 or 8 would decay radioactively before they could participate in chemical reactions [*see box on next page*].

The stability of a nucleus partly depends on its mass, which in turn depends on the masses of the baryons it is made of. Computing the masses of baryons and nuclei starting from the masses of the quarks is extremely challenging even in our universe. But after tweaking the intensity of the interaction between quarks, one can use the baryon masses measured in our universe to estimate how small changes to the masses of the quarks would affect the masses of nuclei.

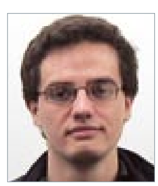
In our world, the neutron is roughly 0.1 percent heavier than the proton. If the masses of the quarks were changed so that the neutron became 2 percent heavier than the proton, no long-lived form of carbon or oxygen would exist. If quark masses were adjusted to make the proton heavier than the neutron, then the proton in a hydrogen nucleus would capture the surrounding electron and turn into a neutron, so that hydrogen atoms could not exist for very long. But deuterium or tritium (hydrogen 3) might still be stable, and so would some forms of oxygen and carbon. Indeed, we found that only if the proton became heavier than the neutron by more than about 1 percent would there cease to be some stable form of hydrogen.

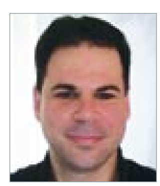
With deuterium (or tritium) substituting for hydrogen 1, oceans would be made of heavy water, which has subtly different physical and chemical properties from ordinary water. Still, there does not appear to be a fundamental obstacle in these worlds to some form of organic life evolving.

In our world, the third-lightest quark—the strange quark—is too heavy to participate in nuclear physics. But if its mass were reduced by a factor of more than about 10, nuclei could be made not just of protons and neutrons but

[THE AUTHORS]

Alejandro Jenkins, a native of Costa Rica, is in the High Energy Physics group at Florida State University. He has degrees from Harvard University and the California Institute of Technology, and he investigated alternative universes while at the Massachusetts Institute of Technology with Bob Jaffe and Itamar Kimchi. **Gilad Perez** is a theorist at the Weizmann Institute of Science in Rehovot, Israel, where he received his Ph.D. in 2003. While at Lawrence Berkeley National Lab, he explored the multiverse with Roni Harnik of Stanford University and Graham D. Kribs of the University of Oregon. He has also done stints at Stony Brook University, Boston University and Harvard.



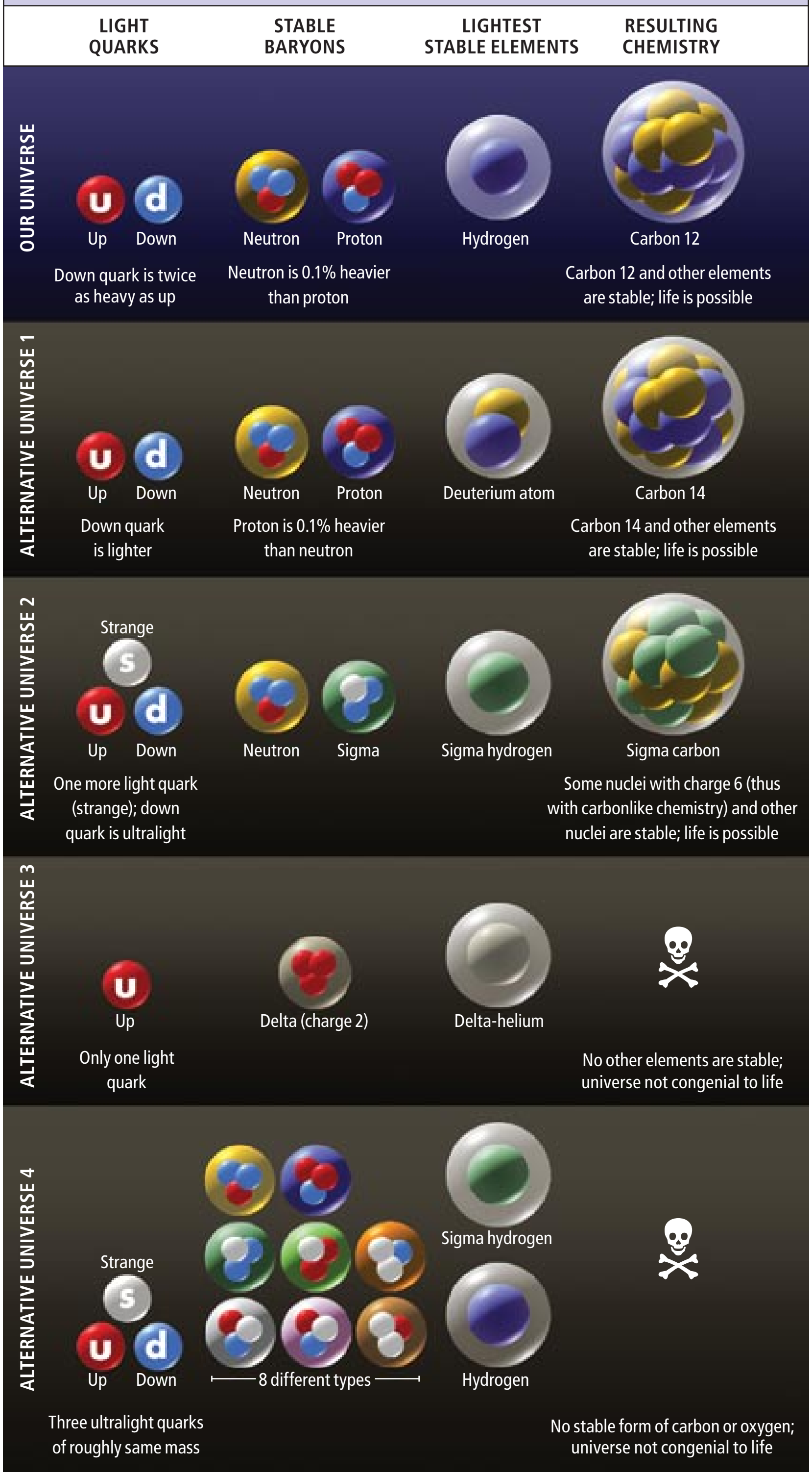


COURTESY OF CHARLES SUGGS *MIT Center for Theoretical Physics (Jenkins)*; COURTESY OF GILAD PEREZ *(Perez)*

[SCENARIO 2: UNIVERSES WITH DIFFERENT QUARKS]

TINKERING WITH MATTER

Imagine changing the masses of the light quarks (meaning the quarks that can form stable baryons, such as neutrons and protons). Would you still get the elements crucial to life as we know it? At the very least, the resulting universe should contain stable nuclei of electrical charge 1, 6 and 8, because those charges would give them properties similar to those of hydrogen, carbon and oxygen, respectively. Here are a few cases of what occurs.



also of other baryons containing strange quarks.

For example, the team identified a universe in which the up and strange quark would have roughly the same mass, whereas the down quark would be much lighter. Then atomic nuclei would not be made of protons and neutrons but instead of neutrons and another baryon, called the Σ^- ("sigma minus"). Remarkably, even such a radically different universe would have stable forms of hydrogen, carbon and oxygen and therefore could have organic chemistry. Whether those elements would be produced abundantly enough for life to evolve somewhere within them is an unanswered question.

But if life can arise, it would again happen much like it does in our world. Physicists in such a universe might be puzzled by the fact that the up and strange quarks would have almost identical masses. They might even imagine that this amazing coincidence has an anthropic explanation, based on the need for organic chemistry. We know, however, that such an explanation would be wrong, because our world has organic chemistry even though the masses of the down and strange quarks are quite different.

On the other hand, universes in which the three light quarks had roughly the same masses would probably have no organic chemistry: any nucleus with more than a couple of units of electrical charge would decay away almost immediately. Unfortunately, it is very difficult to map out in detail the histories of universes whose physical parameters are different from our own. This issue requires further research.

String Landscaping

Fine-tuning has been invoked by some theoretical physicists as indirect evidence for the multiverse. Do our findings therefore call the concept of a multiverse into question? We do not think that this is necessarily the case, for two reasons. The first comes from observation, combined with theory. Astronomical data strongly support the hypothesis that our universe started out as a tiny patch of spacetime, perhaps as small as a billionth the size of a proton, which then went through a phase of rapid, exponential growth, called inflation. Cosmology still lacks a definitive theoretical model for inflation, but theory suggests that different patches could inflate at different rates and that each patch could form a "pocket" that can become a universe in its own right, characterized by its own values for the constants of nature [see "The Self-Reproducing Inflationary Universe," by Andrei Linde; SCIEN-

SLIM FILMS

TIFIC AMERICAN, November 1994]. Space between pocket universes would keep expanding so fast that it would be impossible to travel or send messages from one pocket to the next, even at the speed of light.

The second reason to suspect the existence of the multiverse is that one quantity still seems to be finely tuned to an extraordinary degree: the cosmological constant, which represents the amount of energy embodied in empty space. Quantum physics predicts that even otherwise empty space must contain energy. Einstein's general theory of relativity requires that all forms of energy exert gravity. If this energy is positive, it causes spacetime to expand at an exponentially accelerating rate. If it is negative, the universe would recollapse in a "big crunch." Quantum theory seems to imply that the cosmological constant should be so large—in the positive or negative direction—that space would expand too quickly for structures such as galaxies to have a chance to form or else that the universe would exist for a fraction of a second before recollapsing.

One way to explain why our universe avoided such disasters could be that some other term in the equations canceled out the effects of the cosmological constant. The trouble is that this term would have to be fine-tuned with exquisite precision. A deviation in even the 100th decimal place would lead to a universe without any significant structure.

In 1987 Steven Weinberg, the Nobel Prize–winning theorist at the University of Texas at Austin, proposed an anthropic explanation. He calculated an upper bound on the value of the cosmological constant that would still be compatible with life. Were the value any bigger, space would expand so quickly that the universe would lack the structures that life requires. In a way, then, our very existence predicts the low value of the constant.

Then, in the late 1990s, astronomers discovered that the universe is indeed expanding at an accelerating rate, pushed by a mysterious form of "dark energy." The observed rate implied that the cosmological constant is positive and tiny—within the bounds of Weinberg's prediction—meaning that dark energy is very dilute.

Thus, the cosmological constant seems to be fine-tuned to an exceptional degree. Moreover, the methods our teams have applied to the weak nuclear force and to the masses of quarks seem to fail in this case, because it seems impossible to find congenial universes in which the cosmological constant is substantially larger than the value we observe. Within a multiverse, the vast majority of universes could have cosmological constants incompatible with the formation of any structure.

A real-world analogy—as opposed to an action-movie one—would be to send thousands of people trekking across a mountainous desert. The few who make it out alive might tell stories full of cliffhangers, encounters with poisonous snakes, and other brushes with death that would seem too close to be realistic.

Theoretical arguments rooted in string theory—a speculative extension of the Standard Model that attempts to describe all forces as the vibrations of microscopic strings—seem to confirm such a scenario. These arguments suggest that during inflation the cosmological constant and other parameters could have taken a virtually limitless range of different values, called the string theory landscape [see "The String Theory Landscape," by Raphael Bousso and Joseph Polchinski; SCIENTIFIC AMERICAN, September 2004].

Our own work, however, does cast some doubt on the usefulness of anthropic reasoning, at least beyond the case of the cosmological constant. It also raises important questions. For example, if life really is possible in a weakless universe, then why does our own universe have a weak force at all? In fact, particle physicists consider the weak force in our universe to be, in a sense, not weak enough. Its observed value seems unnaturally strong within the Standard Model. (The leading explanation for this mystery requires the existence of new particles and forces that physicists hope to discover at the newly opened Large Hadron Collider at CERN near Geneva.)

As a consequence, many theorists expect that most universes would have weak interactions that are so feeble as to be effectively absent. The real challenge, then, may be to explain why we do *not* live in a weakless universe.

Eventually only a deeper knowledge of how universes are born can answer such questions. In particular, we may discover physical principles of a more fundamental level that imply that nature prefers certain sets of laws over others.

We may never find any direct evidence of the existence of other universes, and we certainly will never get to visit one. But we may need to learn more about them if we want to understand what is our true place in the multiverse—or whatever it is that is out there. ■

IS ANYBODY OUT THERE?

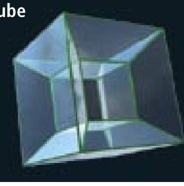
Many more sets of physical laws could emerge from the primordial vacuum. In most cases, including those below, it is unknown if the universes would be congenial to life. But future research may tell.

HELIUM RULES
Certain tweaks to the universe with no weak nuclear force would produce one with virtually no hydrogen left over from the big bang. Stars would be made mostly of helium.

MULTIQUARK
In our universe, quarks form particles in sets of two or three, but in other universes they might also form sets of four, five or more.

HIGHER DIMENSIONS
According to string theory, space has 10 dimensions. In our universe, all but three curled up or otherwise became invisible. What if four or more dimensions were still visible?

4-D hypercube



JEAN-FRANCOIS PODEVIN

➥ MORE TO EXPLORE

A Designer Universe? Steven Weinberg. Conference on Cosmic Design of the American Association for the Advancement of Science, Washington, D.C., April 1999. Available online at **www.physlink.com/Education/essay_weinberg.cfm**

Parallel Universes. Max Tegmark in *Scientific American,* Vol. 288, No. 5, pages 40–51; May 2003.

A Universe without Weak Interactions. Roni Harnik, Graham D. Kribs and Gilad Perez in *Physical Review D,* Vol. 74, No. 3, pages 035006-1–035006-15; August 2006.

Quark Masses: An Environmental Impact Statement. Robert L. Jaffe, Alejandro Jenkins and Itamar Kimchi in *Physical Review D,* Vol. 79, No. 6, pages 065014-1–065014-33; March 2009.

Nanoscience

Increasingly, research at the Charles University in Prague is focusing on nanoscience – research at the range of nanometers or billionths of a meter, where novel properties unseen at larger scales often emerge. We are creating and characterizing nanostructures such as nanodots, nanoparticles, nanowires, nanotubes and thin films for research and application purposes, as well as cultivating sophisticated techniques for nanomaterial studies. These activities are often interdisciplinary, combining physics, chemistry, biology, biomedicine and materials science, and a new PhD program of ours, "Physics of Nanostructures," should fertilize this attractive research field.

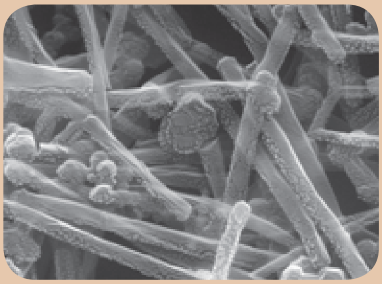


Fig. 1: CNTs coated by Pt-CeO_2 thin film.

Fig. 2: 50 nm thick WO_x nanorods.

Fig. 3: Thermal maps of a liver tissue during RF ablation of a tumor (top with $CoFe_2O_4$ nanoparticles, bottom without $CoFe_2O_4$ nanoparticles); the nanoparticles increase the treatment temperature by 5° C and enlarge the RF ablation sphere approx. twice due to enhanced energy transfer.

Here are recent examples of our research in the nanoworld.

Structure and reactivity of metallic nanostructures: Nanowires and thin films for use in catalysts and gas sensors are being explored intensively at our Department of Surface and Plasma Science. Researchers there are investigating the structure, form and composition of these nanostructures by a variety of techniques, such as scanning electron microscopy, X-ray diffraction and X-ray photoelectron spectroscopy.

Two representative examples of our work include:

1) *Ionic platinum*, which acts as a catalyst in proton exchange membrane (PEM) fuel cells, which transform chemical energy into electricity. We doped a cerium film with nearly fully ionized platinum, and this coating increased the specific power of carbon nanotube anodes (Fig. 1) a thousandfold in a hydrogen-saturated PEM fuel cell when compared to standard anodes catalyzed by commercial platinum-ruthenium nanopowder.
2) *Self-organized nanowires of tungsten oxide*, which have been grown on muscovite mica (Fig. 2). Based on experiments, we developed a growth model for the well-controlled fabrication of single-wire nanosensors by electron beam lithography on potassium-doped silicon.

Magnetic nanostructures are prepared by advanced chemical methods at our Department of Condensed Matter Physics, yielding high quality nanocrystals. Magnetic nanoparticles find a wide range of applications in the IT industry and medicine, including magnetic resonance imaging, drug delivery and tumor treatment (Fig. 3). The paramount goal of this research is the design of nanomaterials that simultaneously exhibit multiple functional properties, for potential use in cooling, electronic memory devices and other applications. Another crucial goal is the development of composite nanostructures comprising several different materials, such as carbon nanotubes and magnetic coatings, magnetic carriers and photonic materials, and so on. Currently the most attractive ones are ferrites like cobalt ferrite or magnetite. We are also researching the excellent catalytic properties and potential ferromagnetic-semiconducting behavior of binary oxides such as cerium oxide and titanium oxide.

Nanocomposite films that could find use in biomedicine are under investigation at our Department of Macromolecular Physics. These films, made of metal or metal oxide inclusions in plasma polymer matrices, are deposited by low-pressure reactive plasmas. One example is composed from a 150-nanometer-high carpet of inclined titanium nano-

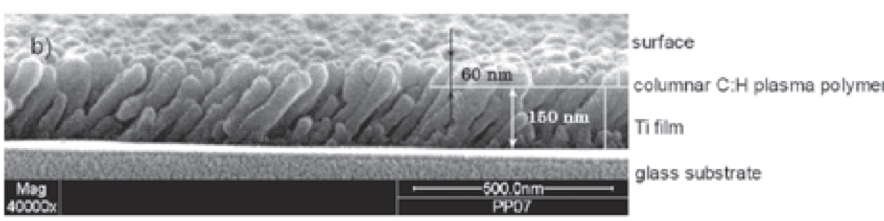


Fig. 4: The SEM image of the hydrocarbon plasma polymer nanocolumns deposited by the GLAD system based on RF magnetron sputtering of Polypropylene (the total Ar gas pressure 0.15 Pa, the deposition angle 75°) on Ti nanocolumns pre-prepared with the same angle of 75°.

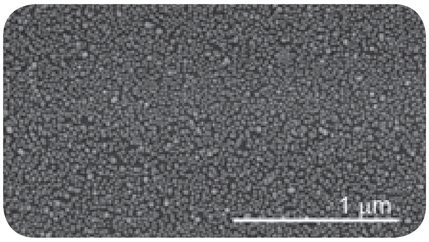


Fig. 5: Typical SEM image of SERS-active system prepared from immobilized gold nanoparticles.

columns topped by hydrocarbon plasma polymer nanorods (Fig. 4).

Nanoparticle systems for studies of biomolecules and complexes of organic molecules are prepared at our Institute of Physics. When stuck onto a rough metal surface, nanoparticles can dramatically enhance a form of light scattering known as the Raman effect by up to 100-trillion-fold in special cases. This Surface Enhanced Raman Scattering allows researchers to detect very low amounts of molecules, down to even single molecules. Recently, we have designed and optimized stable and highly reproducible surfaces made from chemically prepared gold or silver colloidal nanoparticles attached on a glass plate via a self-assembled organosilane monolayer (Fig. 5).

The determination of the real structures of nanosystems by scattering and spectroscopic methods using X-rays and synchrotron radiation is a principal objective of the structure analysis group of our Department of Condensed Matter Physics. The main effort there is focused on semiconductor thin layers, quantum wires and dots, semiconductor, dielectric, and metallic nanoclusters embedded in an amorphous matrix, as well as other systems. Some examples include:

1) *A new way towards magnetic semiconductors with tunable magnetic properties.* Elastic displacements can affect the direction in which magnetic fields are oriented in thin layers of gallium manganese arsenide where periodic lateral gratings are prepared via lithography. By comparing measured and simulated data, the scientists are reconstructing how such magnetic effects are achieved (Fig. 6 and 7).
2) *Semiconductor germanium nanoclusters in amorphous matrices* have potential applications in photonics and photovoltaics. We are researching factors critical to the photoelectronic performance of these nanostructures, including the dispersion of their sizes, their crystalline quality and the widths of the amorphous barriers between the nanoclusters.

Ultrafast femtosecond laser spectroscopy is used by our Department of Chemical Physics and Optics to follow and test the dynamics of spin orientations in charge carriers in semiconductor nanocrystals and films made of cadmium sulfide, silicon, diamond, type III-V semiconductors and ferromagnetic semiconductors such as gallium manganese arsenide.

Positron annihilation spectroscopy is a unique technique applied at our Department of Low Temperature Physics to investigate vacancies, voids and other defects in materials. This method takes advantage of the fact that positrons get trapped at open-volume defects. When they do so, they annihilate nearby electrons and generate gamma rays, analysis of which provides information on the concentrations of defects in a material. Positron annihilation spectroscopy is an especially suitable tool for characterizing nanocrystalline materials, as demonstrated by:

1) *Bulk ultrafine-grained metals*, where defects created by severe plastic deformation play a critical role in their extraordinary material properties.
2) *Materials promising for hydrogen technologies*, where we study the hydrogen interaction with defects to understand how to load more of the fuel into materials such as niobium films (Fig. 8).

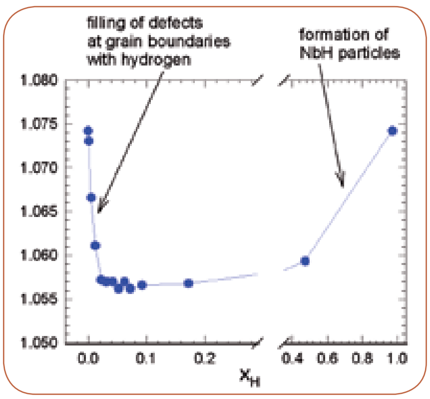


Fig. 8: Dependence of the defect density S on the hydrogen concentration x_H introduced into the film.

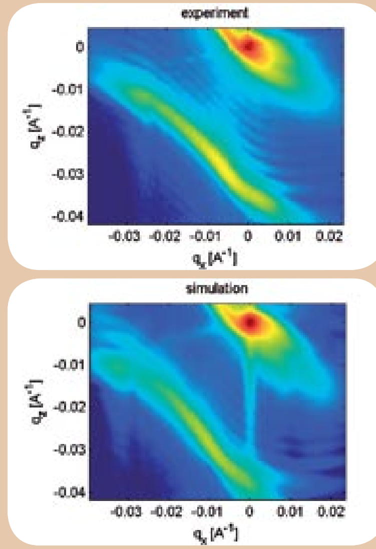


Fig. 6: Measured (*top*) and simulated (*bottom*) distribution of diffracted x-ray intensity in reciprocal space, periodic grating of wires lithographically prepared in a thin layer of (Ga,Mn)As.

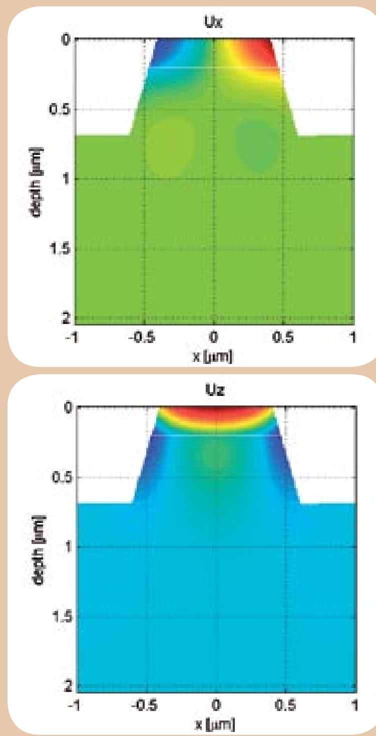


Fig. 7: Lateral (*top*) and vertical (*bottom*) components of the elastic displacement field in a cross-section of a single (Ga,Mn)As wire obtained from the map of diffracted intensity shown in Fig. 6.

THE RISE AND FALL of nanobacteria

Once believed to be the smallest pathogens known, nanobacteria have now proved to be something almost as strange. They do play a role in health—just not the one originally thought

By John D. Young and Jan Martel

KEY CONCEPTS

- Discoveries of purported nanoscale bacteria caused shock and excitement because the organisms seemed too small to live.
- Claims for the tiniest of pathogens outpaced scientific validation until the authors and other scientists showed that although the particles appeared alive, in fact they were merely aberrant crystallizations of minerals and organic molecules.
- The mineral-protein interactions that produce the nanoparticles nonetheless reveal details of processes that can protect or undermine human health.

—The Editors

Evidence of life on Mars, even if only in the distant past, would finally answer the age-old question of whether living beings on Earth are alone in the universe. The magnitude of such a discovery is illustrated by President Bill Clinton's appearance at a 1996 press conference to announce that proof had been found at last. A meteorite chipped from the surface of the Red Planet some 15 million years ago appeared to contain the fossil remains of tiny life-forms that indicated life had once existed on Mars.

Geologic research showing that similar creatures, smaller than any beings previously encountered or even imagined, could have shaped Earth's early terrain suggested these specimens might be relics from the very dawn of life. The only news that could top such findings would come next: evidence that those ancient entities, which would come to be known as nanobacteria, were still among us—indeed, dwelling in our own bodies and potentially causing a range of illnesses.

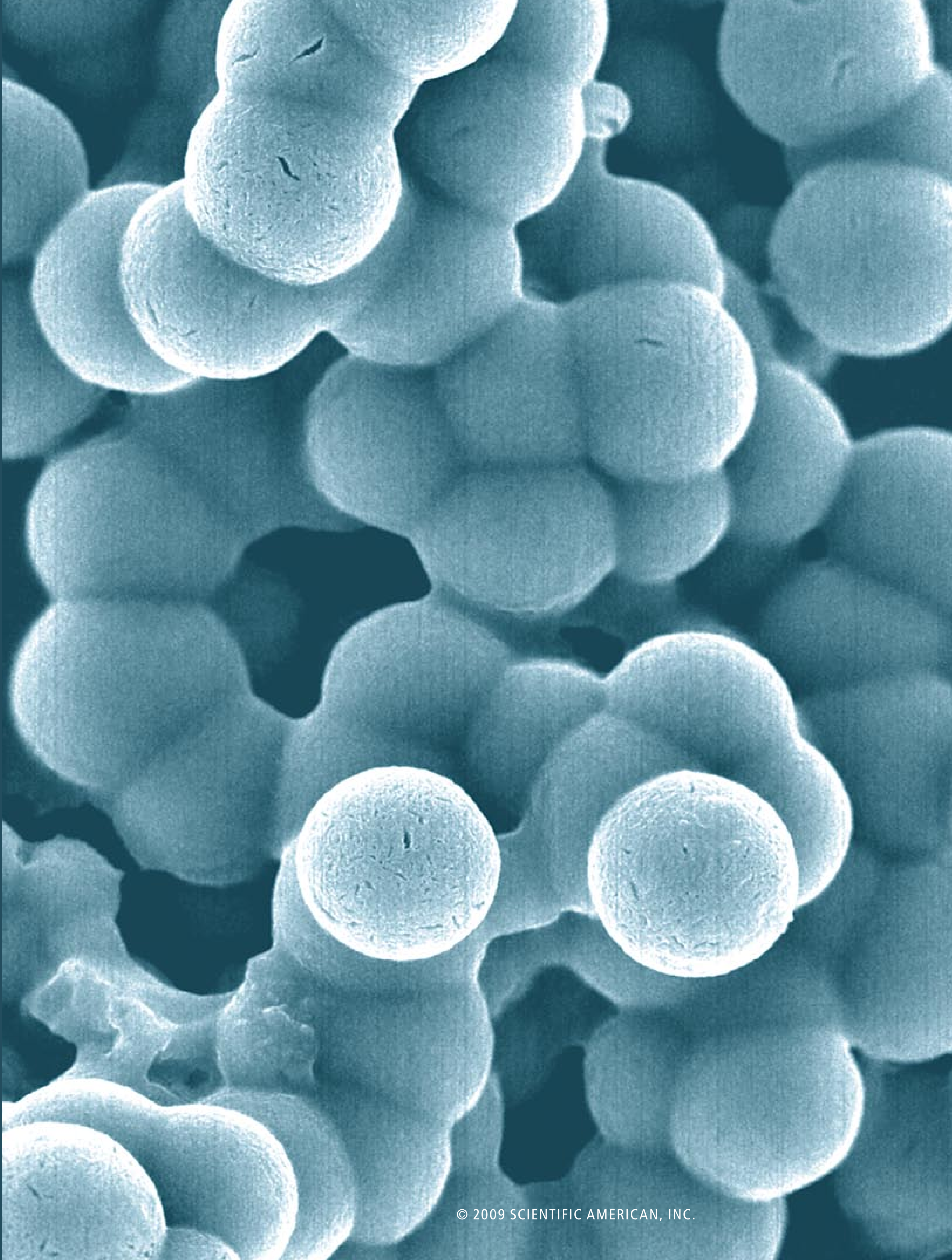
When these collective findings first appeared, plenty of scientists were skeptical, and many signs pointed to the possibility that the discoverers' excitement was outpacing scientific validation of the data. Questions remained about what nanobacteria actually were and what they were not. After more than a decade, understanding of these infinitesimally small particles and their bizarre lifelike behavior has advanced considerably. As it turns out, nanobacteria are not exotic new pathogens—in fact, they are not alive at all. They are no less important to human health, though, and could have played a role in the early evolution of life—just not the one previously assumed.

The evolution of the nanobacteria saga thus offers lessons about how science works and how it can go awry. And like any good story, its real-life ending is even more interesting than the fictional one. Now investigators can move forward to use our knowledge about these nanoentities in advancing human health and nanomaterials research.

Too Tiny for Life?

In 1993 Robert L. Folk, a geologist at the University of Texas at Austin, had been working with rock specimens collected in the Italian hot springs of Viterbo when he first reported what he called "nannobacteria." While examining his samples with an electron microscope, Folk found small spheres that resembled the

NANOPARTICLES FORMED by the binding of proteins to crystallizing mineral ions resemble budding bacterial cells under an electron microscope.



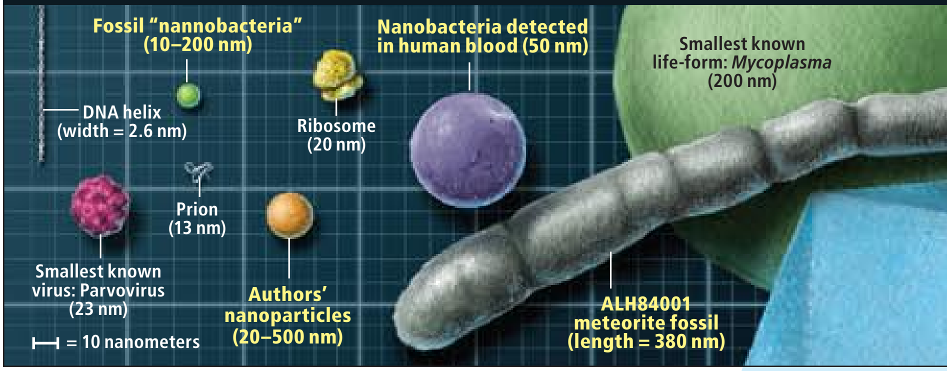
fossilized remains of bacteria. Like bacteria, these little blobs appeared to have cell walls and filamentous surface projections. Folk's spheres were quite small, however, significantly smaller than any known bacteria.

Bacteria themselves normally measure in microns—one micron is a millionth of a meter, which is roughly 100th of a typical hair's width. The fossils observed by Folk were some five to 100 times as small as common bacteria, ranging between 10 to 200 nanometers (one nanometer equals 1,000th of a micron). Folk obtained these nanoentities from the remains of ancient geologic beds, including those from the Paleozoic and Mesozoic periods, considered to have preceded the era of life on Earth. As a result, he proposed that the creatures' cycling of both organic and inorganic matter could have formed the very geologic strata in which they were found.

Folk's findings went largely unnoticed until 1996, when David S. McKay of the NASA Lyndon B. Johnson Space Center in Houston published evidence that a Martian meteorite discovered in Antarctica, ALH84001, carried similar nanofossils. Believed to have been formed from molten material some 4.5 billion years ago, the rock is one of the oldest in the solar system. In addition to finding tiny carbonate spheres resembling Folk's nannobacteria in the meteorite specimen, McKay and his colleagues also detected magnetite and iron sulfide particles, along with polycyclic aromatic hydrocarbons—all raw materials involved in biological processes. These findings were heralded as groundbreaking evidence pointing to the possibility of previous life on Mars and elsewhere in the solar system.

[THE CLAIM]

THE SMALLEST LIFE-FORM



Critics noted that all the claims for these tiniest of creatures had so far been based only on their appearance.

The McKay report, and consequently the earlier Folk studies, were met with great media fanfare but also with great doubt and controversy in scientific circles. Critics noted that all the claims for these tiniest of creatures had so far been based only on their appearance, with no evidence of their ever having been alive. Moreover, the nanoentities unleashed debates on the minimal size required to support life in a unicellular organism. Given that a double strand of DNA is more than two nanometers in diameter, and the protein-manufacturing ribosomes of a

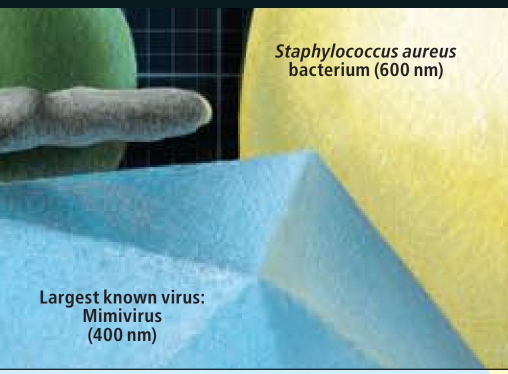
ALLAN HILLS 84001 (*above*), a meteorite discovered in Antarctica, contains nanoscale spheres and elongated formations (*left*) made of carbonate, as well as elements that serve as raw material for life processes.

[THE IMPLICATIONS]

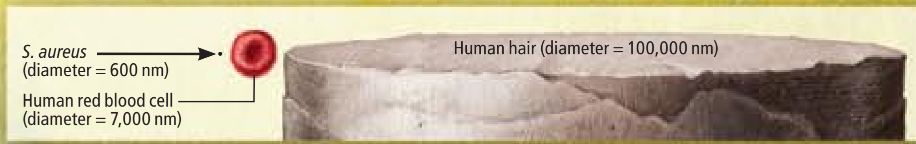
Early Excitement

Carbonate structures thought to be the fossil remains of nanoscale bacteria were first reported in 1993. The spheres identified by geologist Robert L. Folk in rock specimens from Italy (*right*) were 10 to 200 nanometers across. But their discovery received little attention until 1996, when NASA scientists announced finding similar fossils in a meteorite that had originated on Mars (*left*). The prospect of a rock more than four billion years old containing evidence of extraterrestrial life garnered worldwide attention. The potential import of the find prompted President Bill Clinton to comment: "Today rock 84001 speaks to us across all those billions of years and millions of miles. It speaks of the possibility of life. If this discovery is confirmed, it will surely be one of the most stunning insights into our universe that science has ever uncovered."

COURTESY OF JOHN D. YOUNG AND JAN MARTEL (*preceding page*); TRAVIS HEYING *AFP/Newscom* (*meteorite*); COURTESY OF NASA (*SEM*); COURTESY OF ROBERT L. FOLK *University of Texas at Austin* (*calcite crystal*)



SENSE OF SCALE: The possibility of nanoscale organisms was a radical proposition when it was put forth by several groups in the 1990s because the tiny creatures seemed improbable, if not impossible. Fossil "nannobacteria" and "living" nanobacteria identified in laboratory cell cultures ranged from 10 to 500 nanometers (nm) in diameter. Most of these specimens appeared too small to contain and operate sufficient machinery necessary for cellular life, such as protein-making ribosomes, which are themselves 20 nm across, and were tinier than even the smallest known life-form—the *Mycoplasma* bacterium.



cell are some 20 nanometers across, critics questioned whether a nanoscale "cell" could possibly contain the equipment needed to live.

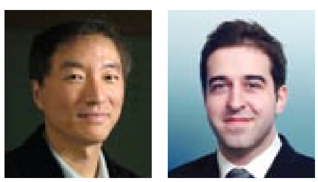
At the height of this controversy, two scientists at the University of Kuopio in Finland, E. Olavi Kajander and Neva Çiftçioğlu, would ignite an even greater debate. In 1998 the Finnish team provided the first evidence for nanobacteria as living entities. The researchers had been examining small "contaminants" in their cell cultures that proved resistant to all efforts at elimination. Not only were these particles making the cultured cells sick, they appeared to resist the usual sterilizing techniques of heat, detergent and antibiotic treatments. Observing the tiny spherical bodies under an electron microscope, Kajander and Çiftçioğlu found that they ranged in size between 50 and 500 nanometers and were so strikingly similar to Folk's nannobacteria, they must be one and the same.

The Smallest Pathogens

On closer examination, the Finnish researchers found nucleic acids and proteins in the small particles—signs of life. Based on the specific sequences of DNA in the specimens, the scientists assigned their discovery, which they named *Nanobacterium sanguineum,* to a subgroup of bacteria that includes *Brucella* and *Bartonella,* both of which have been shown to cause disease. The Finnish group also noted unusual features of the nanobacteria, including their ability to change shapes in culture, a property known as pleomorphism, which is a rare trait in living organisms. The nanobacteria were seen to change from small spherical bodies to films and clumps of mineralized material. The mineral in question turned out to be hydroxyapatite (apatite), a crystalline complex of calcium and phosphate found everywhere in nature, including mammalian bones as well as the shells of some invertebrates.

COURTESY OF LIN SHOU-SHENG *Taiwan Tatler* (*Young*); COURTESY OF JAN MARTEL (*Martel*); JEN CHRISTIANSEN (*Illustration*)

[THE AUTHORS]



John D. Young is chair of Chang Gung University (CGU) and Mingchi University of Technology in Taiwan and head of the CGU Laboratory of Nanomaterials. He is mainly interested in understanding the interactions of organic with inorganic materials and how they affect health. Young was head of the Laboratory of Molecular Immunology and Cell Biology at the Rockefeller University, where he remains an adjunct professor. **Jan Martel** is a doctoral candidate at the Graduate Institute of Biomedical Sciences at Chang Gung University. Originally from Sherbrooke, Quebec, he joined Young's group in Taiwan to investigate blood-borne pathogens and the potential bases for alternative therapies.

The small, round nanobacteria were not only covered by apatite walls but were often found hiding within large "igloo-shaped castles" or "dwelling places," the researchers wrote.

Attempting to identify the source of nanobacteria, the Finnish team was surprised to find the creatures in most animal and human body fluids they examined—blood, saliva and urine, among others—and concluded that the tiny bugs posed a risk for diseases involving abnormal mineral agglomerations, such as kidney stones. Eventually conditions linked by various researchers with nanobacteria would expand to include many types of cancer, atherosclerosis, degenerative diseases such as arthritis, scleroderma, multiple sclerosis, peripheral neuropathy, Alzheimer's disease, and even viral infections such as HIV. Initial studies by the Finnish team had shown that 14 percent of healthy Scandinavian adults tested positive for antibodies against nanobacteria. Other scientists, such as Andrei P. Sommer of the University of Ulm in Germany, would later promote the idea that nanobacteria behave as transmissible pathogens, incriminating nanobacteria as a global health hazard.

Despite all these frightening implications, in many ways nanobacteria fulfilled the wildest dream of every scientist. Their very primitive nature, unusual characteristics and ubiquitous distribution suggested that nanobacteria might help explain the origins of life—not only on Earth but elsewhere in the cosmos. Moreover, they could represent a new unifying disease principle by virtue of being associated with practically every disease process imaginable, an unprecedented scenario. For all the extraordinary characteristics attributed to nanobacteria, however, many critics remained unconvinced. One who still deemed nanobacteria too small to be true, Jack Maniloff of the University of Rochester Medical Center, labeled them "the cold fusion of microbiology."

By 2000 research led by John O. Cisar of the National Institutes of Health provided the first alternative view of nanobacteria. Cisar found that phospholipids—common components of cell membranes—would bind to both calcium and phosphate, fostering the formation of calcium-phosphate (apatite) crystals. The small crystalline clumps seeded this way bore an uncanny resemblance to the nanobacteria described by the Finnish group. Remarkably these same crystalline blobs were seen to grow and replicate in the test tube as if they were alive. As for the presence of unique nucleic acid sequences that had been previously identified as hallmarks of nanobacteria, the Cisar study demonstrated that these same sequences could occur in the genomes of common bacteria that often contaminate laboratory reagents and glassware.

The nanobacteria fervor started to lose momentum. Then suddenly in 2004, a Mayo clinic team led by Virginia Miller and John C. Lieske claimed to have found nanoparticles in specimens of calcified blood vessels that not only harbored DNA and proteins but also seemed to synthesize RNA, the intermediate molecules that all living things use to convert DNA instructions into cellular proteins. Overnight, the nanobacteria debate, along with all the familiar controversies and media attention, was reignited.

Heralded as prototypes of a new mechanism of disease, perhaps resembling prions—the proteinaceous particles responsible for such conditions as mad cow disease—nanobacteria were now a threat to public health, which opened avenues for commercial interests to begin selling methods to detect and treat the tiny pathogens. Nanobac OY, a company founded by the Finnish scientists who had first discovered "living" nanobacteria, became a major supplier of diagnostic reagents, including antibodies, designed to detect nanobacteria in human tissues. Later, Nanobac Pharmaceuticals, a Florida company that absorbed Nanobac OY in 2003, became a provider of medicines for nanobacteria "infections."

Building Nanobacteria

Intrigued by the extraordinary claims and counterclaims about the behavior of nanobacteria, our research group embarked in 2007 on a series of experiments to dissect the particles' chemical and biological nature. Before discussing the possible roles of these nanoparticles in disease, we thought, scientists must first establish what the particles are and what they are not, including whether they are really alive. Toward that end, we set out to see if nanobacteria could be replicated with nonliving materials.

We worked with simple calcium compounds such as calcium carbonate (limestone) and calcium phosphate, knowing that they have a natural tendency to aggregate in a precise molecular pattern to form crystals. Crystals are highly ordered, self-nucleating structures similar to geometric prisms, with flat surfaces and sharp edges. If their growth is disturbed or interrupted, however, they can take on dramatically different properties. We hypothesized that doping the minerals with proteins and other nonmineral compounds would disrupt the precise order of lattices needed for crystal seeding, leaving the mineral aggregates amorphous—organized in a random or disorderly manner at the molecular level.

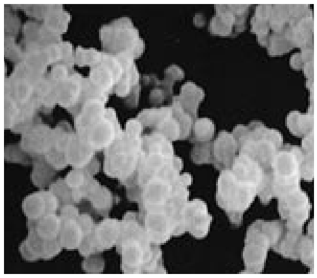
We also thought this disruption would simply abort the mineral aggregates' growth as crystals. Surprisingly, these mineral agglomerations continued to grow and to propagate as particles, or more precisely, as nanoparticles. We certainly did not expect that such simple compounds would readily assume shapes and geometries that make them look virtually identical to nanobacteria, acquiring cell-like walls and appearing to divide just like living bacteria. Using these simple nanoparticle constructs as a springboard, we then proceeded to attempt to reconstruct the entire nanobacteria biology. That is, we tried to see whether all the exotic properties of nanobacteria already described by other scientists could actually be reproduced through the interaction of simple organic molecules and minerals.

It soon became clear that the nanoparticles made of calcium carbonate–phosphate mixtures are rather sticky. They bind avidly to any charged molecules, whether ions, small organic compounds (such as carbohydrates), lipids, or even DNA and other nucleic acids. Binding to charged groups stabilizes the growing particles, giving them structural integrity and impelling the calcium particles to continue to grow and assume complex shapes. Eventually, however, one of two scenarios prevails. If excess minerals are available, the particles will finally crystallize into apatite. But if the organic compounds available exceed the local amount of minerals, crystallization may cease altogether or will continue slowly, with the particles continuing to evolve into more complex forms.

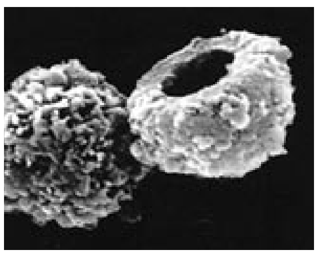
Among the charged groups we studied, the most interesting and complex effects were produced when proteins were the binding agents. Proteins roam freely in the body. Some proteins,

LOOKING ALIVE

Finnish scientists Olavi Kajander and Neva Çiftçioğlu claimed in 1998 to have discovered nanoscale bacteria whose calcium phosphate coatings created mineral structures thought to reflect the changing shapes and activities of the proliferating organisms.



In the Finnish group's experiments, mineralized particles slowly multiplied and grew to sizes ranging in diameter from 20 to 500 nanometers in cell culture dishes.



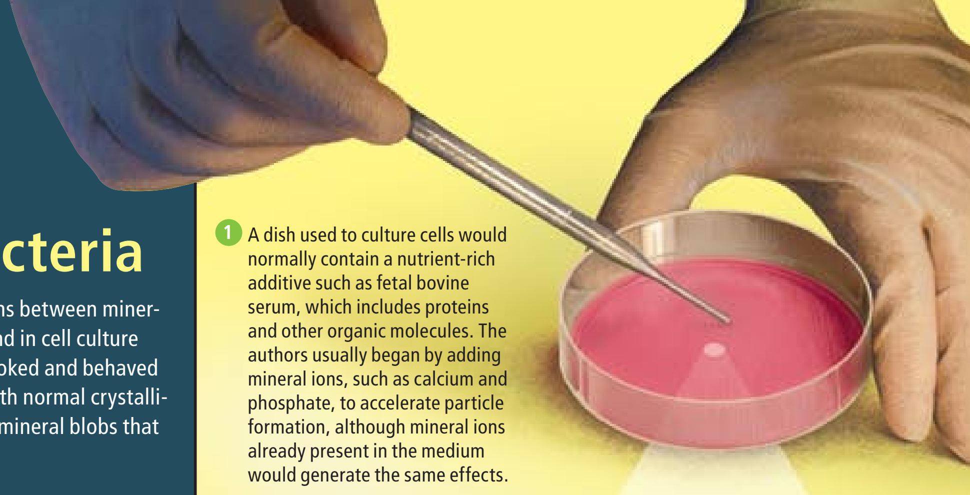
Empty hydroxyapatite structures seen in the cultures were characterized as "dwellings" made by the nanobacteria from accumulated minerals.

THIS PAGE: "NANOBACTERIA: AN ALTERNATIVE MECHANISM FOR PATHOGENIC INTRA- AND EXTRACELLULAR CALCIFICATION AND STONE FORMATION," BY E. OLAVI KAJANDER AND NEVA ÇIFTÇIOĞLU, IN *PNAS*, VOL. 95, NO. 14; JULY 7, 1998 (*mineral structures*); OPPOSITE PAGE: COURTESY OF JOHN D. YOUNG AND JAN MARTEL (*top three micrographs*); "PUTATIVE NANOBACTERIA REPRESENT PHYSIOLOGICAL REMNANTS AND CULTURE BY-PRODUCTS OF NORMAL CALCIUM HOMEOSTASIS," BY JOHN D. YOUNG ET AL., IN *PLOS ONE*, VOL. 4, NO. 2; FEBRUARY 9, 2009 (*bottom two micrographs*); JEN CHRISTIANSEN (*illustration*)

[A CLOSER LOOK]

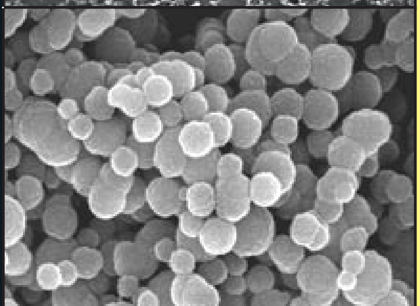
Recipe for Nanobacteria

Experiments by the authors revealed that interactions between minerals, proteins and other inert molecules typically found in cell culture media could produce particles (*micrographs*) that looked and behaved just like putative nanobacteria. Proteins interfere with normal crystallization of mineral ions, yielding instead amorphous, mineral blobs that grow and change shapes, as living things might do.



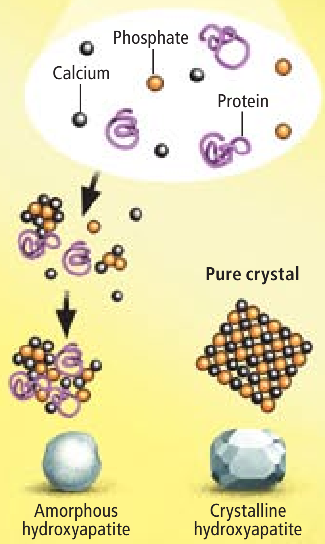
1 A dish used to culture cells would normally contain a nutrient-rich additive such as fetal bovine serum, which includes proteins and other organic molecules. The authors usually began by adding mineral ions, such as calcium and phosphate, to accelerate particle formation, although mineral ions already present in the medium would generate the same effects.

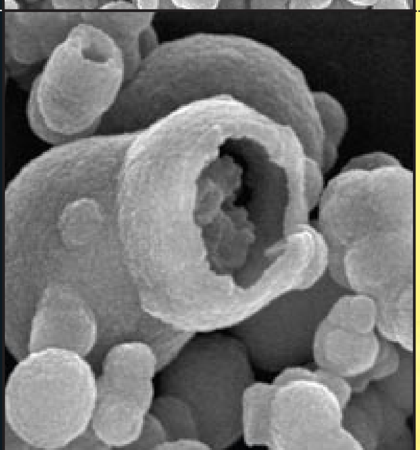
Within hours after ions are added to cell culture medium, nanoparticles 20 to 50 nanometers in diameter are visible by electron scanning microscope.



These particles, each 100 to 500 nanometers, could resemble living cells because of their uniform shapes and sizes. They do resemble purported nanobacteria.

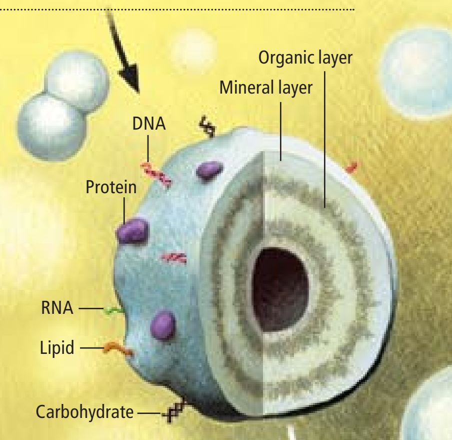
2 Calcium and phosphate ions naturally bind together to form larger mineral particles of calcium phosphate (hydroxyapatite); however, certain proteins also avidly bind calcium and interfere with this crystallization process. Instead of an orderly lattice structure typical of pure hydroxyapatite crystals (*far right*), the resulting mineral-protein particles have an amorphous molecular structure and visible shape.





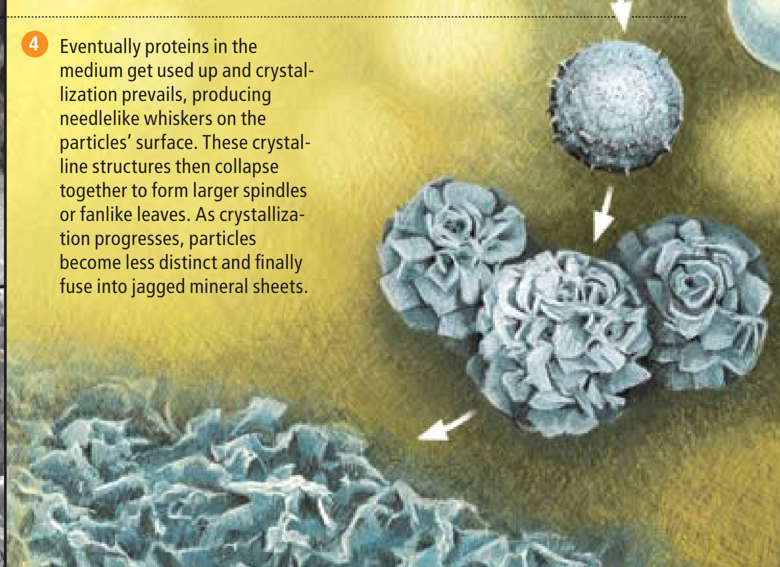
By the time particles reach several hundred nanometers in diameter, their continued fusion creates odd shapes and sometimes the appearance of dividing cells.

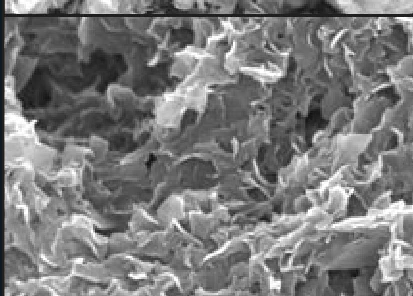
3 As the particles continue to grow by the accretion of layers of mineral-protein material, they may also fuse into larger particles and adopt diverse shapes. In addition to minerals and serum proteins, the particles incorporate any other readily available molecules in the culture medium. This organic material provides structural support for the particles' continued growth.



Crystallization is prevailing in these particles, each 600 nanometers wide, producing sharp-edged mineral petals.

4 Eventually proteins in the medium get used up and crystallization prevails, producing needlelike whiskers on the particles' surface. These crystalline structures then collapse together to form larger spindles or fanlike leaves. As crystallization progresses, particles become less distinct and finally fuse into jagged mineral sheets.





Finally, the mineralized particles collapse into solid mats that will eventually cover the entire bottom of the culture dish.

such as albumin or fetuin-A, are present in large amounts in the blood and are also avid binders of calcium. Albumin alone accounts for half of the calcium-binding capacity of blood serum. Fetuin-A is even more unusual in that it binds not only to calcium but also strongly to calcium phosphate in the form of nascent apatite.

The ability of these proteins to bind nascent apatite crystals is well known to abort further crystallization and thereby protect against unwanted mineralization of body tissues. Considering the fact that all body fluids, including blood, contain supersaturated concentrations of calcium and phosphate yet do not undergo spontaneous calcification, the protection offered by these proteins is clearly important. Without it, blood vessels would become hardened, and bony formations would crop up everywhere.

The growing nanoparticles simply hijack any readily available proteins in their surrounding environment.

As we were pursuing this line of inquiry, an independent study led by Didier Raoult of the Medical School of Marseille in France gathered important evidence indicating that the main protein detected in nanobacteria turned out to be fetuin-A. Our own experiments later showed that fetuin-A is only one of several proteins found embedded in the calcium nanoparticles. Others include albumin, lipid-binding proteins known as apolipoproteins, complement proteins, and many common proteins that are normally abundant in the blood and that are all well known to avidly bind calcium and apatite. In essence, our tests indicated that the growing nanoparticles simply hijack any readily available proteins in their surrounding environment that are capable of binding to calcium and apatite.

We were also able to show that the antibodies sold as diagnostic tools for nanobacteria by the Nanobac group of companies are in fact detecting fetuin-A and albumin. Thus, the earlier studies using the Nanobac antibodies to find nanobacteria in human tissue cultures were actually detecting common blood proteins. More alarmingly, the antibodies purported to detect exotic nanobacterial proteins in human blood were actually specific to the versions of those proteins in the cow. As bizarre as this discovery may sound, it can be easily explained by the fact that laboratories generally include fetal bovine serum, an excellent source of nutrients, in cell culture media. In the case of nanobacteria cultures, however, this serum is also a main source of the proteins integrated into the particles, leaving a final bovine imprint on the nanoparticles. In retrospect, the numerous studies claiming to have detected nanobacterial proteins with these antibodies can now be seen as fundamentally flawed.

What's Really Going On

Although nanobacteria have now been conclusively shown to be nonliving nanoparticles crystallized from common minerals and other materials in their surroundings, these nanoentities may still play an important role in human health. We believe that nanobacterialike particles are generated through a natural process that normally protects the body against unwanted crystallization but that can also promote nanoparticle formation under certain conditions.

Many minerals aggregate spontaneously in nature and may even display a tendency to crystallize. Calcium, for example, avidly binds car-

[MECHANISM]

MINERAL MANAGEMENT

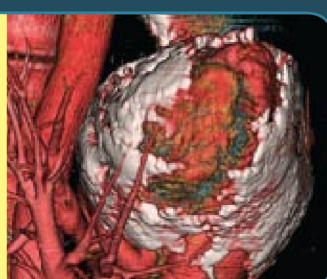
Aggregates of nanobacterialike particles may resemble the calcified deposits seen in human tissues because both arise from natural mineralo-protein interactions responsible for mineralizing teeth and bone and for inhibiting unwanted calcification. Abnormal tissue calcifications are often a symptom, rather than a cause, of disease; however, when abnormal calcification becomes advanced, it can produce illnesses such as kidney stones.

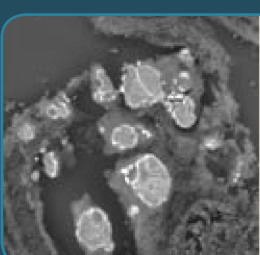
NORMAL MINERALIZATION

Bone formation requires 10-nanometer hydroxyapatite spheres to fuse into strings of mineral beads interwoven among collagen fibers. These apatite building blocks gradually coalesce into fibers, then into mineralized mats that envelop the collagen scaffold, giving bone its tensile strength.

HARDENED HEARTS

Calcified deposits (*white*) in the heart and arteries form by the same mineralization mechanisms as bone and are a sign of cardiovascular disease. The calcifications are believed to be a response to tissue injury and may halt or recede if the underlying disease is treated.





CAUSE OR EFFECT?

Tiny calcifications are seen in other parts of the body, such as this sample of nonmalignant tissue from a human thyroid affected by cancer. The calcium-phosphate structures may reflect a failure of normal mineral clearance processes in the diseased tissue. Another possibility is that the mineralizations are seeded by foreign particles, such as pollutants, a theory that remains to be tested.

MEDICAL BODY SCANS *Photo Researchers, Inc.* (*bone*); OLIVIER VOISIN *Photo Researchers, Inc.* (*heart*); COURTESY OF ANTONIETTA M. GATTI *University of Modena and Reggio Emilia* AND STEFANO MONTANARI *Nanodiagnostics Srl* bonate and phosphate to form crystals of calcite and apatite. Any molecule with a high affinity for calcium or nascent apatite crystals, whether a protein, a lipid or some other charged moiety, can therefore be seen as a calcification inhibitor in the sense that it will directly interfere with the process of crystallization by binding to the minerals. Inside the body, the binding of calcium and nascent crystals by proteins would also target the complexes for either storage or elimination.

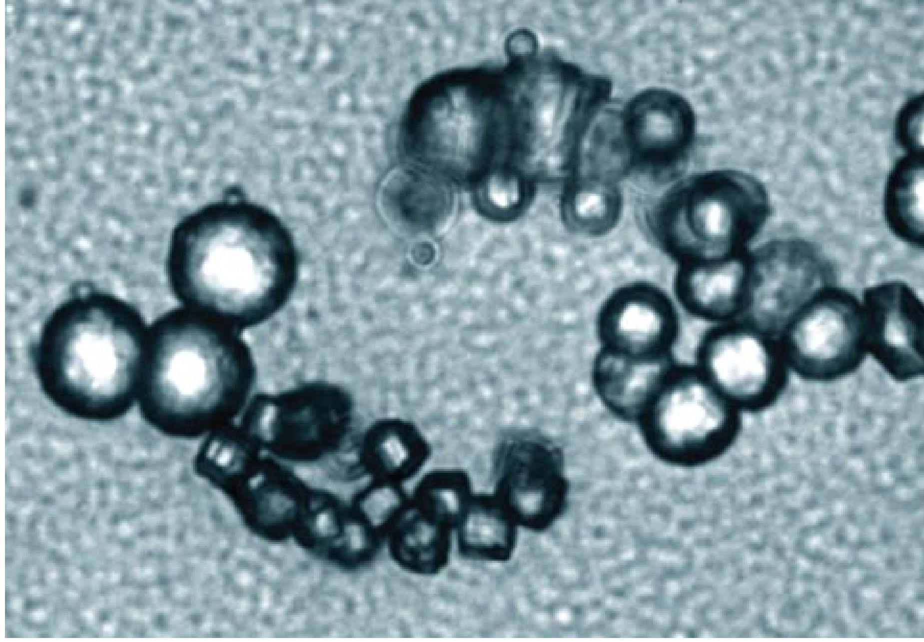
This constant clearance of the minerals serves to prevent abnormal calcium deposits that could cause disease. More proteins are continually needed to bind the minerals, however, and if the minerals come to outnumber the inhibitory proteins, the inhibitory mechanism is eventually overwhelmed. When the minerals saturate the binding sites of proteins, the protein-bound minerals can instead become seeds for further crystallization, creating a runaway process that may produce not only the phenomenon of nanobacteria but also anomalous calcification, such as stone formation and calcification of arteries. As potential agents of disease, these nanoparticles must first be viewed as parts of a larger cycle of normal calcium regulation. The mechanisms of mineral-protein complex formation described here are certainly involved in normal bone formation as well. Rather than being the cause of ailments involving abnormal calcification, therefore, the calcified deposits may be the end result of other metabolic anomalies that affect mineral inhibition and clearance.

It is too early to know how these insights may be translated into therapeutic approaches. This inhibition/seeding concept can probably explain the entire body of prior observations about nanobacteria, however. By growing in size through fusion, for instance, these mineral-protein spheres evolve and coalesce into spindles and, eventually, films. Those shape changes can now be documented and explained by the simple interaction of proteins and minerals, with mineralization finally winning out. According to our hypothesis, nanobacterialike particles arise in culture dishes because the dynamic clearance mechanisms operating in the body are absent. The nanobacteria described in cell cultures may now be seen as simple by-products of normal calcium metabolism under static conditions.

All the nanobacteria particles that we were able to assemble from blood and other body fluids have demonstrated a simple and predictable chemical composition, one that mirrors the nature of the building blocks available in the surrounding medium. By changing the medium composition, we can easily alter the constitution of the nanoparticles, and today we are able to engineer nanobacterialike particles to any prescribed composition. Exploiting this process, we have been able to produce an entire family of biologically related and structurally similar ion complexes that we have termed bions. Bions come in all sizes and shapes and they can mimic biological forms that appear alive. Beyond demonstrating the nonliving nature of nanoparticles, they promise to further elucidate how building materials consisting of tiny nanoblocks are fabricated and assembled in nature.

Understanding how such small particles composed of minerals complexed with organic molecules are generated naturally may shed light on the emergence of life on Earth billions of years ago. It is conceivable that by a process of self-replication similar to nanoparticle growth, minerals complexed with small organic molecules formed the first building blocks of life and found a way of perpetuating themselves. Such mineral-organic complexes could have served to shelter and compartmentalize the earliest life-related processes and perhaps could have become the very catalytic centers needed to initiate the life processes themselves. This remains an exciting possibility, which we are currently exploring.

That such a wide array of calcifications seen in nature and in so many chronic diseases can now be at last understood in the context of molecular interactions between proteins, lipids, minerals and other discrete factors is an exciting prospect. Unlike the nanobacteria hypotheses advocated in the past, current understanding of well-defined naturally occurring mineral-organic particles will allow scientists to move forward in exploring how these tiny entities can benefit life, even if they are not themselves alive. ■



COURTESY OF JOHN D. YOUNG AND JAN MARTEL

PURE CRYSTALS of calcium carbonate can take varying shapes. Understanding how nanoparticles form naturally and how they might affect human health will help scientists to control the properties of man-made nanoparticles.

➥ MORE TO EXPLORE

Nanobacteria: An Alternative Mechanism for Pathogenic Intra- and Extracellular Calcification and Stone Formation. E. Olavi Kajander and Neva Çiftçioğlu in *Proceedings of the National Academy of Sciences USA,* Vol. 95, No. 14, pages 8274–8279; July 7, 1998.

Purported Nanobacteria in Human Blood as Calcium Carbonate Nanoparticles. Jan Martel and John Ding-E Young in *Proceedings of the National Academy of Sciences USA,* Vol. 105, No. 14, pages 5549–5554; April 8, 2008.

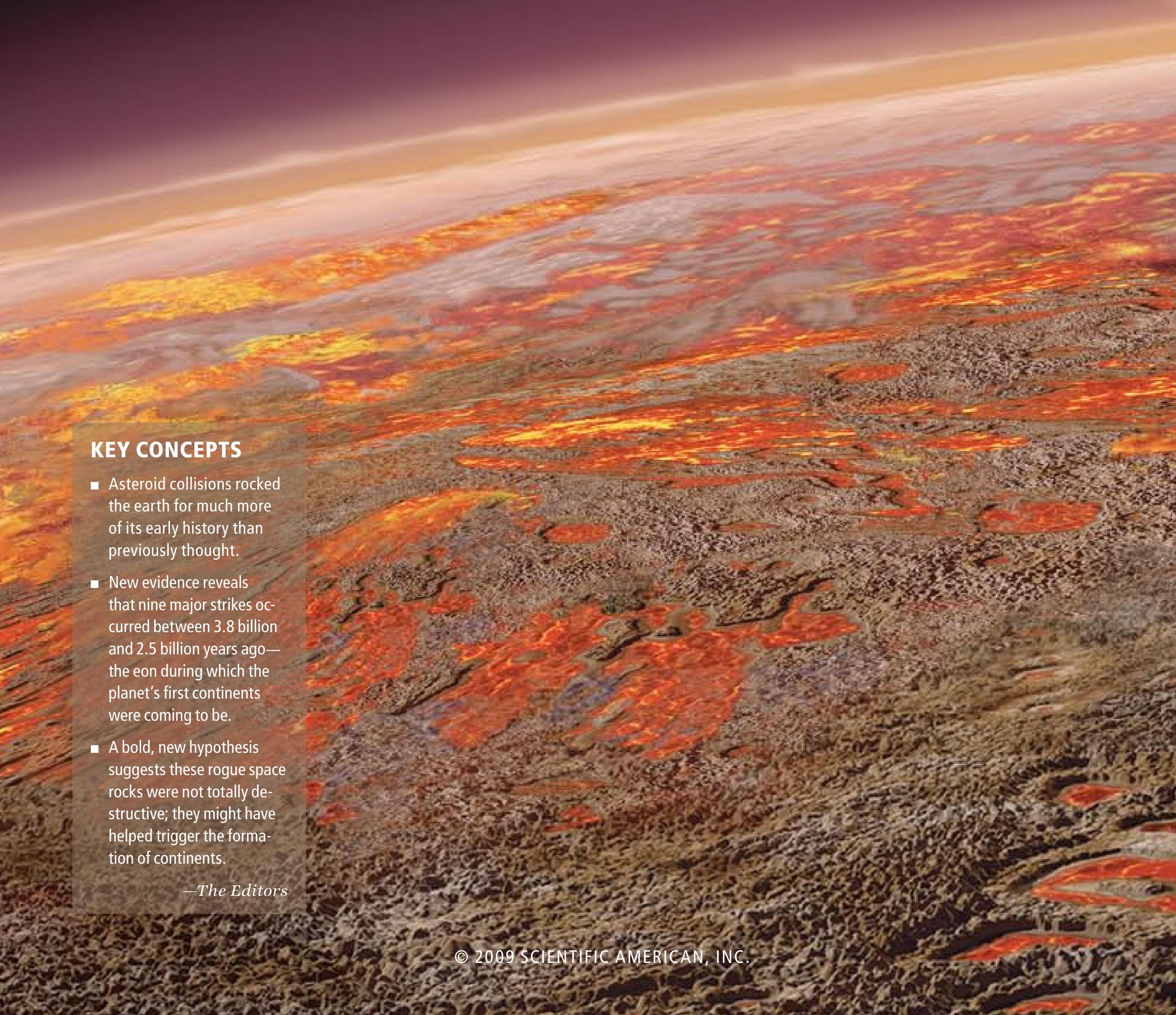
Putative Nanobacteria Represent Physiological Remnants and Culture By-products of Normal Calcium Homeostasis. John D. Young et al. in *PLoS ONE,* Vol. 4, No. 2, page e4417; February 9, 2009.

Characterization of Granulations of Calcium and Apatite in Serum as Pleomorphic Mineralo-Protein Complexes and as Precursors of Putative Nanobacteria. John D. Young et al. in *PLoS ONE,* Vol. 4, No. 5, page e5421; May 1, 2009.

VIOLENT ORIGINS *of*

Did asteroid strikes during the earth's youth spawn the earliest fragments of today's landmasses?

By Sarah Simpson



KEY CONCEPTS

- Asteroid collisions rocked the earth for much more of its early history than previously thought.
- New evidence reveals that nine major strikes occurred between 3.8 billion and 2.5 billion years ago—the eon during which the planet's first continents were coming to be.
- A bold, new hypothesis suggests these rogue space rocks were not totally destructive; they might have helped trigger the formation of continents.

—The Editors

CONTINENTS

Roiling, incandescent magma and boiling gases covered the earth in the wake of its formation 4.6 billion years ago. Regions of this fiery sea eventually cooled enough to crust over, leaving the planet's first hard rocks floating like slag on the white-hot liquid. But they were nothing more than a thin veneer. The thick roots of terra firma were much longer in the making.

Exactly how—and how quickly—continents arose and grew is a matter of ongoing debate. Scientific wisdom long held that the earth's inner workings alone drove continent formation. But recent findings have turned the spotlight toward a once heretical idea: that large asteroid impacts played a constructive role as well.

A basic assumption was that asteroid bombardments—frequent during the earth's infancy—had all but petered out by about 3.8 billion years ago. By then, the planet had cooled enough for nascent oceans to harbor microscopic life. Major impacts since that time were typically considered rare and utterly destructive. (Think demise of the dinosaurs.)

Recently, though, scientists have been forced to wrestle with the discov-

DON DIXON

ery of an unexpected series of massive blows between 3.8 billion and 2.5 billion years ago, a span of the earth's youth known as the Archean eon. The crust-obliterating reputation of asteroids seems at odds with a hallmark of the Archean: it was the most productive period of continent formation in all of earth history. By some estimates, 65 percent of today's continental crust came into being during that time.

Attempting to reconcile this apparent conundrum, geologists are scouring the ancient rock record for clues about how these colossal collisions shaped the planet. One of these geologists—Andrew Y. Glikson, a professor at the Australian National University in Canberra—has been convinced by 40 years of fieldwork that extraterrestrial impacts actually aided the growth of the planet's first continents, including ones with remnants now preserved in the ancient cores of South Africa and Western Australia.

Many scientists cast Glikson's assertion a tentative glance, arguing that direct evidence for what was happening on the ancient earth is exceedingly rare and controversial. Yet computer simulations of the potential effects of large impacts lend some intriguing support to his hypothesis. It may be too early to overhaul the classic view of the early evolution of continents, but even skeptics agree it is time to consider the earthly outcomes of these powerful forces from space.

Land, Ho!

Scientists spent decades deciphering the origin of continents before the potential influence of Archean asteroid impacts came into focus. These efforts have always been tricky because creating a continent is such a complicated process; it requires building up a slab of crust so thick and buoyant that it can no longer sink back into the earth's hot interior. That quality is what makes today's continents so different from the crust underlying the oceans. Relatively thin and dense, iron-rich ocean crust sinks easily, most of it within a mere 200 million years of its formation. Continental crust, on the other hand, is packed with lower density rocks such as granite, which have kept some ancient fragments afloat, like icebergs at sea, for nearly four billion years.

The story of the earth's first continent varies from one textbook to another, but one common version unfolds something like this:

During brief reprieves from the heavy asteroid bombardment following the planet's birth, the earth's natural tendency to cool caused the surface to crust over repeatedly. This crust was not perfectly continuous; it consisted of several dozen pieces that skidded across the ever churning magma. Like hot wax rising in a lava lamp, plumes of hot mantle rock rose up, cooled slightly as they moved across the surface, and then sank—easily dragging those original, ultradense crustal fragments down with them. Meanwhile volcanoes spewing gases from the earth's interior created a primitive atmosphere, and rain condensed out of the sky, forming shallow oceans atop the thin, crusted magma.

The embryo of a continent formed, so continues this storyline, when the heat from a rising plume partially melted a patch of the dense crust before it could sink—allowing lighter minerals, which have a lower melting point, to separate out. More buoyant than the surrounding rock,

DON DIXON

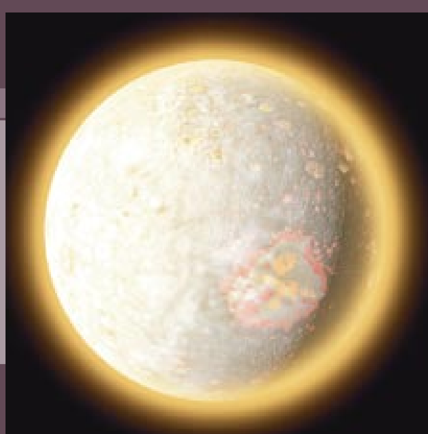
[SNAPSHOTS IN TIME]

Continents Shape Up

4.6 billion years ago

INCANDESCENT MAGMA OCEAN

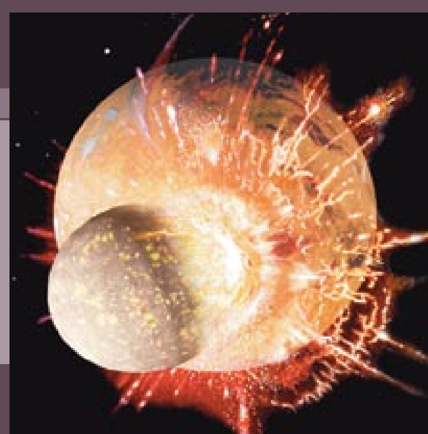
As the earth condenses from the debris swirling within the solar nebula, it is a roiling ball of magma and boiling gases.



4.5 billion years ago

HEAVY BOMBARDMENT

The planet solidifies as it loses heat. But blows by massive asteroids, one probably the size of Mars, destroy nearly all of the nascent crust.



this newly separated magma tended to rise up; once hardened, this lighter rock was less likely to sink later on.

Repeated cycles of partial melting and separation of lighter magma led eventually to the production of granite. It is impossible to know the precise timing of this process, but at least one trace from the first 160 million years of the earth's infancy remains: tiny, 4.4-billion-year-old zircon crystals eroded from a primordial granite and were later deposited within younger sedimentary rock formations in what is now Australia [see "A Cool Early Earth?" by John W. Valley; Scientific American, October 2005].

These traces of early granite were probably a minor component of the first masses of rock to grow thick enough to protrude above the early oceans. And they certainly would have been a far cry from today's continents, which cover 30 percent of the planet's surface and are on average 35 kilometers thick. Early protocontinents probably gained stature slowly, much as landmasses do today: collisions among them merged thickened crust into larger masses, and hot mantle plumes triggered surges of fresh magma from below.

By three billion years ago, most geologists agree, the earth had its first bona fide continent: a barren, volcano-strewn mound of rock almost certainly smaller than present-day Australia. It is even possible that ancient cores, or cratons, of present-day Australia and Africa were part of that original continent. Western Australia's Pilbara craton and the Kaapvaal craton of South Africa's scenic Barberton Mountain lands "are stunningly similar geologically," notes geologist Bruce M. Simonson of Oberlin College, who has spent months combing the dry, brushy, hillside outcrops of both regions. "I'm a firm believer that Barberton and Pilbara are one continent that got split in two."

Where on the globe the first continent sat is unknown, but as the earth's hot interior continued churning, that landmass split apart as others sprung up. A well-documented series of breakups and mergers of continents ensued, leading eventually to the modern arrangement.

Knowing Where to Look

The dance of crustal plates clearly explains the transition of continents from youth into adulthood. But what transpired beforehand is rife with uncertainty. That is why geologists turn to those ancient landforms in South Africa and Australia for clues about continental nativity. Compared with the cratons of other modern continents, Kaapvaal and Pilbara have undergone less metamorphism and remain some of the most well-preserved traces of Archean-aged crust. Of particular interest within these cratons are greenstone belts—rock formations that took shape between 3.5 billion and 2.4 billion years ago, right as the first continents were coming to be.

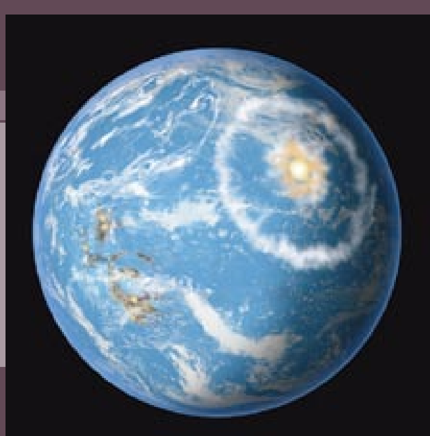
Since the 1970s most geologists have interpreted greenstone belts as ancient analogs to the strings of volcanic islands that arise along the overlapping edges of colliding crustal plates—and later become part of a continental landmass. Crustal collision continues over millions of years, and the lower plate dives ever deeper into the earth's hot interior, forming a deep trench known as a subduction zone. As the islands ride the sinking plate toward the trench, these thicker parts

By three billion years ago the earth had its first bona fide continent: a barren mound of rock strewn with volcanoes.

3.2 billion years ago

FLEDGLING LANDMASSES

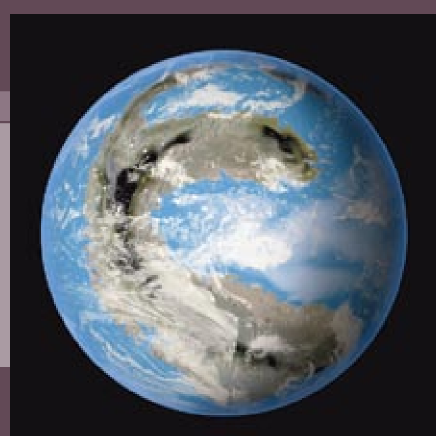
Partial melting and amalgamation of older crustal fragments have produced the first bona fide continent. Large impacts still occur, though less frequently.



1.1 billion years ago

FIRST SUPERCONTINENT

Collisions among crustal fragments merge fledgling landmasses into the earth's first well-known supercontinent, Rodinia.



Clearly, the early Archean impacts were not something the planet took lightly.

are thrust onto the side of a looming landmass; rather than being pulled down with their parent crust, they are scraped right off the top. The Sierra Nevada and other mountain ranges of the western U.S. glommed onto western North America in this way.

Yet this modern style of continental growth cannot explain all the geologic features seen in the greenstone belts, Glikson notes. When studying the South African and Australian belts in detail years ago, he found that the belts' oldest segments—those between three billion and 3.5 billion years old—all appeared to have accumulated vertically, as eroded material was laid down in layers between dome-shaped bodies of granite-forming magma pushing up from below. These formations showed none of subduction's telltale signs: sediments and volcanic material that accrued horizontally as two crustal fragments collided.

A dearth of evidence for subduction is not surprising. Most researchers agree that plate tectonics was probably less efficient in the early Archean, if it operated at all. The planet was hotter then, and so less vigorous was the lava lamp–like convection that drives plate motion. Still, something swift must have taken a hand in the formation of the oldest parts of the Archean belts, Glikson says. The specific ages of various rocks within them suggest that massive granite bodies were emplaced in a series of abrupt, well-defined episodes. But if subduction was not the driving force, what was?

These difficulties led Glikson to seek new explanations for what shaped the Archean earth. He knew that one factor most geologists had ignored was the potential effect of collisions by asteroids and comets. Asteroid bombardment peaked around 3.9 billion years ago, yet studies of moon craters indicate large impacts continued until about 3.2 billion years ago. Could those later bombardments have been involved? The first step in finding out would be identifying good evidence of such strikes on the earth. Had this evidence been destroyed, or were geologists looking at it without recognizing it?

Solid Blows

A pair of American geologists answered the latter question in 1986. During their annual research excursions to the greenstone belt in the Barberton Mountains, Donald R. Lowe of Stanford University and Gary R. Byerly of Louisiana State University had stumbled across a thin layer of ancient ocean sediment containing hundreds of hollow, glasslike beads. On closer inspection, these sand-size spheres appeared nearly identical to the so-called impact spherules that became some of the strongest evidence of an asteroid striking the planet 65 million years ago, ending the reign of the dinosaurs. These Barberton spherules, dated to 3.2 billion years ago—plus another spherule bed found in Australia's Pilbara craton—became the first evidence that large extraterrestrial objects smashed into the earth during the Archean.

Additional discoveries followed. Knowing that the spherule layer from the dino-killing impact showed up around the globe, Lowe and Byerly soon correlated the Australian bed with a 3.5-billion-year-old impact they found in Barberton. They also discovered two more 3.2-billion-year-old spherule beds in South Africa. Simonson, too, ran across unexpected spherule beds during his explorations of iron formations in the Pilbara region in the early 1990s, extending the surprising series of asteroid strikes just beyond the end of the Archean eon, 2.5 billion years ago.

Inspecting the Archean greenstone belts with ancient impacts in mind gave these geologists additional insight into the asteroids and their aftermath. From the magnesium- and iron-rich composition of the spherules, for example, Lowe and Byerly deduced that the errant space rocks most likely struck the dense rock of an ocean basin—probably a fair distance away from the regions where the preserved spherules landed. Signs of globe-sweeping tsunamis that accompany each of the spherule beds they have uncovered in South Africa further corroborate that the asteroids smashed into an ocean rather than an exposed landmass, they say.

Glikson noted that the timing of some strikes coincides with the formation of "an abundant supply of angular boulders, including blocks up to 250 meters across," in the Pilbara region. Such jumbled blocks are the shattered result of the rise and collapse of the earth's surface along major earthquake faults in the area. Indeed, intense swarms of strong earthquakes would be one of the most immediate effects of a large asteroid impact.

Clearly, the early Archean impacts were not something the planet took lightly. Lowe and Byerly estimated their asteroids were big: between 20 and 50 kilometers in diameter, based on the distribution of spherules and other comparisons with the ejecta from younger impacts. (For comparison, best estimates suggest that the errant as-

BRUCE M. SIMONSON *Oberlin College (spherules)*; SCOTT HASSLER *Oberlin College (Pilbara region)*; DON LOWE *Stanford University (Barberton Mountains)*; CAT WILSON *(maps)*

[DIRECT EVIDENCE]

Repeated Blows to an Ancient Continent

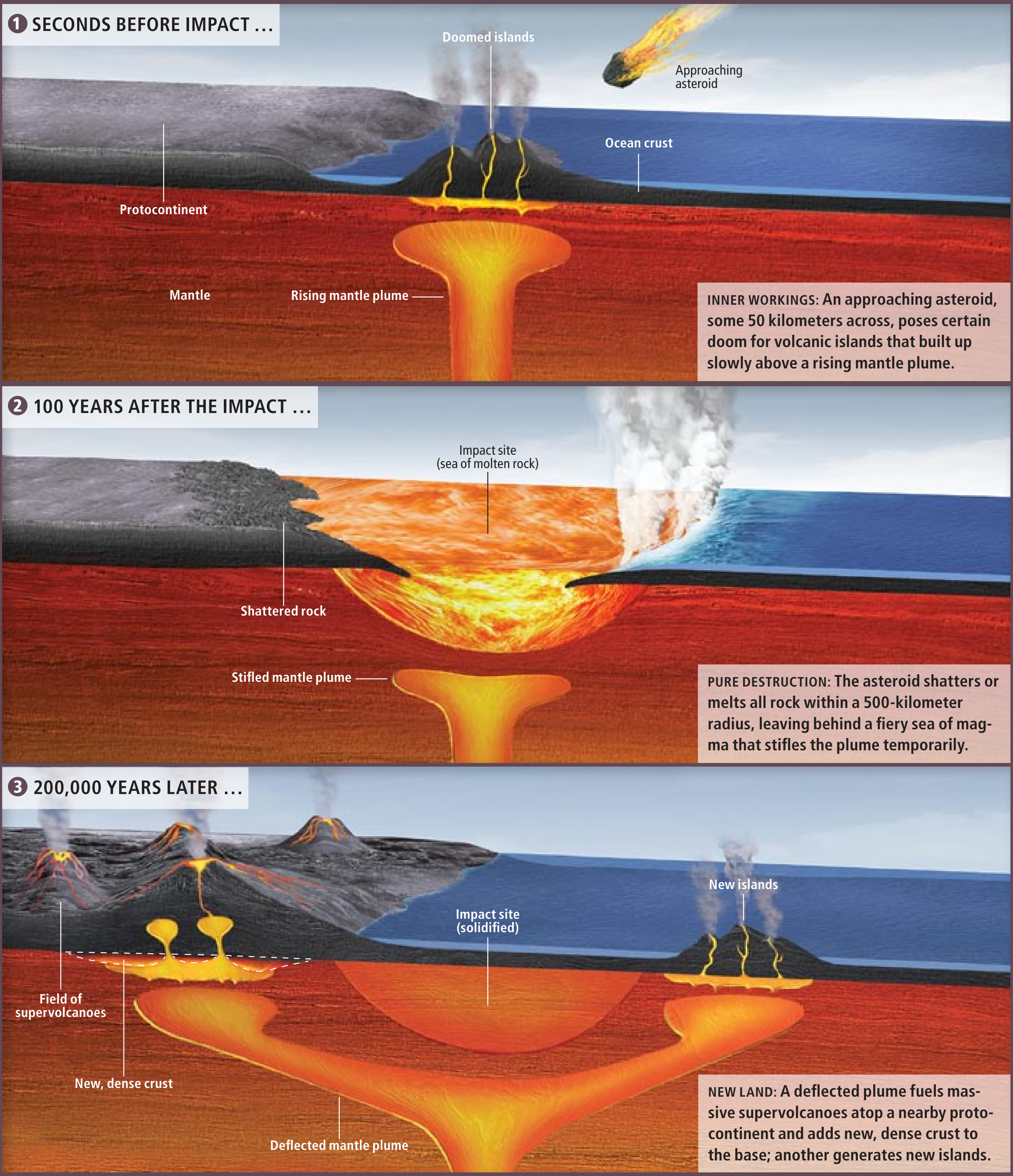
Ancient landforms in South Africa and Australia have the most to say about continental nativity. Indeed, some geologists argue that parts of South Africa's Barberton Mountains (*top right*) and the Pilbara region of northwestern Australia (*bottom*) are remains of the same original landmass. To date, geologists working in these areas have discovered vestiges of at least nine large asteroid strikes between about 3.5 billion and 2.5 billion years ago, each consisting of a layer of so-called impact spherules (*top left*).

▲ Sand-size spheres called impact spherules condensed from a cloud of hot, vaporized rock kicked up during an asteroid collision with the earth 2.5 billion years ago. Winds dispersed this rock vapor around the globe, and as it cooled, it condensed as droplets that solidified and fell to earth, becoming entrained in layers of ancient seafloor sediment now exposed on land in northwestern Australia.

[IMPACT SCENARIO]

How Land Might Emerge from Cosmic Chaos

Billions of years ago the earth's inner workings produced new landmasses above rising mantle plumes much as it does today—the hot, buoyant material partially melted the rock above, thereby fueling massive volcanoes that thickened the crust (*1*). A large asteroid impact would have stifled this process temporarily (*2*). But computer simulations suggest that, over the long haul, such a collision could have imparted a constructive influence by deflecting the plume to surrounding regions (*3*).



teroid that killed the dinosaurs was no more than 15 kilometers wide.) Such indications of the asteroids' size fueled Glikson's notion that they could have played a role in continent formation. He soon began drawing attention to other abrupt changes in the rock record right around the time of what he sees as a particularly illuminating trio of impacts: those Lowe and Byerly found clustered in South African sediments deposited around 3.2 billion years ago.

In a recent technical paper, Glikson observes that the timing of these impacts coincides with major signs that these regions were rising above sea level for the first time—presumably forming a new continental landmass. Specifically, the rock record laid down before the impacts consists of thick layers of ocean crust and types of sediments that form on the seafloor. During the period encompassing the asteroid strikes, those basalt layers are deformed, uplifted and eroded—kinds of upheaval easily attributable to the shock of asteroid collisions, he explains. In contrast, all the rocks formed *after* the time of the impact trio represent the eroded remnants of rocks that could have formed only on land. This change suggests that not long after the asteroid strikes, great forces within the earth raised the crust above the surface of the ocean, granites and other continental-type rocks formed, and they eventually eroded.

Glikson further suggests that the asteroid strikes themselves were the source of this upheaval. Most critical to his argument are the great masses of granite-forming magmas that intruded into both the Pilbara and Kaapvaal regions from below about 3.2 billion years ago. The similar timing of the asteroid impacts and the formation of this new magma was more than a mere coincidence, Glikson argues; they were cause and effect. He asserts that their planet-altering forces "caused major uplift of earlier nascent continents and intrusion of granitic magmas, both testifying to the violent origin of at least some parts of continental crust." The critical question is: What heating process generated the magma? Glikson's answer: the disruptive force of the 3.2-billion-year-old asteroid impacts shifted mantle convection patterns, triggering new mantle plumes that rose up and heated the crust from below.

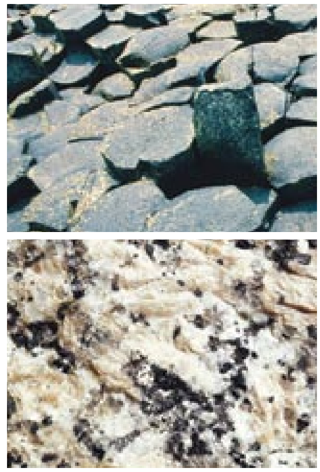
Constructive Criticism

The plausibility of Glikson's assertion hinges in great part on the size of the errant asteroid. From the perspective of the earth's inner workings, a rock the size of the dino-killing asteroid would be hardly more than a "bug on the windshield," Simonson suggests. But if the early Archean impacts were truly double that size, they could have left a more lasting impression. In particular, impacts as large as 50 kilometers in diameter could indeed shift patterns of heat flow inside the earth, says geophysicist Jay Melosh of Purdue University. Based on computer simulations of hypothetical impacts that he and his colleagues have developed for other purposes, Melosh describes how a sufficiently large early Archean asteroid impact might actually help a continent bulk up [*see box on opposite page*].

In this hypothetical scenario, Melosh assumes that an asteroid 50 kilometers wide smacks into an ocean basin at about 20 kilometers per second. Such an impact does not excavate a crater; instead it generates an enormous sea of molten rock some 500 kilometers across and nearly as deep. If such an asteroid-induced magma lake forms atop a mantle plume, its intense heat stifles the rising plume and then deflects it to surrounding regions. A plume deflected underneath dense ocean crust might generate new islands that might much later find their way to a subduction zone and thicken a growing continent from the side. Or if the deflected plume happened to rise below a protocontinent already containing less dense rock, the new heat source might be sufficient to produce fresh upward surges of granitic magma such as those located in the greenstone belts of Pilbara and Kaapvaal, thereby thickening the continent from below.

But this scenario is rife with uncertainty, Melosh warns. Proving that a given asteroid deflected mantle plumes to create specific continental embryos found in the rock record is virtually impossible. The craters the asteroids generated have long since been subducted or eroded away. And even if a plume was indeed responsible for the production of the granite, who is to say it was not already rising beneath a protocontinent even before the asteroid hit?

In the end, Glikson has illuminated an amazing coincidence in timing between the early Archean asteroid strikes and insurgence of new magma in ancient fragments of today's continents—and he has tied them together with a credible mechanism for how a cosmic strike could actually lead to the production of such magma. "It's a very possible hypothesis of what might have happened," Lowe says. "But it's only one interpretation." Undoubtedly, though, planet-altering impacts interrupted the earth's internal dynamics—and their violence may not have been entirely destructive. ■



DENSITY MATTERS: Basalt (*top*) is the main rock type making up ocean basins. Less-dense granite (*bottom*) is a prime component of continents. Its buoyancy keeps continents afloat while ocean floor sinks readily into the earth's hot interior.

KEVIN HAND (*illustration on opposite page*), SOURCE: JAY MELOSH *Purdue University*; PETER SCOONES *Getty Images (basalt)*; ERICH SCHREMPP *Photo Researchers, Inc. (granite)*

➥ MORE TO EXPLORE

The Evolution of Continental Crust. S. Ross Taylor and Scott M. McLennan in *Scientific American*, Vol. 274, No. 1, pages 76–81; January 1996.

Field Evidence of Eros-Scale Asteroids and Impact Forcing of Precambrian Geodynamic Episodes, Kaapvaal (South Africa) and Pilbara (Western Australia) Cratons. Andrew Y. Glikson in *Earth and Planetary Science Letters,* Vol. 267, pages 558–570; 2008.

Explore the aftermath of asteroid impacts at **www.lpl.arizona.edu/impacteffects**

REAL MONEY *from* VIRTUAL WORLDS

Online fantasy games enable developing world entrepreneurs to make a living by trading stashes of make-believe gold for hard cash **By Richard Heeks**

KEY CONCEPTS

- A new type of service industry has emerged to meet the needs of the millions who play online fantasy games such as World of Warcraft.
- Players called gold farmers amass game "currency" to sell to other players for a fee.
- This controversial practice violates the rules of play but has become a means for hundreds of thousands of developing world players to earn a wage comparable to that of factory workers.

—The Editors

It sounds like a digital alchemist's question. How do you turn virtual gold into the real item? Hundreds of thousands of "gold farmers" in developing countries have found a lucrative answer. They have become entrepreneurs who make their living by profiting from online games. By assuming fantasy roles in these games, they kill monsters, mine ore or engage in other activities that earn "virtual gold" that they then sell to other players, often in rich nations, for real-world currency. Although it flaunts the rules of the game, buyers and sellers of this make-believe currency use the gold to determine the fate of a character in these fantasy games.

A gold farmer in China who plays games and sells virtual currency can earn the same wage and, sometimes, more than might be paid for assembling toys in a factory for 12 hours a day. As a result, this activity has emerged in the past 10 years as an ingenious, though controversial, way for poorer nations to earn money from information and communications technologies and a way for impoverished workers to build digital skills that might be later transferred to other information technology jobs unrelated to game playing.

In just a few years gold farming has become a vast enterprise. A best estimate suggests that Asia, and particularly China, where most of the gold farmers reside, employs more than 400,000 players who spend their days stocking up on gold. Total annual trade in virtual gold probably amounts to at least $1 billion. Perhaps as many as 10 million players worldwide buy gold or services from farmers that help them advance in the game.

Once almost invisible to nongamers, gold farming now draws considerable attention from economists and sociologists as a nexus where rich and poor, real and virtual intersect. In recent years academics and popular media have developed a fascination for the dynamics of games that represent tiny worlds in fast forward—the fates of players and groups rise and fall in a matter of days and weeks rather than the decades or centuries that represent a human lifespan or an entire society. I became interested in gold farming after en-

PHIL ASHLEY *Getty Images (money)*; JUAN CARLOS PIÑEIRO ESCORIAZA *Pure West (gold farmers, top right)*; DUNCAN SMITH *Getty Images (arrow keys)*; COURTESY OF BLIZZARD ENTERTAINMENT, INC. *(game stills)*;

countering virtual gold merchants while playing online fantasy games. The relation of this endeavor to international development, my field of expertise, led me to a new line of research exploring the sociology and economics of gold farming.

How It Works

The grassroots gold farming industry exists on the periphery of the world of online games known as MMORPGs (massively multiplayer online role-playing games) such as World of Warcraft and EverQuest II. Not only do these games create a virtual world on-screen for their players—one with houses, landscapes and fantasy characters (including dwarfs and trolls)—they also have a virtual economy.

The make-believe gold of gamers buys new armor and weapons, food and medicine, a faster horse or a better-equipped spaceship, depending on the game's particular imaginary milieu. By killing monsters and other adversaries, mining ore, cutting timber, and so forth, players can build up their own store of gold. As in the real world, getting rich can be a tedious process that may take weeks or months. Thus, many players possessing real-world wealth have turned to an alternative. They do what people often do when faced with cleaning their houses or washing their cars: they get someone—gold farmers instead of domestic servants—to do their dirty work.

After farmers stockpile currency, they typically sell the virtual riches for real money on one of thousands of Web sites that market virtual merchandise for use in game play. The transaction is consummated through PayPal or other services that transfer payments online to gold farming firms, and it amounts to buying foreign exchange in a virtual world. In World of Warcraft, currently the game most subscribed to, 1,000 gold units retail for around $10, which is about the same as the yen-to-dollar exchange rate.

Once the real-money payment has taken place, buyer and seller meet at a designated rendezvous point in the fantasy world, where a farmer gives the virtual currency to the buyer. Although farmers make most of their money by

"PLAYBORERS," the nickname for those who make money from collecting the "gold" used to buy weapons and other implements in online games, usually hail from Asia and number in the hundreds of thousands.

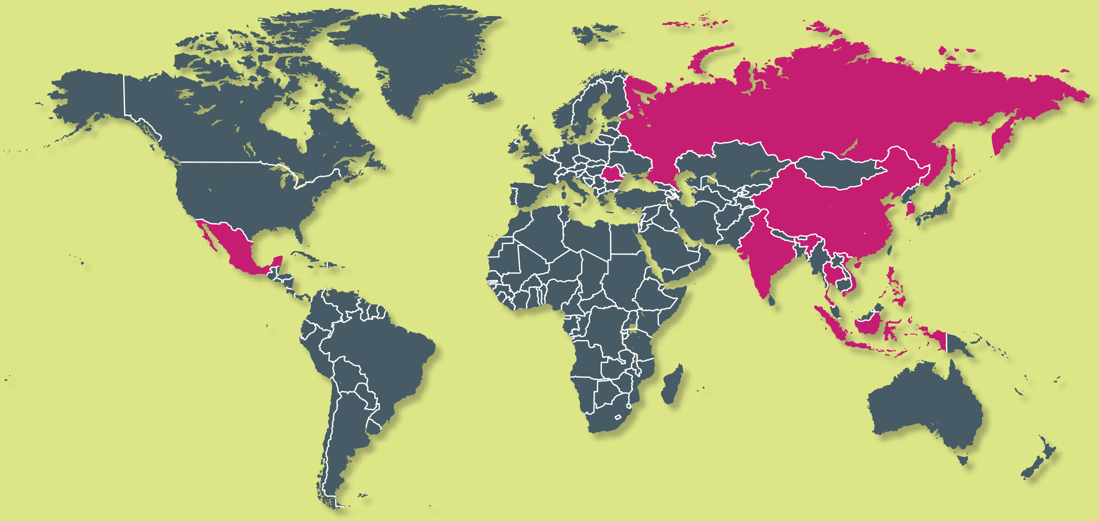
ANTHONY GILMORE *Nameless Films (gold farmers, center left)*; GETTY IMAGES *(hands on keyboard)*; JULIAN DIBBELL *(gold farmers, center right)*; JUAN CARLOS PIÑEIRO ESCORIAZA *Pure West (gold farmers, bottom left* and *right)*; GETTY IMAGES *(screen shot)*; BRYAN MULLENNIX *Getty Images (dollar sign)*

[GAZETTEER]

A Geography of Gold Farming

Developing countries, particularly China, have emerged as hotspots (*pink*) for gold farmers, trading virtual merchandise collected through online game playing for cold cash. Trading firms, generally in urban areas, often specialize by dedicating themselves to local, regional or global markets.

The Chinese industry began by providing low-cost services for the Korean market but rapidly went global. Some countries, including India, noted for its call-center businesses, still serve only the domestic market.



50 million
Number of global online game players (20 million subscription players)

100,000 to 1 million
Estimated number of gold farmers

$150
Average monthly salary of a gold farmer in China

$4.00
Usual piecework rate for every 1,000 units of Warcraft gold gathered

60,000 to 100,000
Number of gold-farming firms worldwide

selling gold, they can also engage in "power leveling." They take over a client's low-level (weak, poorly skilled) game character and build it up to high levels of health, strength and skill. Getting a boost from level one to level 50 in Lord of the Rings Online costs around $150. Sometimes, instead of assuming a client's character, farmers serve as escorts that accompany players through dangerous or difficult tasks—the equivalent of hiring Sherpas to ascend Himalayan peaks.

Prehistory of Virtual Agriculture

Trade in virtual gold equals perhaps half of the revenues that game companies themselves earn in player subscriptions, which constitute a gamer's initial outlay. How did we arrive at this point? Through my studies, I discovered that the gold farming industry has developed in much the same way as real-world economies, beginning with barter and evolving eventually into a complex web of global trade.

MUD (Multi-User Dungeon), introduced in 1978 at the University of Essex in England, was the first MMORPG. Generally seen as the key forerunner for modern online games, the original MUD and its early descendants allowed multiple players to assemble in an online world, albeit one that conveyed information about characters, players and objects solely in text. In the scheme of economic development, MUD players represented the equivalent of subsistence farmers in preindustrial society. Players produced and consumed items only for themselves.

Just as in a typical subsistence community, barter began to appear for valued game items. If I picked up an extra amber necklace and you had an extra longsword, we might arrange to swap. (Male players also reportedly donated rare items to female players in the probably unfulfilled hope of an emotional or physical payback.) Barter began to include exchange of game gold pieces, and at some point in the 1980s it made the leap from game currency to real currency. Players started offering hard cash for intangible items. In economic terms, virtual commodities had become "monetized," and the term "real-money trading" (RMT) today describes the exchange of cash for virtual currency, objects or services.

Real-money trading of virtual items trundled along during the 1980s and 1990s. One might call players of that era "gold-market gardeners." Moving up from bartering, they sold virtual gold on the side, just as a factory laborer might cultivate a vegetable garden in the backyard and sell the produce to earn some extra cash. These players still focused primarily on the game's recreational aspects. And part-timers who make an odd buck by selling surplus items or characters can still be found today in the cybercafes of India and Indonesia.

Two things happened in 1997 to move this economic backwater to the next stage of virtual industrial development. The first was the launch of Ultima Online, which became the original truly mass-subscription online game. The second was the start of eBay, offering a low-cost way for items to be traded. The gold-market gardeners gradually realized they could make more than occasional pocket money. They began to specialize in obtaining game items and currency

MELISSA THOMAS

that they could sell, focusing only on their specialty game, and, in some cases, abandoning other occupations to seek virtual gold full-time. These players, mainly based in Western countries, became the first true gold farmers. They were the equivalent of an individual artisan or cottage industry model of production. Whenever a new online game was launched, currency and weapons or other items would be available for sale on eBay within a few weeks.

The year 1997 also witnessed the Asian currency crisis, an event that laid the foundation for the current gold farming industry. Asian governments sought to spend their way out of the crisis by investing heavily in information and communications technologies, including broadband. Some of the unemployed set up new businesses such as public kiosks that rented time on personal computers for game playing, which helped to foster a strong games culture in East Asia.

The Golden Age of Gold Farming

By 2001 some of the more entrepreneurial U.S. gold farmers had started recruiting friends or even hiring staff to make money from this new trade. A few farmers—often with overseas family connections—looked further afield at low-cost locations such as Latin America and Asia. At the same time, South Koreans began to convert their cybercafes to gold-farming establishments for the medieval fantasy game Lineage, the first MMORPG from a non-Western country. Soon traders began to sell the game currency, called adena, to other players.

As gold-trading firms grew in the U.S. and Asia, they followed the example of Walmart and other companies, as they looked to cut costs by outsourcing their basic supply operations. Their natural focus was East Asia, with its ready pool of low-cost labor that was skilled or readily trainable and its growing broadband infrastructure. Because of the size and skill of its labor force, China was the most attractive location, making it the global focal point for gold farming. In 2004 huge growth and profits for gold farmers arrived with the release of World of Warcraft, which became the most successful MMORPG ever. By 2010 an estimated 11 million subscribers had assumed the role of a character and embarked on adventures in the fantasy world of Azeroth.

The largest gold farms have become increasingly specialized, just as agriculture or manufacturing does in any advanced industrial society. Different players at a farming firm often assume different roles within a particular game: hunters may be responsible for tracking down and killing monsters. Bankers might store assets and "mule" them from one place to another. "Barkers" advertise gold farming services to other players. Moreover, independent traders have begun to use the services of gold farmers to make money without ever actually playing a game. They have started to buy and sell characters or game implements as if they were Wall Street financial instruments. A trader will, say, buy an account linked to a particular character, employ the services of a gold farmer to raise it to a higher level, and then sell it to an interested player for a profit.

A crisis took shape in gold farming in the mid-2000s, along with the global housing and financial bubble. The leading firm IGE (Internet Gaming Entertainment), acting as a broker between gold farmers in China and Western players, earned between $10 million and $20 million a month and paid salaries in the millions of dollars to its senior staff. A single Chinese gold farmer reportedly made $1.3 million over a two-year period. Individual items sold for as much as $20,000. But from 2005 to 2009 virtual currencies devalued by 85 percent against the U.S. dollar. Research at the University of Manchester's Center for Development Informatics, which I direct, showed that the gold bubble popped when too many entrepreneurs entered the market. Gold

$200 million to $3 billion
Estimated total real-money trading worldwide (gold-farming and other unauthorized online game goods and services)

$400
Cost of power leveling (getting to level 75 in Final Fantasy XI)

$1.3 million
Highest reported amount made by a gold farmer over a two-year period

$13.50
Exchange rate (dollars for virtual gold) for 5 million gold pieces for the game RuneScape

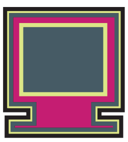
4 million to 12 million
Estimated number of consumers of gold-farming services

ELBOW-TO-ELBOW working conditions characterize many gold farming establishments, some of which even use the formality of time clocks and punch cards to log employees' long hours at the keyboard.

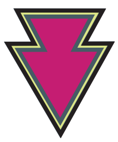
SOURCE FOR STATISTICS: "CURRENT ANALYSIS AND FUTURE RESEARCH AGENDA ON 'GOLD FARMING': REAL-WORLD PRODUCTION IN DEVELOPING COUNTRIES FOR THE VIRTUAL ECONOMIES OF ONLINE GAMES," BY RICHARD HEEKS. INSTITUTE FOR DEVELOPMENT POLICY AND MANAGEMENT, UNIVERSITY OF MANCHESTER, 2008; ANTHONY GILMORE *Nameless Films* (*gold farmers*); JULIAN DIBBELL (*time cards*)

FARMER-SPEAK

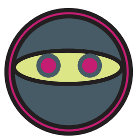
The complex alternative realities of online gaming engender their own intricate idioms, reminiscent of the cyberpunk fictional genre. The examples here describe activities that relate to gold farming.



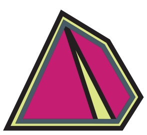
Botting: Deployment of automated game characters, "bots," that act on their own as if they were controlled by a human.



Nerfing: An action initiated so that some item or activities related to gold farming are reduced in value or power.



Ninja looting: Taking resources in a manner that violates the rules of good sportsmanship. One example: grabbing "loot" from a killed monster before a group of players decides how it should be allocated.



Spawn camping: A mined vein of a coveted resource automatically replenishes, or "respawns," after a predetermined interval. Gold farmers are sometimes accused of lurking in wait to capture the renewed supply.

farming still flourishes. In recent years, though, gold-farming operations have begun to seek out even lower-cost locations for their businesses, spurring the growth of start-ups in Vietnam.

An Emerging Backlash

Gold farming has become a contentious practice because amassing game currency and selling it for real dollars explicitly violates the rules of play. The companies that market online games have tried to put a stop to the marketing of gold by taking measures such as banning individual players or initiating lawsuits.

Apart from legal questions, some players view gold farming as patently unfair because it shortcuts the time-consuming task of aggregating wealth and gradually ascending to higher levels of game play. Also, gold farming can create a distraction for players, in the same way that e-mail spam does. It may be hard to imagine yourself as a medieval knight defending your kingdom if you are being bombarded by exhortations that pop up on the computer screen to view various Web addresses to buy gold.

During the early years game companies and mainstream players treated gold farming as a minor irritant. But as it grew into a thriving enterprise, that attitude changed. The companies responded by introducing low-level disruptions: random events that attack and kill "bots" (characters that perform automated, repetitive tasks, such as mining ore, without direct player control); "nerfing"—downgrading or removing items or game activities that gold farmers utilize; banning of farmers' game accounts; and, finally, "patching," which introduces new game software code, that, for example, delays the exchange of currency between characters, giving the company time to investigate a transaction.

Although such actions are a nuisance, gold farmers readily find ways to circumvent them. In response, companies have taken more substantive measures, such as banning certain Chinese Internet (IP) addresses from accessing North American or European servers. And in 2007 eBay finally acceded to pressure to ban all sales of virtual items, currency and accounts, an action that merely spawned the creation of hundreds of brokerages that provide gold-trading and power-leveling services directly to customers.

Companies also try to limit gold farming by legal maneuvering. Before subscribing to an MMORPG, a player must agree not to engage in real-money trading. But the issue of who owns a character's virtual items and currency remains unresolved. Does a game company have rights to everything in a virtual world, in which case real-money trading is illegal? Or is gold or a sword the property of players who create and pay for a character and its possessions? The game companies have yet to win a clear victory on this point when taking gold farming firms to court. In fact, in China players have won rulings requiring local game companies to return virtual merchandise that had been lost because of inadequacies of the game system, cases that proved that players have ownership rights over intangible online goods.

Finally, companies have resorted to game redesigns that exclude gold farmers, changes that have sometimes had a deep effect on the game. In 2007, in response to complaints about gold farmers from players, Jagex redesigned its game RuneScape to make selling virtual gold much more difficult. The cure, however, brought its own problems. It led to many complaints that game play deteriorated because of the restrictive measures, causing some wags to rechristen the game RuinedScape. Even now trading in gold

SPARTAN LIFESTYLE marks the world of gold farmers who receive free room and board in barracklike housing in exchange for up to 12 hours of work seven days a week and a wage of perhaps 50 cents an hour.

CAT WILSON *(icons)*; ANTHONY GILMORE *Nameless Films (kitchen and shower)*; JULIAN DIBBELL *(eating and sleeping quarters)* earned in RuneScape continues, albeit in reduced and modified form. Some companies have gone so far as to adopt gold farmers' own methods. Eschewing the standard practice of making game players pay for subscriptions, these companies now receive payments for game items purchased as their main source of revenue.

A View from the Developing World

Game players as well as companies have at times adopted aggressive tactics to fight gold farmers. About a quarter of players are vociferously antagonistic. This group has launched rather disorganized campaigns against game characters they (sometimes mistakenly) think are controlled by gold farmers. As one example, girl dwarfs, a type of character in one game, are often attacked or harassed because they are thought to be tools of gold farmers.

Some of the antagonism seems fueled by racial stereotyping. Analyst Nick Yee of the Palo Alto Research Center has described parallels between the reaction to gold farming and the way Chinese immigrant laborers were treated during the California gold rush of the mid- to late 19th century. In both cases, the derogatory epithets associating East Asians with disease and pestilence have justified the need for the Asians' "extermination": either actual ethnic cleansing from American soil or else expulsion from the U.S.-based game servers. Author James John Bell quotes one gold farmer's experience with U.S. players: "They treat me bad … they keep calling me farmer, China dog and such. I do not have any problems with other players except American players, they nonstop racist me."

Gold farming also remains stigmatized because the working conditions in gold farms often bear the label "virtual sweatshop." But the validity of this portrayal is open to debate. Gold farmers typically earn about 50 cents per hour for working 10 to 12 hour shifts every day of the week. From a Western perspective, these conditions might appear exploitative. Yet gold farmers themselves generally consider their pay to be good, and it is often higher than they would earn doing other local jobs. Food and accommodation are rudimentary, but workers pay nothing, and for many—such as recent rural migrants—the only alternative is unemployment. Some of the work can be monotonous, but most farmers report enjoying their time at the keyboard. This mixture of work and play has even given them the moniker "playborers."

For developing countries, gold farming offers a way to gain benefits from information technology. It creates hundreds of thousands of jobs, while slightly easing the growing problem of urban poverty, and anecdotal evidence suggests it reduces crime, by putting young, urban, unemployed males to work. For that reason, although farmers operate nominally as part of the underground economy, a number of Chinese local governments have even provided investment capital to help create gold farms in their localities.

The allure of gold farming continues to build for many low-wage workers attracted by the possibility of enriching themselves through game playing. The ranks of online gamers worldwide expand by more than 50 percent annually, creating a swelling pool of demand. Even during the recent global financial crisis, Chinese gold farms reported increases in sales and employment.

Gold farming points a way to opportunities for developing countries. As people spend more of their work and leisure time online, the need for related online services—under the rubric of "cyberwork"—will only grow. Future investigations on gold farming will illuminate how international trade and the Internet can spur such entrepreneurial activity.

But they must also raise difficult questions. Should China and other developing countries support gold farming as a way to expand exports and employment? Can gold farmers migrate to higher-skilled information technology jobs? Does gold farming provide a template for new forms of economic development? What other types of cyberwork may emerge from the shadows? Research questions for social scientists abound, but all are a reminder that broadband communications will give poorer countries a pivotal role in the burgeoning digital economy. ■

COURTESY OF THE UNIVERSITY OF MANCHESTER (*Heeks*)

[THE AUTHOR]

Richard Heeks is chair of development informatics at the University of Manchester in England and director of the university's Center for Development Informatics. He has 30 years of experience working at the intersection of digital technologies and international development, including advisory work for governments and international agencies. Just occasionally, and for research purposes only, of course, he can be found playing online games.

➥ MORE TO EXPLORE

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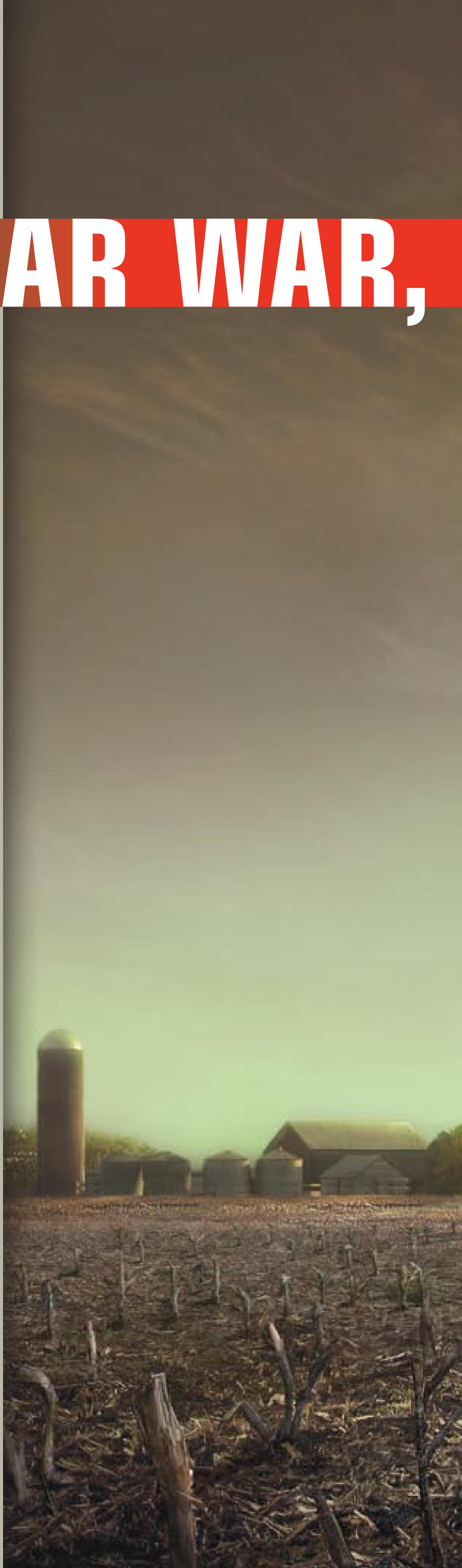
LOCAL NUCLEAR WAR,

Worry has focused on the U.S. versus Russia, but a regional nuclear war between India and Pakistan could blot out the sun, starving much of the human race

BY ALAN ROBOCK AND OWEN BRIAN TOON



RICHARD LEE

KEY CONCEPTS

- Nuclear bombs dropped on cities and industrial areas in a fight between India and Pakistan would start firestorms that would put massive amounts of smoke into the upper atmosphere.
- The particles would remain there for years, blocking the sun, making the earth's surface cold, dark and dry. Agricultural collapse and mass starvation could follow. Hence, global cooling could result from a regional war, not just a conflict between the U.S. and Russia.
- Cooling scenarios are based on computer models. But observations of volcanic eruptions, forest fire smoke and other phenomena provide confidence that the models are correct.

—The Editors

Twenty-five years ago international teams of scientists showed that a nuclear war between the U.S. and the Soviet Union could produce a "nuclear winter." The smoke from vast fires started by bombs dropped on cities and industrial areas would envelop the planet and absorb so much sunlight that the earth's surface would get cold, dark and dry, killing plants worldwide and eliminating our food supply. Surface temperatures would reach winter values in the summer. International discussion about this prediction, fueled largely by astronomer Carl Sagan, forced the leaders of the two superpowers to confront the possibility that their arms race endangered not just themselves but the entire human race. Countries large and small demanded disarmament.

Nuclear winter became an important factor in ending the nuclear arms race. Looking back later, in 2000, former Soviet Union leader Mikhail S. Gorbachev observed, "Models made by Russian and American scientists showed that a nuclear war would result in a nuclear winter that would be extremely destructive to all life on earth; the knowledge of that was a great stimulus to us, to people of honor and morality, to act."

Why discuss this topic now that the cold war has ended? Because as other nations continue to acquire nuclear weapons, smaller, regional nuclear wars could create a similar global catastrophe. New analyses reveal that a conflict between India and Pakistan, for example, in which

GLOBAL SUFFERING

HUMAN TOLL

An all-out nuclear war between India and Pakistan could slaughter people locally and lead to more deaths across the planet.

20 million people in the region could die from direct bomb blasts and subsequent fire and radiation.

1 billion people worldwide with marginal food supplies today could die of starvation because of ensuing agricultural collapse.

100 nuclear bombs were dropped on cities and industrial areas—only 0.4 percent of the world's more than 25,000 warheads—would produce enough smoke to cripple global agriculture. A regional war could cause widespread loss of life even in countries far away from the conflict.

Regional War Threatens the World

By deploying modern computers and modern climate models, the two of us and our colleagues have shown that not only were the ideas of the 1980s correct but the effects would last for at least 10 years, much longer than previously thought. And by doing calculations that assess decades of time, only now possible with fast, current computers, and by including in our calculations the oceans and the entire atmosphere—also only now possible—we have found that the smoke from even a regional war would be heated and lofted by the sun and remain suspended in the upper atmosphere for years, continuing to block sunlight and to cool the earth.

India and Pakistan, which together have more than 100 nuclear weapons, may be the most worrisome adversaries capable of a regional nuclear conflict today. But other countries besides the U.S. and Russia (which have thousands) are well endowed: China, France and the U.K. have hundreds of nuclear warheads; Israel has more than 80, North Korea has about 10 and Iran may well be trying to make its own. In 2004 this situation prompted one of us (Toon) and later Rich Turco of the University of California, Los Angeles, both veterans of the 1980s investigations, to begin evaluating what the global environmental effects of a regional nuclear war would be and to take as our test case an engagement between India and Pakistan.

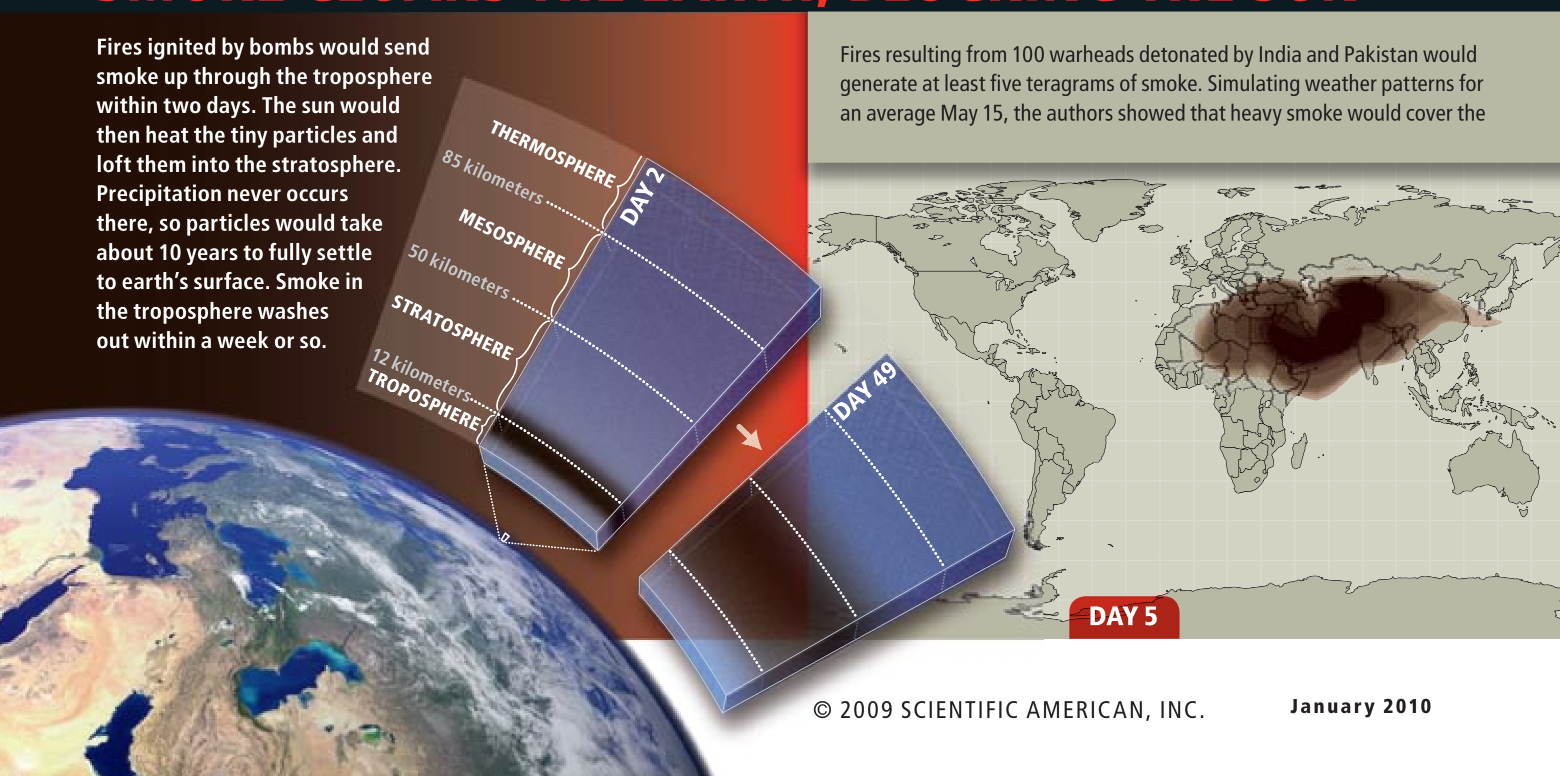
The latest estimates by David Albright of the Institute for Science and International Security and by Robert S. Norris of the Natural Resources Defense Council are that India has 50 to 60 assembled weapons (with enough plutonium for 100) and that Pakistan has 60 weapons. Both countries continue to increase their arsenals. Indian and Pakistani nuclear weapons tests indicate that the yield of the warheads would be similar to the 15-kiloton explosive yield (equivalent to 15,000 tons of TNT) of the bomb the U.S. used on Hiroshima.

Toon and Turco, along with Charles Bardeen, now at the National Center for Atmospheric Research, modeled what would happen if 50 Hiroshima-size bombs were dropped across the highest population-density targets in Pakistan and if 50 similar bombs were also dropped across India. Some people maintain that nuclear weapons would be used in only a measured way. But in the wake of chaos, fear and broken communications that would occur once a nuclear war began, we doubt leaders would limit attacks in any rational manner. This likelihood is particularly true for Pakistan, which is small and could be quickly overrun in a conventional conflict. Peter R. La-

NASA/THE VISIBLE EARTH *(globe)*; JEN CHRISTIANSEN *(atmosphere cutaway* and *smoke-density maps)*

[ATMOSPHERIC CHANGE]

SMOKE CLOAKS THE EARTH, BLOCKING THE SUN

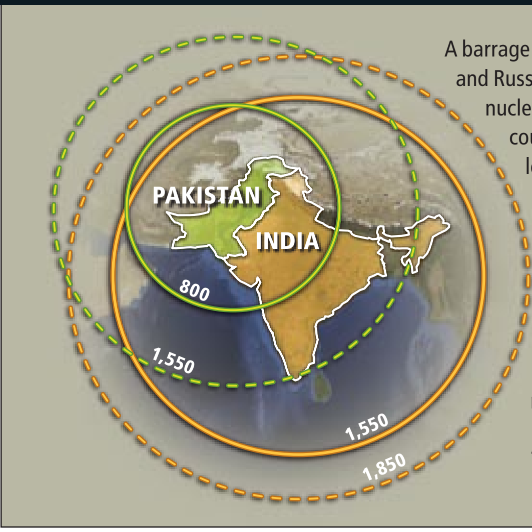


Fires ignited by bombs would send smoke up through the troposphere within two days. The sun would then heat the tiny particles and loft them into the stratosphere. Precipitation never occurs there, so particles would take about 10 years to fully settle to earth's surface. Smoke in the troposphere washes out within a week or so.

Fires resulting from 100 warheads detonated by India and Pakistan would generate at least five teragrams of smoke. Simulating weather patterns for an average May 15, the authors showed that heavy smoke would cover the

[NUCLEAR THREAT]

INDIA VS. PAKISTAN



A barrage of nuclear attacks between the U.S. and Russia could plunge the earth into nuclear winter, but regional conflicts could do the same. India and Pakistan, long at odds, have more than 50 nuclear warheads apiece; if each country dropped that many bombs on cities and industrial areas, the smoke from fires would stunt agriculture worldwide for 10 years. Ballistic missiles from either country could reach most if not all areas in the other's territory.

Approximate missile range (in miles)
— Operational range
– – In development

Globally, nine nations have nuclear weapons. By using their arsenals, all of the countries other than North Korea and Iran could jeopardize civilization.

COUNTRY	WARHEADS
Russia	15,000
U.S.	9,900
France	350
China	200
U.K.	200
Israel	80
Pakistan	60
India	50
North Korea	<10
Iran	In development?

SOURCE: Natural Resources Defense Council

JEN CHRISTIANSEN (*missile range map*); NASA/THE VISIBLE EARTH (*base map*); CATHERINE WILSON (*flags*)

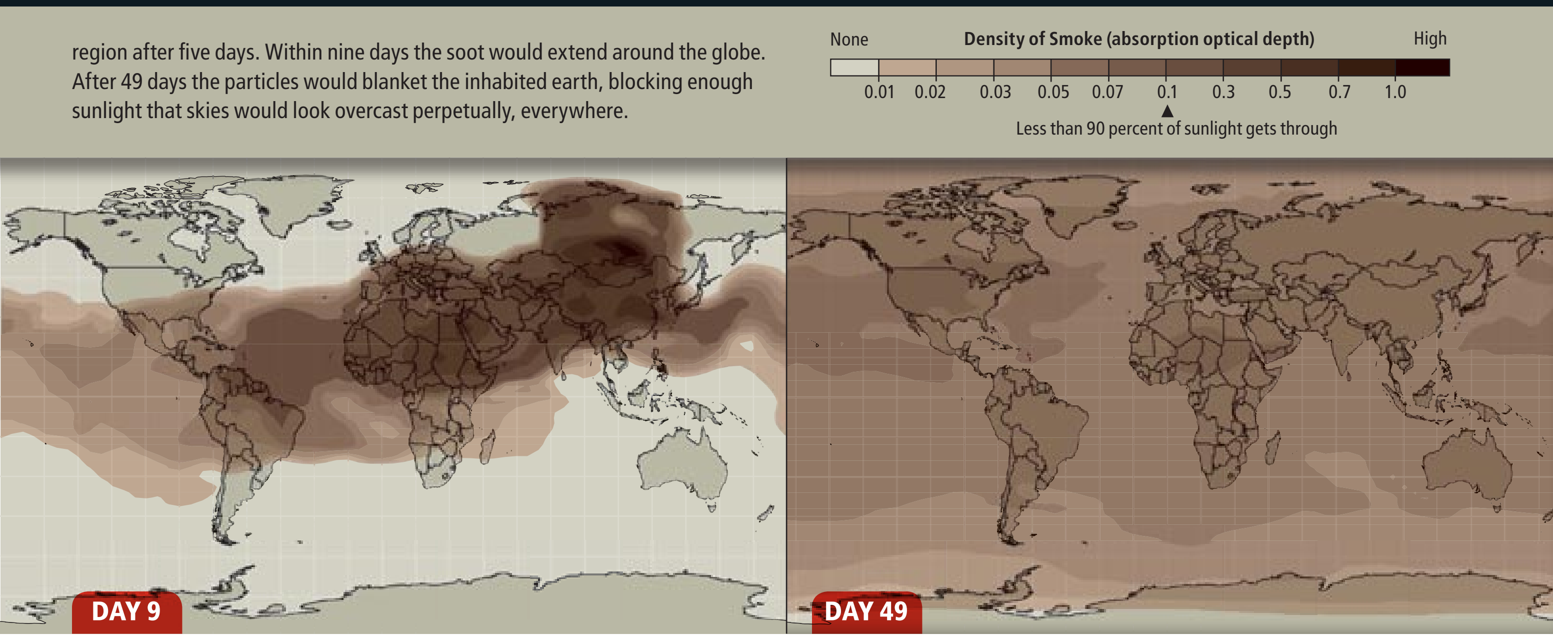
voy of the Naval Postgraduate School, for example, has analyzed the ways in which a conflict between India and Pakistan might occur and argues that Pakistan could face a decision to use all its nuclear arsenal quickly before India swamps its military bases with traditional forces.

Obviously, we hope the number of nuclear targets in any future war will be zero, but policy makers and voters should know what is possible. Toon and Turco found that more than 20 million people in the two countries could die from the blasts, fires and radioactivity—a horrible slaughter. But the investigators were shocked to discover that a tremendous amount of smoke would be generated, given the megacities in the two countries, assuming each fire would burn the same area that actually did burn in Hiroshima and assuming an amount of burnable material per person based on various studies. They calculated that the 50 bombs exploded in Pakistan would produce three teragrams of smoke, and the 50 bombs hitting India would generate four (one teragram equals a million metric tons).

Satellite observations of actual forest fires have shown that smoke can be lofted up through the troposphere (the bottom layer of the atmosphere)

Pakistan could elect to use its nuclear arsenal before India swamps its military bases.

region after five days. Within nine days the soot would extend around the globe. After 49 days the particles would blanket the inhabited earth, blocking enough sunlight that skies would look overcast perpetually, everywhere.



and sometimes then into the lower stratosphere (the layer just above, extending to about 30 miles). Toon and Turco also did some "back of the envelope" calculations of the possible climate impact of the smoke should it enter the stratosphere. The large magnitude of such effects made them realize they needed help from a climate modeler.

It turned out that one of us (Robock) was already working with Luke Oman, now at the NASA Goddard Space Flight Center, who was finishing his Ph.D. at Rutgers University on the climatic effects of volcanic eruptions, and with Georgiy L. Stenchikov, also at Rutgers and an author of the first Russian work on nuclear winter. They developed a climate model that could be used fairly easily for the nuclear blast calculations.

Robock and his colleagues, being conservative, put five teragrams of smoke into their modeled upper troposphere over India and Pakistan on an imaginary May 15. The model calculated how winds would blow the smoke around the world and how the smoke particles would settle out from the atmosphere. The smoke covered all the continents within two weeks. The black, sooty smoke absorbed sunlight, warmed and rose into the stratosphere. Rain never falls there, so the air is never cleansed by precipitation; particles very slowly settle out by falling, with air resisting them. Soot particles are small, with an average diameter of only 0.1 micron (µm), and so drift down very slowly. They also rise during the daytime as they are heated by the sun, repeatedly delaying their elimination. The calculations showed that the smoke would reach far higher into the upper stratosphere than the sulfate particles that are produced by episodic volcanic eruptions. Sulfate particles are transparent and absorb much less sunlight than soot and are also bigger, typically 0.5 µm. The volcanic particles remain airborne for about two years, but smoke from nuclear fires would last a decade.

Killing Frosts in Summer

The climatic response to the smoke was surprising. Sunlight was immediately reduced, cooling the planet to temperatures lower than any experienced for the past 1,000 years. The global average cooling, of about 1.25 degrees Celsius (2.3 degrees Fahrenheit), lasted for several years, and even after 10 years the temperature was still 0.5 degree C colder than normal. The models also showed a 10 percent reduction in precipitation worldwide. Precipitation, river flow and soil moisture all decreased because blocking sunlight reduces evaporation and weakens the hydrologic cycle. Drought was largely concentrated in the lower latitudes, however, because global cooling would retard the Hadley air circulation pattern in the tropics, which produces a large fraction of global precipitation. In critical areas such as the Asian monsoon regions, rainfall dropped by as much as 40 percent.

The cooling might not seem like much, but even a small dip can cause severe consequences. Cooling and diminished sunlight would, for example, shorten growing seasons in the midlatitudes. More insight into the effects of cooling came from analyses of the aftermaths of massive volcanic eruptions. Every once in a while such eruptions produce temporary cooling for a year or two. The largest of the past 500 years, the 1815 Tambora eruption in Indonesia, blotted the sun and produced global cooling of about 0.5 degree C for a year; 1816 became known as "The Year without a Summer" or "Eighteen Hundred and Froze to Death." In New England, although the average summer temperature was lowered only a few degrees, crop-killing frosts occurred in every month. After the first frost, farmers replanted crops, only to see them killed by the next frost. The price of grain skyrocketed, the price of livestock plummeted as farmers sold the animals they could not feed, and a mass migration began from New England to the Midwest, as people followed reports of fertile land there. In Europe the weather was so cold and gloomy that the stock market collapsed, widespread famines occurred and 18-year-old Mary Shelley was inspired to write *Frankenstein*.

Certain strains of crops, such as winter wheat, can withstand lower temperatures, but a lack of sunlight inhibits their ability to grow. In our scenario, daylight would filter through the high smoky haze, but on the ground every day would seem to be fully overcast. Agronomists and farmers could not develop the necessary seeds or adjust agricultural practices for the radically different conditions unless they knew ahead of time what to expect.

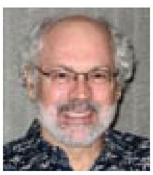
In addition to the cooling, drying and darkness, extensive ozone depletion would result as the smoke heated the stratosphere; reactions that create and destroy ozone are temperature-dependent. Michael J. Mills of the University of Colorado at Boulder ran a completely separate climate model from Robock's but found similar results for smoke lofting and stratospheric temperature changes. He concluded that although surface temperatures would cool by a small amount, the

WHY BELIEVE IT

Some people think that the nuclear winter theory developed in the 1980s was discredited. And they may therefore raise their eyebrows at our new assertion that a regional nuclear war, like one between India and Pakistan, could also devastate agriculture worldwide. But the original theory was thoroughly validated. The science behind it was supported by investigations from the National Academy of Sciences, by studies sponsored within the U.S. military, and by the International Council of Scientific Unions, which included representatives from 74 national academies of science and other scientific bodies.

Our current work has appeared in leading peer-reviewed journals. Still, we seem to be the only ones pursuing research into the global environmental risks of nuclear exchanges. We urge others to evaluate and repeat the calculations both for the effects of a superpower conflagration and for more regional nuclear wars. —*A.R. and O.B.T.*

[THE AUTHORS]




COURTESY OF SHERRI L. WEST (*Robock*); COURTESY OF OWEN BRIAN TOON (*Toon*)

Alan Robock is professor of climatology at Rutgers University and associate director of the school's Center for Environmental Prediction, where he studies many aspects of climate change. He is a fellow of the American Meteorological Society and a participant in the Intergovernmental Panel on Climate Change. Owen Brian Toon is chair of the department of atmospheric and oceanic sciences at the University of Colorado at Boulder and a fellow of the Laboratory for Atmospheric and Space Physics there. He is a fellow of the American Meteorological Society and the American Geophysical Union.

stratosphere would be heated by more than 50 degrees C, because the black smoke particles absorb sunlight. This heating, in turn, would modify winds in the stratosphere, which would carry ozone-destroying nitrogen oxides into its upper reaches. Together the high temperatures and nitrogen oxides would reduce ozone to the same dangerous levels we now experience below the ozone hole above Antarctica every spring. Ultraviolet radiation on the ground would increase significantly because of the diminished ozone.

Less sunlight and precipitation, cold spells, shorter growing seasons and more ultraviolet radiation would all reduce or eliminate agricultural production. Notably, cooling and ozone loss would be most profound in middle and high latitudes in both hemispheres, whereas precipitation declines would be greatest in the tropics.

The specific damage inflicted by each of these environmental changes would depend on particular crops, soils, agricultural practices and regional weather patterns, and no researchers have completed detailed analyses of such agricultural responses. Even in normal times, however, feeding the growing human population depends on transferring food across the globe to make up for regional farming deficiencies caused by drought and seasonal weather changes. The total amount of grain stored on the planet today would feed the earth's population for only about two months [see "Could Food Shortages Bring Down Civilization?" by Lester R. Brown; Scientific American, May]. Most cities and countries have stockpiled food supplies for just a very short period, and food shortages (as well as rising prices) have increased in recent years. A nuclear war could trigger declines in yield nearly everywhere at once, and a worldwide panic could bring the global agricultural trading system to a halt, with severe shortages in many places. Around one billion people worldwide who now live on marginal food supplies would be directly threatened with starvation by a nuclear war between India and Pakistan or between other regional nuclear powers.

Independent Evidence Needed

Typically scientists test models and theories by doing experiments, but we obviously cannot experiment in this case. Thus, we look for analogues that can verify our models.

Burned cities. Unfortunately, firestorms created by intense releases of energy have pumped vast quantities of smoke into the upper atmosphere. San Francisco burned as a result of the 1906 earthquake, and whole cities were incin-

CATHERINE WILSON (*graph*); SOURCE FOR GRAPH: "A CLOSER LOOK AT UNITED STATES AND GLOBAL SURFACE TEMPERATURE CHANGE," BY J. E. HANSEN ET AL., IN *JOURNAL OF GEOPHYSICAL RESEARCH*, VOL. 106; 2001 (*actual temperature variation*); GEORGE RETSECK (*ozone globes*); JUSTIN SULLIVAN *Getty Images* (*oranges*)

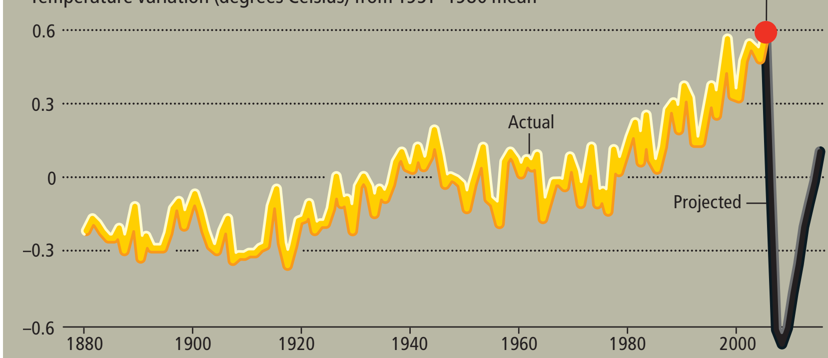
[ENVIRONMENTAL FALLOUT]

Agriculture Collapses

Five teragrams of smoke shrouding the earth would cause temperatures to drop and ultraviolet radiation to rise, threatening crops worldwide.

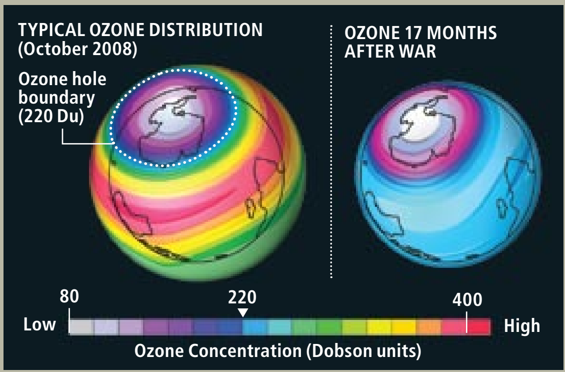
TEMPERATURE

The average surface-air temperature around the globe would drop by 1.25 degrees Celsius, and after 10 years would still be 0.5 degree lower. The depression would also trigger summer frosts.



OZONE DEPLETION

Smoke would absorb enough sunlight to greatly heat the stratosphere, drawing nitrogen oxides upward, thinning ozone concentration. In effect, the ozone hole that occurs annually over the South Pole (*left*, *purple* and *dark blue*) would exist globally (*right*), allowing dangerous levels of ultraviolet radiation to strike the earth's surface.



CROPS RUINED

Diminished sunlight, cooler temperatures and drought would shorten growing seasons. Unseasonal frosts and more ultraviolet radiation piercing through a thinner ozone layer would further harm crops. Yields would decline around the world all at once, halting food trade. Above, a severe cold snap in 2007 damaged 70 percent of California's citrus harvest.

REAL EVENTS such as explosive volcanic eruptions and massive wildfires help to verify simulations that predict the consequences of nuclear war. In 1991 the Mount Pinatubo volcano threw ash miles into the air (*top*), which subsequently formed distinct particle layers that circumnavigated the planet (*bottom*).

TIME & LIFE PICTURES *Getty Images* (*Mount Pinatubo*); CORBIS (*particle layers*)

erated during World War II, including Dresden, Hamburg, Tokyo, Hiroshima and Nagasaki. These events confirm that smoke from intense urban fires rises into the upper atmosphere.

The seasonal cycle. In actual winter the climate is cooler because the days are shorter and sunlight is less intense; the simple change of seasons helps us quantify the effects of less solar radiation. Our climate models re-create the seasonal cycle well, confirming that they properly reflect changes in sunlight.

Eruptions. Explosive volcanic eruptions, such as those of Tambora in 1815, Krakatau in 1883 and Pinatubo in 1991 provide several lessons. The resulting sulfate aerosol clouds that formed in the stratosphere were transported around the world by winds. The surface temperature plummeted after each eruption in proportion to the thickness of the particulate cloud. After the Pinatubo eruption, the global average surface temperature dropped by about 0.25 degree C. Global precipitation, river flow and soil moisture all decreased. Our models reproduce these effects.

Forest fires. Smoke from large forest fires sometimes is injected into the troposphere and lower stratosphere and is transported great distances, producing cooling. Our models perform well against these effects, too.

Extinction of the dinosaurs. An asteroid smashed into Mexico's Yucatán Peninsula 65 million years ago. The resulting dust cloud, mixed with smoke from fires, blocked the Sun, killing the dinosaurs. Massive volcanism in India at the same time may have exacerbated the effects. The events teach us that large amounts of aerosols in the earth's atmosphere can change climate drastically enough to kill robust species.

We have used such analogues to test and improve our models in the past. But we hope more people will do further work. Independent models that either verify or contradict ours would be very instructive. Agricultural impact studies, which we have not conducted, would be particularly welcomed.

Abolition: The Only Policy

People have several incorrect impressions about nuclear winter. One is that the climatic effects were disproved; this is just not true [*see sidebar on page 78*]. Another is that the world would experience "nuclear autumn" instead of winter. But our new calculations show that the climate effects even of a regional conflict would be widespread and severe. The models and computers used in the 1980s were not able to simulate the lofting and persistence of the smoke or the long time it would take oceans to warm back up as the smoke eventually dissipated; current models of a full-scale nuclear exchange predict a nuclear winter, not a nuclear fall.

Another misimpression is that the problem, even if it existed, has been solved by the end of the nuclear arms race. In fact, a nuclear winter could readily be produced by the American and Russian nuclear arsenals that are slated to remain in 2012. Furthermore, the increasing number of nuclear states raises the chances of a war starting deliberately or by accident. For example, North Korea has threatened war should the world stop its ships and inspect them for transporting nuclear materials. Fortunately, North Korea does not now have a usable nuclear arsenal, but it may have one capable of global reach in the near future. Some extremist leaders in India advocated attacking Pakistan with nuclear weapons following recent terrorist attacks on India. Because India could rapidly overrun Pakistan with conventional forces, it would be conceivable for Pakistan to attack India with nuclear weapons if it thought that India was about to go on the offensive. Iran has threatened to destroy Israel, already a nuclear power, which in turn has vowed never to allow Iran to become a nuclear state. Each of these examples represent countries that imagine their existence to be threatened completely and with little warning. These points of conflict have the potential to erupt suddenly.

The first nuclear war so shocked the world that in spite of the massive buildup of these weapons since then, they have never been used again. But the only way to eliminate the possibility of climatic catastrophe is to eliminate the weapons. Rapid reduction of the American and Russian arsenals would set an example for the rest of the world that nuclear weapons cannot be used and are not needed.

Under the Strategic Offensive Reductions Treaty, the U.S. and Russia both committed to reduce deployed strategic nuclear warheads down to between 1,700 to 2,200 apiece by the end of 2012. In July 2009 President Barack Obama and Russian president Dmitry Medvedev agreed to drop that range further, to 1,500 to 1,675 by 2016. Although smaller strategic arsenals are to be commended, our new results show that even the lower counts are far more than enough to destroy agriculture worldwide, as is a regional nuclear war. If this mother lode of weapons were used against urban targets, hundreds of millions of people would be killed and a whopping 180 Tg of smoke would be sent into the global stratosphere. Average temperatures would remain below freezing even in the summer for several years in major agricultural regions. Even the warheads on one missile-carrying submarine could produce enough smoke to create a global environmental disaster.

The combination of nuclear proliferation, political instability and urban demographics may constitute one of the greatest dangers to the stability of society since the dawn of humans. Only abolition of nuclear weapons will prevent a potential nightmare. Immediate reduction of U.S. and Russian arsenals to the same levels as other nuclear powers (a few hundred) would maintain their deterrence, reduce the possibility of nuclear winter and encourage the rest of the world to continue to work toward the goal of elimination.

President Obama understands this logic. In his first press conference as president, on February 9, 2009, he said, "It is important for the United States, in concert with Russia … to restart the conversations about how we can start reducing our nuclear arsenals in an effective way so that we then have the standing to go to other countries and start stitching back together the nonproliferation treaties." Then, on September 24, the president led the United Nations Security Council to approve a draft resolution that would step up efforts to rid the world of nuclear weapons. Our modeling results only strengthen the reasons to support further progress on such policy. ■

The only way to eliminate the possibility of climatic catastrophe is to eliminate the nuclear weapons.

CHARLES DHARAPAK *AP Photo*

PRESIDENT BARACK OBAMA **and Russian president Dmitry Medvedev sign an agreement in July 2009 to reduce the number of each nation's deployed, strategic nuclear warheads. Further cuts could inspire all nuclear nations to dramatically reduce weapons worldwide.**

➥ MORE TO EXPLORE

Consequences of Regional-Scale Nuclear Conflicts. Owen B. Toon, Alan Robock, Richard P. Turco, Charles Bardeen, Luke Oman and Georgiy L. Stenchikov in *Science,* Vol. 315, pages 1224–1225; March 2, 2007.

Climatic Consequences of Regional Nuclear Conflicts. A. Robock, L. Oman, G. L. Stenchikov, O. B. Toon, C. Bardeen and R. P. Turco in *Atmospheric Chemistry and Physics,* Vol. 7, No. 8, pages 2003–2012; April 2007.

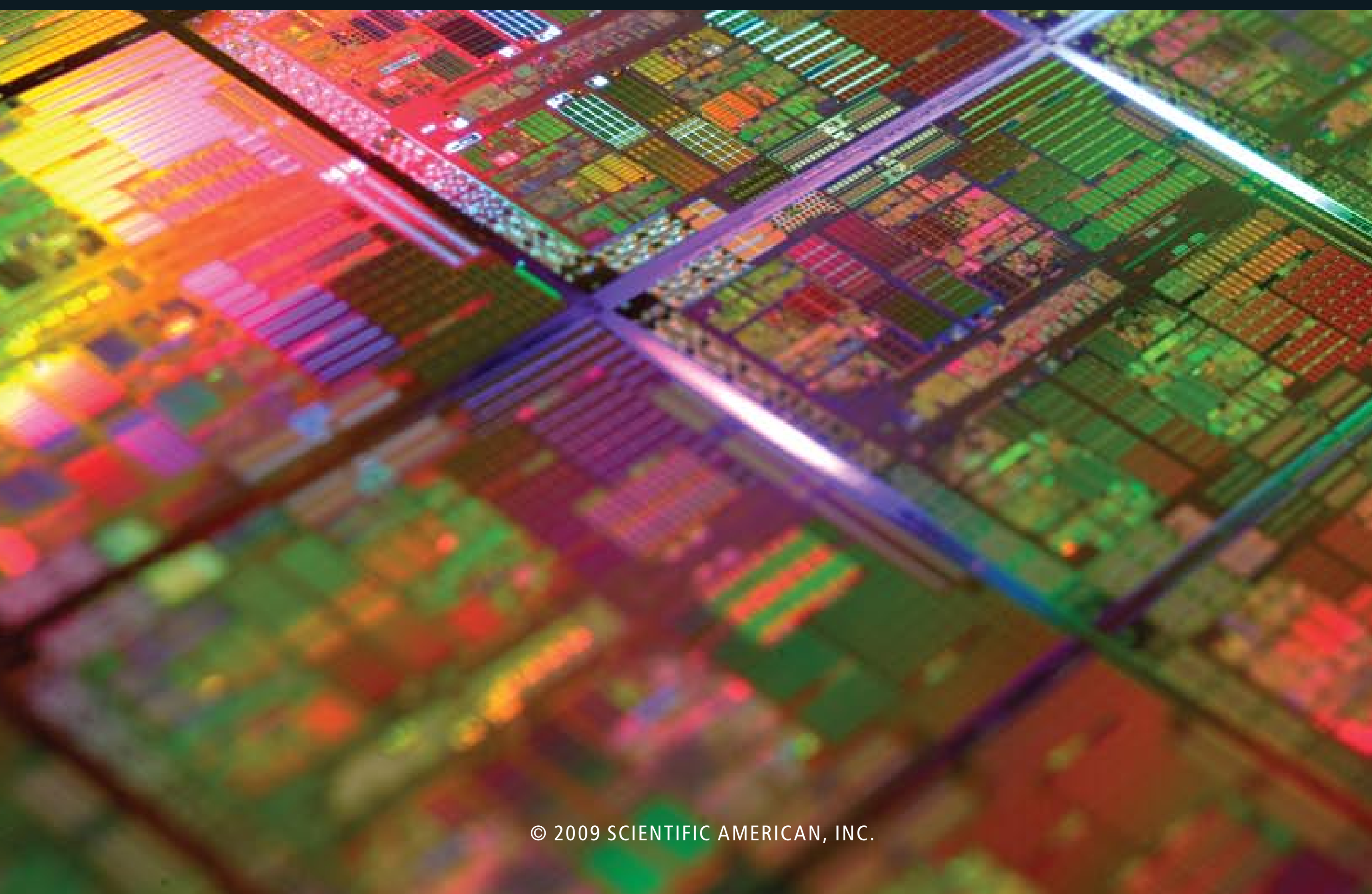
Nuclear Winter Revisited with a Modern Climate Model and Current Nuclear Arsenals: Still Catastrophic Consequences. Alan Robock, Luke Oman and Georgiy L. Stenchikov in *Journal of Geophysical Research,* Vol. 112; July 2007.

Massive Global Ozone Loss Predicted following Regional Nuclear Conflict. Michael J. Mills, Owen B. Toon, Richard P. Turco, Douglas E. Kinnison and Rolando R. Garcia in Proceedings of the *National Academy of Sciences USA,* Vol. 105, No. 14, pages 5307–5312; April 2008.

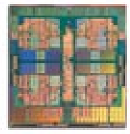
Environmental Consequences of Nuclear War. Owen B. Toon, Alan Robock and Richard P. Turco in *Physics Today,* Vol. 61, No. 12, pages 37–42; December 2008.

THE NEXT 20 YEARS OF MICROCHIPS

Designers are pushing all the boundaries to make integrated circuits smaller, faster and cheaper ◻ ◻ ◻ **By the Editors**



◀ EACH PHENOM X4 processor chip (*in array at left*) from AMD packs 758 million transistors.



◀ Actual chip size

In 1975 electronics pioneer Gordon Moore famously predicted that the complexity of integrated-circuit chips would double every two years. Manufacturing advances would allow the chip's transistors to shrink and shrink, so electrical signals would have to travel less distance to process information. To the electronics industry and to consumers, Moore's Law, as it became known, meant computerized devices would relentlessly become smaller, faster and cheaper. Thanks to ceaseless innovation in semiconductor design and fabrication, chips have followed remarkably close to that trajectory for 35 years.

Engineers knew, however, they would hit a wall at some point. Transistors would become only tens of atoms thick. At that scale, basic laws of physics would impose limits. Even before the wall was hit, two practical problems were likely to arise. Placing transistors so small and close together while still getting a high yield—usable chips versus defective ones—could become overly expensive. And the heat generated by the thicket of transistors switching on and off could climb enough to start cooking the elements themselves.

Indeed, those hurdles arose several years ago. The main reason common personal computers now have the loudly marketed "dual-core" chips—meaning two small processors instead of one—is because packing the needed number of transistors onto a single chip and cooling it had become too problematic. Instead computer designers are choosing to place two or more chips side by side and program them to process information in parallel.

Moore's Law, it seems, could finally be running out of room. How, then, will engineers continue to make chips more powerful? Switching to alternative architectures and perfecting nanomaterials that can be assembled atom by atom are two options. Another is perfecting new ways to process information, including quantum and biological computing. In the pages ahead, we take a look at a range of advances, many currently at the prototype stage, that in the next two decades could keep computing products on the "smaller, faster, cheaper" path that has served us so well.

KEY CONCEPTS

- It may soon be impossible to make transistors on integrated-circuit chips even smaller. Alternative materials and designs will be needed for chips to continue to improve.
- Nanowires, graphene, quantum particles and biological molecules could all spawn new generations of chips that are more powerful than today's best.

—The Editors

SIZE: CROSSING THE BAR

The smallest commercial transistors now made are only 32 nanometers wide—about 96 silicon atoms across. The industry acknowledges that it may be extremely hard to make features smaller than 22 nanometers using the lithography techniques that have improved for decades.

One option that has circuit features of a similar size but offers greater computing power is known as crossbar design. Instead of fabricating transistors all in one plane (like cars packed into the lanes of a jammed silicon highway), the crossbar approach has a set of parallel nanowires in one plane that crosses over a second set of wires at right angles to it (two perpendicular highways). A buffer layer one molecule thick is slipped between them. The many intersections that exist between the two sets of wires can act like switches, called memristors, that represent 1s and 0s (binary digits, or bits) the way transistors do. But the memristors can also store information. Together these capabilities can perform a number of computing tasks. Essentially one memristor can do the work of 10 or 15 transistors.

Hewlett-Packard Labs has fabricated prototype crossbar designs with titanium and platinum wires that are 30 nanometers wide, using materials and processes similar to those already optimized for the semiconductor industry. Company researchers think each wire could get as small as eight nanometers. Several research groups are also fashioning crossbars made from silicon, titanium and silver sulfide.

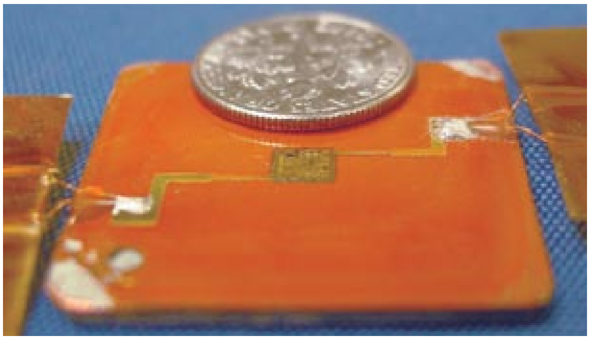
MEMRISTOR, from Hewlett-Packard, is a new kind of circuit element created at each raised intersection of overlapping nanowires.

COURTESY OF AMD GLOBAL COMMUNICATIONS (*left and top chips*); COURTESY OF R. STANLEY WILLIAMS *Hewlett-Packard Labs (crossbar architecture)*

HEAT: REFRIGERATORS OR WIND

With as many as one billion transistors on a chip, getting rid of heat generated as the transistors switch on and off is a major challenge. Personal computers have room for a fan, but even so about 100 watts of power dissipation per chip is as much as they can cool. Designers are therefore devising some novel alternatives. The MacBook Air notebook computer has a sleek case made from thermally conductive aluminum that serves as a heat sink. In the Apple Power Mac G5 personal computer, liquid runs through microchannels machined into the underside of its processor chip.

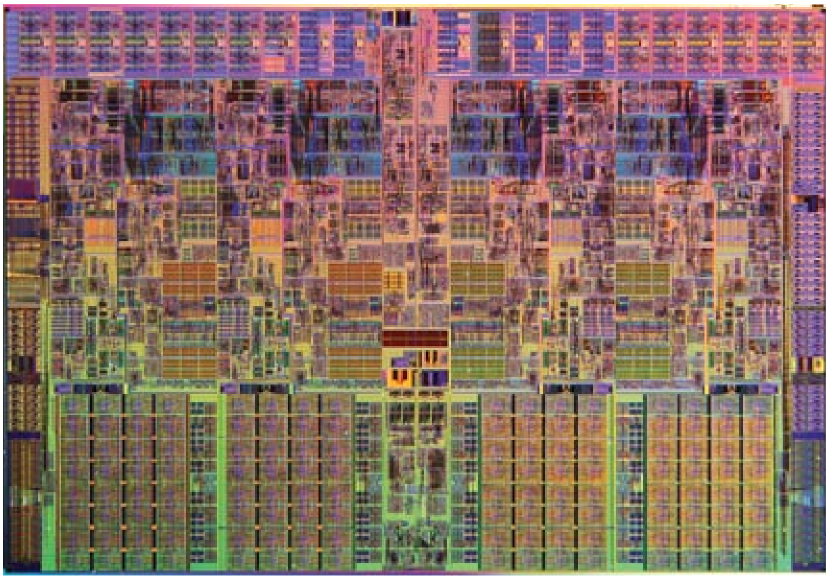
Fluids and electronics can be a dicey mix, however, and smaller, portable gadgets such as smart phones simply do not have room for plumbing—or fans. A research group led by Intel has crafted a thin-film superlattice of bismuth telluride into the packaging that encases a chip (*above*). The thermoelectric material converts temperature gradients into electricity, in effect refrigerating the chip itself.



COOLING PATCH (*center, gold*) made of bismuth telluride would transfer heat away from a much larger chip fastened on top of it to a thin dissipation layer (*orange*). The patch and layer use less space and power than current heat sinks.

Based on work at Purdue University, start-up company Ventiva is making a tiny solid-state "fan" with no moving parts that creates a breeze by harnessing the corona wind effect—the same property exploited by silent household air purifiers. A slightly concave grating has live wires that generate a microscale plasma; the ions in this gaslike mixture drive air molecules from the wires to an adjacent plate, generating a wind. The fan produces more airflow than a typical mechanical fan yet is much smaller. Other innovators are crafting Stirling engine fans, still somewhat bulky, that create wind but consume no electricity; they are powered by the difference in temperature between hot and cool regions of the chip.

ARCHITECTURE: MULTIPLE CORES



INTEL I7 processor has four cores (*bottom*) that work in parallel to quicken computation.

Smaller transistors can switch between off and on to represent 0 and 1 more quickly, making chips faster. But the clock rate—the number of instructions a chip can process in a second—leveled off at three to four gigahertz as chips reached the heat ceiling. The desire for even greater performance within the heat and speed limits led designers to place two processors, or cores, on the same chip. Each core operated only as quickly as previous processors, but because the two worked in parallel they could process more data in a given amount of time and consumed less electricity, producing less heat. The latest personal computers now sport quadruple cores, such as the Intel i7 and the AMD Phenom X4.

The world's most powerful supercomputers contain thousands of cores, but in consumer products, using even a few cores most effectively requires new programming techniques that can partition data and processing and coordinate tasks. The basics of parallel programming were worked out for supercomputers in the 1980s and 1990s, so the challenge is to create languages and tools that software developers can use for consumer applications. Microsoft Research, for example, has released the F# programming language. An early language, Erlang, from the Swedish company Ericcson, has inspired newer languages, including Clojure and Scala. Institutions such as the University of Illinois are also pursuing parallel programming for multiple-core chips.

If the approaches can be perfected, desktop and mobile devices could contain dozens or more parallel processors, which might individually have fewer transistors than current chips but work faster as a group overall.

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SLIMMER MATERIALS: NANOTUBES AND SELF-ASSEMBLY

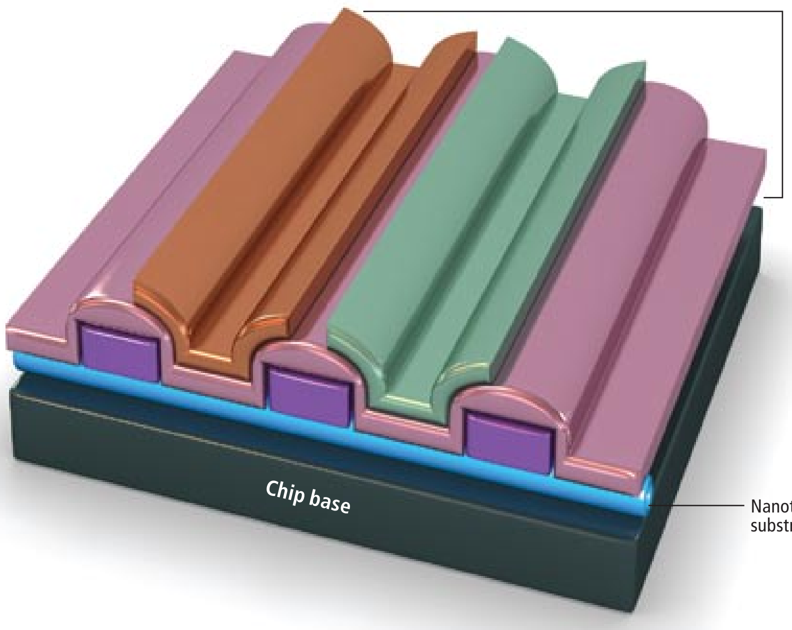
For a decade already, pundits have hailed nanotechnology as the solution to all sorts of challenges in medicine, energy and, of course, integrated circuitry. Some enthusiasts argue that the semiconductor industry, which makes chips, actually created the nanotechnology discipline as it devised ever tinier transistors.

The higher expectation, however, is that nanotechniques would allow engineers to craft designer molecules. Transistors assembled from carbon nanotubes, for example, could be much smaller. Indeed, engineers at IBM have fabricated a traditional, complementary metal-oxide-semiconductor (CMOS) circuit that uses a carbon nanotube as the conductive substrate, instead of silicon (*right*). Joerg Appenzeller from that team, now at Purdue University, is devising new transistors that are far smaller than CMOS devices, which could better exploit a minuscule nanotube base.

Arranging molecules or even atoms can be tricky, especially given the need to assemble them at high volume during chip production. One solution could be molecules that self-assemble: mix them together, then expose them to heat or light or centrifugal forces, and they will arrange themselves into a predictable pattern.

IBM has demonstrated how to make memory circuits using polymers tied by chemical bonds. When spun on the surface of a silicon wafer and heated, the molecules stretch and form a honeycomb structure with pores only 20 nanometers wide. The pattern could subsequently be etched into the silicon, forming a memory chip at that size.

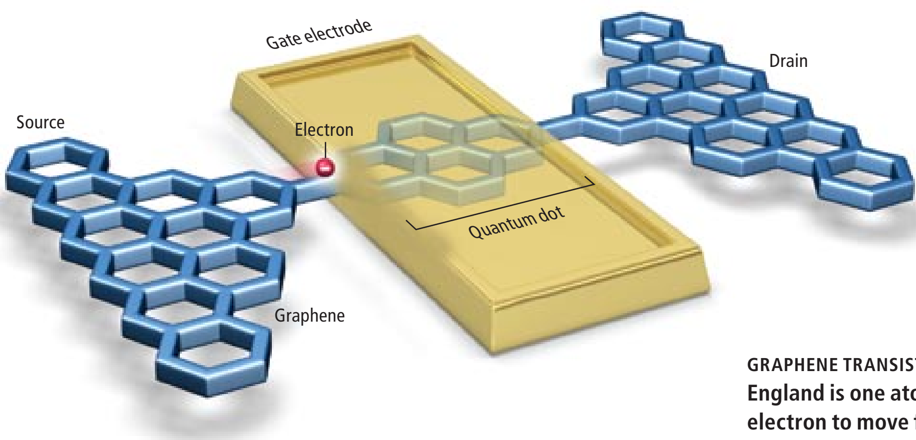
RING OSCILLATOR circuit is built on a single carbon nanotube that connects the circuit elements.



FASTER TRANSISTORS: ULTRATHIN GRAPHENE

The point of continually shrinking transistors is to shorten the distance that electrical signals must travel within a chip, which increases the speed of processing information. But one nanomaterial in particular—graphene—could function faster because of its inherent structure.

Most logic chips that process information use field-effect transistors made with CMOS technology. Think of a transistor as a narrow, rectangular layer cake, with an aluminum (or more recently, polysilicon) layer on top, an insulating oxide layer in the middle, and a semiconducting silicon layer on the bottom. Graphene—a newly isolated form of carbon molecule—is a flat sheet of repeating hexagons that looks like chicken wire but is only one atomic layer thick. Stacked atop one another, graphene sheets form the mineral graphite, familiar to us as pencil "lead." In its pure crystal form, graphene conducts electrons faster than any other material at room temperature—far faster than field-effect transistors do. The charge carriers also lose very little energy as a result of scattering or colliding with atoms in the lattice, so less waste heat is generated. Scientists isolated graphene as a material only in 2004, so work is very early, but researchers are confident they can make graphene transistors that are just 10 nanometers across and one atom high. Numerous circuits could perhaps be carved into a single, tiny graphene sheet.



GRAPHENE TRANSISTOR fabricated at the University of Manchester in England is one atom thick. A quantum dot allows only a single electron to move from source to drain, registering a 1 or 0.

SPLASHLIGHT

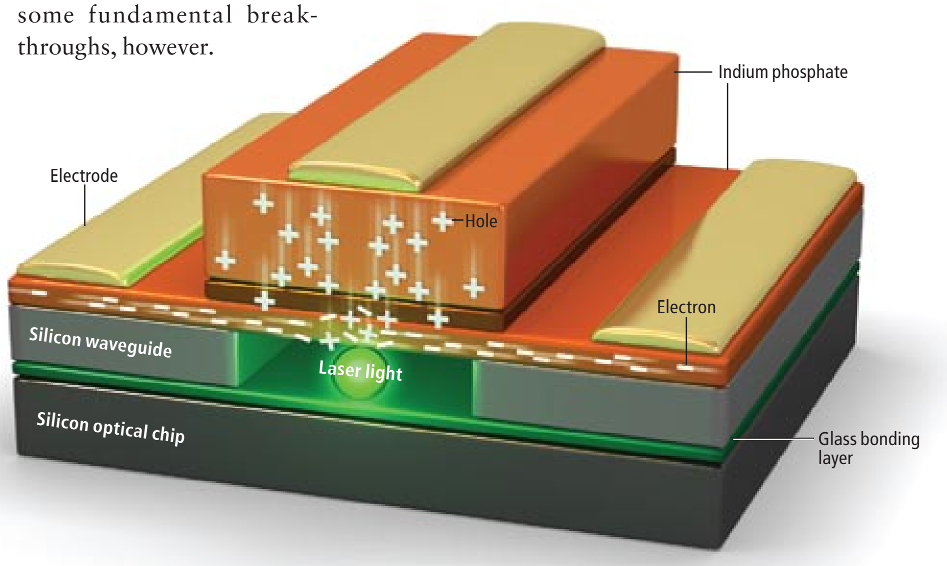
OPTICAL COMPUTING: QUICK AS LIGHT

Radical alternatives to silicon chips are still so rudimentary that commercial circuits may be a decade off. But Moore's Law will likely have run its course by then, so work is well under way on completely different computing schemes.

In optical computing, electrons do not carry information, photons do, and they do so far faster, at the speed of light. Controlling light is much more difficult, however. Progress in making optical switches that lie along fiber-optic cables in telecommunications lines has helped optical computing, too. One of the most advanced efforts, ironically, aims to create an optical interconnect between the traditional processors on multicore chips; massive amounts of data must be shuttled between cores that are processing information in parallel, and electronic wires between them can become a bottleneck. Photonic interconnects could improve the flow. Researchers at Hewlett-Packard Labs are evaluating designs that could move two orders of magnitude more information.

Other groups are working on optical interconnects that would replace the slower copper wires that now link a processor chip to other components inside computers, such as memory chips and DVD drives. Engineers at Intel and the University of California, Santa Barbara, have built optical "data pipes" from indium phosphate and silicon using common semiconductor manufacturing processes (*below*). Completely optical computing chips will require some fundamental breakthroughs, however.

OPTICAL CHIP can compute fast if it has an internal, controllable light source. Electrons and holes in indium phosphate layers recombine at the center to generate light that spreads down a silicon waveguide and through a glass layer.

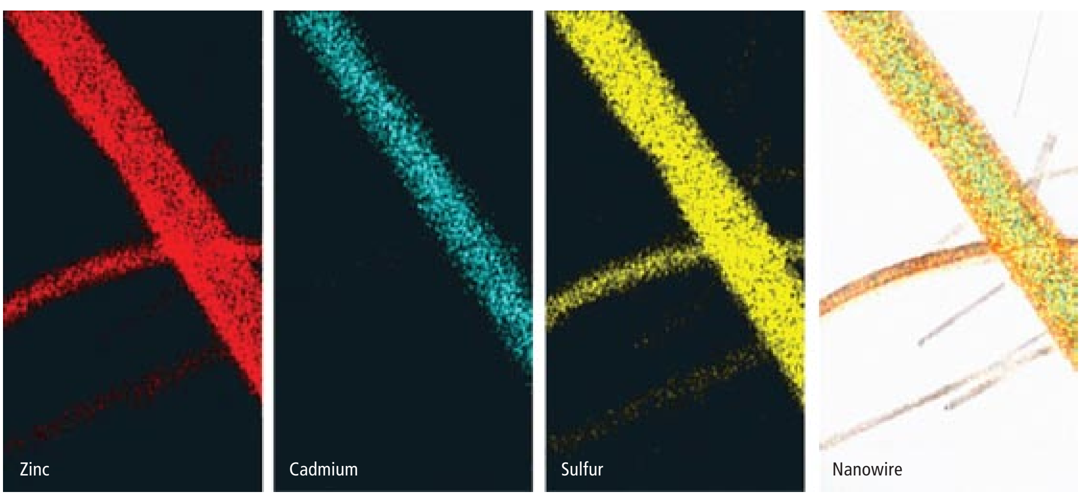


MOLECULAR COMPUTING: ORGANIC LOGIC

In molecular computing, instead of transistors representing the 1s and 0s, molecules do so. When the molecule is biological, such as DNA, the category is known as biological computing [see "Biological Computing: Chips That Live," on opposite page]. To be clear, engineers may refer to computing with nonbiological molecules as molecular logic, or molectronics.

A classic transistor has three terminals (think of the letter Y): source, gate and drain. Applying a voltage to the gate (the stem of the Y) causes electrons to flow between source and drain, establishing a 1 or 0. Molecules with branchlike shapes could theoretically cause a signal to flow in a similar way. Ten years ago researchers at Yale and Rice universities crafted molecular switches using benzene as a building block.

Molecules can be tiny, so circuits built with them could be far smaller than those made in silicon. One difficulty, however, is finding ways to fabricate complex circuits. Researchers hope that self-assembly might be one answer. In October 2009 a team at the University of Pennsylvania transformed zinc and crystalline cadmium sulfide into metal-semiconductor superlattice circuits using only chemical reactions that prompted self-assembly (*below*).



THIN ZINC, cadmium and sulfur nanowires self-assemble into a thicker nanowire and shell (*far right*) appropriate for a circuit, when exposed to a half-second pulse of dimethylzinc vapor.

SPLASHLIGHT (*top*); COURTESY OF RITESH AGARWAL *University pf Pennsylvania (bottom)*

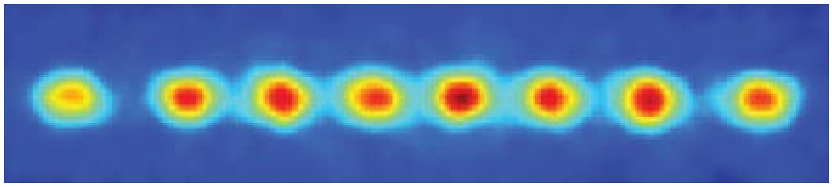
QUANTUM COMPUTING: SUPERPOSITION OF 0 AND 1

Circuit elements made of individual atoms, electrons or even photons would be the smallest possible. At this dimension, the interactions among the elements are governed by quantum mechanics—the laws that explain atomic behavior. Quantum computers could be incredibly dense and fast, but actually fabricating them and managing the quantum effects that arise are daunting challenges.

Atoms and electrons have traits that can exist in different states and can form a quantum bit, or qubit. Several research approaches to handling qubits are being investigated. One approach, called spintronics, uses electrons, whose magnetic moments spin in one of two directions; think of a ball spinning in one direction or the other (representing 1 or 0). The two states can also coexist in a single electron, however, creating a unique quantum state known as a superposition of 0 and 1. With superposition states, a series of electrons could represent exponentially more information than a string of silicon transistors that have only ordinary bit states. U.C. Santa Barbara scientists have created a number of different logic gates by tapping electrons in cavities that are etched into diamond.

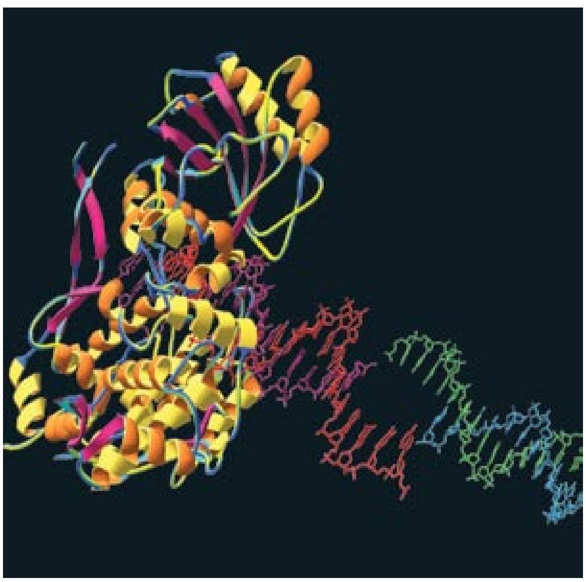
In another approach being pursued by the University of Maryland and the National Institute of Standards and Technology, a string of ions is suspended between charged plates, and lasers flip each ion's magnetic orientation (their qubits). A second option is to detect the different kinds of photons an ion emits, depending on which orientation it takes.

In addition to enjoying superposition, quantum elements can become "entangled." Information states are linked across many qubits, allowing powerful ways to process information and to transfer it from location to location.



LEVITATED STRING of calcium ions in a vacuum chamber can perform quantum calculations.

BIOLOGICAL COMPUTING: CHIPS THAT LIVE



COMPUTATION can occur when a DNA molecule (*right, green*) provides data to software DNA molecules (*center, red*) that a FokI enzyme (*colored ribbon*) can process.

COURTESY OF R. BLATT *Institute for Experimental Physics, University of Innsbruck (top);* COURTESY OF EHUD SHAPIRO *Weizmann Institute of Science (bottom)*

Biological computing replaces transistors with structures usually found in living organisms. Of great interest are DNA and RNA molecules, which indeed store the "programming" that directs the lives of our cells. The taunting vision is that whereas a chip the size of a pinky fingernail might contain a billion transistors, a processor of the same size could contain trillions of DNA strands. The strands would process different parts of a computing task at the same time and join together to represent the solution. A biological chip, in addition to its having orders of magnitude more elements, could provide massively parallel processing.

Early biological circuits process information by forming and breaking bonds among strands. Researchers are now developing "genetic computer programs" that would live and replicate inside a cell. The challenge is finding ways to program collections of biological elements to behave in desired ways. Such computers may end up in your bloodstream rather than on your desktop. Researchers at the Weizmann Institute of Science in Rehovot, Israel, have crafted a simple processor from DNA (*above*), and they are now trying to make the components work inside a living cell and communicate with the environment around that cell.

➡ MORE TO EXPLORE

A Future of Integrated Electronics: Moving Off the Roadmap. Edited by Daniel J. Radack and John C. Zolper. Special issue of *Proceedings of the IEEE,* Vol. 96, No. 2; February 2008.

Carbon Wonderland. Andre K. Geim and Philip Kim in *Scientific American,* Vol. 298, No. 4, pages 90–97; April 2008.

Molecular Implementation of Simple Logic Programs. Tom Ran et al. in *Nature Nanotechnology,* Vol. 4, pages 642–648; October 2009.

A Plan to Defeat NEGLECTED TROPICAL DISEASES

The poorest people are not only poor. They are also chronically sick, making it harder for them to escape poverty. A new global initiative may break the vicious cycle

BY PETER JAY HOTEZ

KEY CONCEPTS

- A group of seven tropical diseases, mostly caused by parasitic worms, afflict a billion impoverished people worldwide. They seldom kill directly but cause lifelong misery that stunts children's growth, leaves adults unable to function to their fullest, and heightens the risk of other diseases.
- Fortunately, they can be easily treated, often with a single pill. Various agencies and foundations are collaborating to deliver these drugs, although they have reached only about 10 percent of the population so far.
- The U.S. has its own neglected parasitic diseases that affect millions of rural and urban poor.

—The Editors

In the north of Burkina Faso, not far to the east of one of the best-known backpacker destinations in West Africa, the Bandiagara Escarpment in Mali, lies the town of Koumbri. It was one of the places where the Burkina Ministry of Health began a mass campaign five years ago to treat parasitic worms. One of the beneficiaries, Aboubacar, then an eight-year-old boy, told health workers he felt perpetually tired and ill and had noticed blood in his urine. After taking a few pills, he felt better, started to play soccer again, and began focusing on his schoolwork and doing better academically.

The Burkina Faso program, which treated more than two million children, was both a success story and an emblem of the tragedy of disease in the developing world. For want of very simple treatments, a billion people in the world wake up every day of their lives feeling sick. As a result they cannot learn in school or work effectively.

Most people in richer countries equate tropical disease with the big three—HIV/AIDS, tuberculosis and malaria—and funding agencies allocate aid accordingly. Yet a group of conditions known collectively as neglected tropical diseases (NTDs) has an even more widespread impact. They may not often kill, but they debilitate by causing severe anemia, malnutrition, delays in intellectual and cognitive development, and blindness. They can lead to horrific limb and genital disfigurement and skin deformities and increase the risk of acquiring HIV/AIDS and suffer-

ISSOUF SANGO *AFP/Getty Images*

ONE TABLET **of ivermectin per year is enough to protect against river blindness. Health workers in the Ivory Coast have been battling a resurgence of the disease.**

[DISEASE STATS]

THE GRISLY SEVEN

The neglected tropical diseases comprise seven parasitic or bacterial infections that are common in impoverished areas.

DISEASE	CASES	CAUSE	TRANSMISSION	EFFECTS
Roundworm (Ascariasis)	800 million	5- to 14-inch-long *Ascaris* worms that live in the small intestine (*shown actual size*)	Soil	■ Malnutrition and intestinal obstruction in young children ■ Child stunting ■ Impaired cognition
Whipworm (Trichuriasis)	600 million	1- to 2-inch-long *Trichuris* worms that live in the colon (large intestine)	Soil	■ Colitis and inflammatory bowel disease ■ Child stunting and impaired cognition
Hookworm	600 million	0.5-inch-long *Necator* worms that live in the small intestine	Soil	■ Severe iron deficiency anemia and protein malnutrition ■ "Yellow disease"(anemia) ■ Child stunting and impaired intellectual and cognitive development ■ Maternal morbidity and mortality in pregnancy
Schistosomiasis	200 million	0.5- to 1-inch-long blood flukes that live in veins of the bladder or intestines	Freshwater	■ Spiny eggs that damage the bladder, intestine or liver and cause inflammation ■ Chronic pain, anemia, malnutrition and stunting ■ Liver and intestinal fibrosis (for *Schistosoma mansoni* and *S. japonicum*) ■ Blood in urine, kidney disease, female genital schistosomiasis (for *S. haematobium*)
Lymphatic filariasis (LF) (elephantiasis)	120 million	2- to 4-inch-long *Wuchereria* worms that live in the limbs, breasts and genitals	Mosquitoes	■ Leg swelling ■ Scrotum enlargement ■ Disfigurement
Onchocerciasis	30–40 million	1- to 20-inch-long *Onchocerca* worms living in nodules under the skin	Black flies	■ Microfilariae (larvae) in the skin and eyes ■ *Onchocerca* skin disease ■ Blindness
Trachoma	60–80 million	*Chlamydia* intracellular bacteria	Poor hygiene, house flies	■ Blindness

[THE AUTHOR]

Peter Jay Hotez became interested in medicine as child when he read Paul De Kruif's classic book *Microbe Hunters* and asked his parents for a microscope. He went on to obtain both a Ph.D. and an M.D., specializing in parasitology. He now chairs the department of microbiology, immunology and tropical medicine at George Washington University. Hotez is president of the Sabin Vaccine Institute, a member of the Institute of Medicine of the National Academies of Science, and co-founder of the Global Network for Neglected Tropical Diseases.

ing complications during pregnancy. They not only result from poverty but also help to perpetuate it. Children cannot develop to their full potential, and adult workers are not as productive as they could be.

Such diseases are not confined to developing nations. I estimate that millions of Americans living in poverty also suffer from NTD-like infections. Parasitic diseases such as cysticercosis, Chagas disease, trichomoniasis and toxocariasis occur with high frequency in our inner cities, post-Katrina Louisiana, other parts of the Mississippi Delta, the border region with Mexico, and Appalachia [*see box on page 94*].

NTDs have plagued humankind for thousands of years. Historians have found accurate descriptions of many of them in ancient texts as diverse as the Bible, the Talmud, the Vedas, the writings of Hippocrates, and Egyptian papyri. What is new, however, is that donors, drugmakers, health ministries in low- and middle-income countries, the World Health Organization (WHO), and public-private partnerships are linking their efforts to combat the NTDs in a more coordinated and systematic way. Over the past half a decade the Bill & Melinda Gates Foundation, the Dubai-based sustainable development fund Legatum, and the U.S. and British governments have committed serious money, while major pharmaceutical companies have donated urgently needed NTD drugs. But the battle has only begun.

Like Leeches in Your Gut

The scale and extent of the global NTD problem are hard to take in. Almost every destitute person living in sub-Saharan Africa, Southeast Asia and Latin America is infected with one or more of these diseases. The illnesses last years, decades and often even a lifetime. The seven most common NTDs have the most devastating impact.

Three of them are caused by parasitic worms, also known as helminths, that live in the intestines. The large common roundworm, which results in ascariasis, afflicts 800 million people and the whipworm, which results in trichuriasis, 600 million people. These helminths rob children of nutrients, stunting their growth. Even

COURTESY OF GW MEDICAL CENTER MARKETING AND COMMUNICATIONS (*Hotez*); CAT WILSON (*worms*); ERIK S. LESSER *Redux Pictures* (*woman and child*); MARIELLA FURRER *Redux Pictures* (*woman crying*)

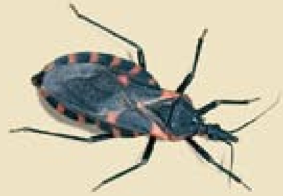
ENDEMIC AREAS	TREATMENT	MAJOR CONTROL PROGRAMS
Asia, Africa, Americas	Albendazole, mebendazole	WHO, Children Without Worms, Deworm the World
Asia, Africa, Americas	Albendazole, mebendazole	WHO, Children Without Worms, Deworm the World
Asia, Africa, Americas	Albendazole, mebendazole	WHO, Children Without Worms, Deworm the World, Sabin Vaccine Institute
Mostly in Africa; remainder in Brazil, East Asia, Middle East	Praziquantel	Schistosomiasis Control Initiative
Asia, Africa, Americas	Ivermectin or diethylcarbamazine and albendazole	Global Program to Eliminate Lymphatic Filariasis, Lymphatic Filariasis Support Center, Carter Center
Mostly in Africa, some in Latin America	Ivermectin	African Program for Onchocerciasis Control, Carter Center, Mectizan Donation Program
Africa, Asia, Americas	Azithromycin; SAFE strategy: simple surgery, antibiotics, face washing, environment (such as sanitation)	International Trachoma Initiative, Carter Center, Helen Keller International, Sight Savers, Christian Blind Mission

worse are hookworms, which are found in 600 million people. These half-inch-long worms attach to the inside of the small intestine and suck blood, like an internal leech. Over a period of months or years they produce severe iron-deficiency anemia and protein malnutrition. Children with chronic hookworm anemia take on a sickly and sallow complexion and have trouble learning in school. More than 40 million pregnant women are also infected with hookworm, rendering them vulnerable to malaria or additional blood losses in childbirth. Their babies are born with low birth weights [see "Hookworm Infection," by Peter J. Hotez and David I. Pritchard; Scientific American, June 1995].

Schistosomiasis is the next most common NTD. It is caused by parasitic worms known as schistosomes that live in the veins draining the intestines or bladder. More than 90 percent of the 200 million cases occur in sub-Saharan Africa, with another few million cases in Brazil and several other countries. Female schistosomes release eggs equipped with tiny spears that invade and damage organs, including the intestine and liver or the bladder and kidneys, depending on the species. Roughly 100 million school-aged children and young adults pass blood in their urine or feces every day as a result. The inflammation produces pain, malnutrition, growth stunting and anemia. In women, schistosomes deposit eggs in the cervix and vagina, causing disabling pain during sexual intercourse and tripling the risk of acquiring HIV/AIDS [see "Fighting Killer Worms," by Patrick Skelly; Scientific American, May 2008].

Two other important helminth infections are lymphatic filariasis (LF) and onchocerciasis. The worms that cause LF live in the limbs, breasts and genitals of 120 million people in Asia, Africa and Haiti. They lead to elephantiasis, a gross-

ELEPHANTIASIS (*below, in Haiti*) and blindness (*right, in Ethiopia*) are two of the most visible consequences of neglected tropical diseases.



[PARASITIC INFECTIONS IN THE U.S.]

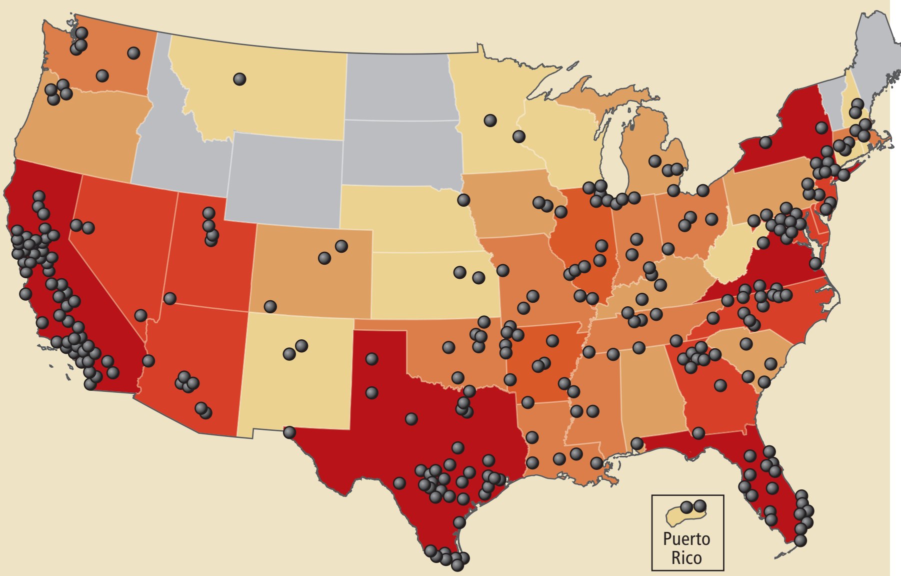
Horrors of the Kissing Bug

The U.S., too, suffers high rates of parasitic diseases. These so-called neglected infections of poverty closely resemble the neglected tropical diseases (NTDs) and are found predominantly in areas of intense poverty. They disproportionately affect African-Americans and Hispanic-Americans, because a higher percentage of these populations live in poverty and under stressful conditions.

In the Mississippi Delta, post-Katrina Louisiana and other areas of the American South, as well as in inner cities, an estimated three million African-Americans are either currently infected or have been infected in the past with a helminth infection known as toxocariasis. The worm eggs are found in soil or sand laced with dog feces and can contaminate food. Once the worm eggs hatch in the digestive tract, the released larvae migrate through the lungs, liver and brain, leading to wheezing, seizures and developmental delays. Another infection is trichomoniasis, a sexually transmitted protozoan parasite that causes inflammation and hemorrhages in the cervix. It increases the risk of acquiring additional sexually transmitted diseases, possibly including HIV/AIDS.

Among Hispanic-Americans, two important infections of poverty are Chagas disease and cysticercosis. Chagas results from a trypanosome protozoan acquired when people are bitten by a kissing bug, a type of assassin bug—a cockroachlike insect often found in dilapidated housing where rats nest (*photograph above*). The parasites can produce a severe dilation of the heart and can prove fatal. An estimated 300,000 people in the U.S. have Chagas disease. Cysticercosis is a parasitic helminth infection that occurs in as many as 170,000 people and is the leading cause of seizures in cities near the Mexican border.

Most of these infections were not introduced into the U.S. as a result of immigration. Instead they most likely persist through transmission within U.S. borders. Despite their prevalence, research on these conditions has been fairly limited. Health officials do not know the precise numbers of people infected or why poverty is a risk factor. Diagnostic methods and treatments are also fairly rudimentary. —*P.J.H.*



BLOOD DONORS TESTING POSITIVE FOR CHAGAS DISEASE, BY STATE, 2007–2009

1–2 | 3-4 | 5–10 | 11–69 | 70–375 | Data unavailable

Locations of confirmed cases

SOURCE: AABB

CHAGAS DISEASE afflicts an estimated 300,000 people in the U.S. Screening of donated blood, started in 2007, finds that cases are concentrated in areas with large numbers of immigrants from Latin America living in substandard housing.

ly disfiguring condition that prevents adults from working and leaves women, in particular, unable to marry or abandoned by their husbands. Onchocerciasis, or river blindness, causes a horribly itchy and disfiguring skin disease as well as blindness in middle-aged adulthood. Almost all of its 30 million to 40 million cases occur in Africa, except for a few locations in the Americas and Yemen.

The seventh important NTD, trachoma, is not caused by a parasitic worm but is a chronic bacterial infection caused by the *Chlamydia* microorganism. Occurring in 60 million to 80 million people, it is the leading infectious cause of blindness [see "Can Chlamydia Be Stopped?" by David M. Ojcius, Toni Darville and Patrik M. Bavoil; Scientific American, May 2005].

In a series of policy papers, my colleagues and I studied the repercussions of these seven NTDs. Together their global health damage, as measured by the number of healthy life years lost because of disability, is roughly equivalent to that of HIV/AIDS or malaria. Because of their devastating toll on child education and development, pregnancy, and agricultural worker productivity, these NTDs are a major cause of poverty. One case study by Hoyt Bleakley, a development economist, found that chronic hookworm infection in childhood reduced a person's lifetime earning power by more than 40 percent; K. D. Ramaiah and others in India estimated more than $800 million lost annually from reduced worker productivity as a result of LF. Other studies have found similar effects for onchocerciasis and trachoma.

Curing the Sick with Salt

The good news is that these NTDs can be treated, or even prevented, simply and cheaply [*see table on preceding two pages*]. In many cases, a single pill is enough. The available drugs have an excellent safety record, and each is either provided free of charge by multinational companies or available as cheap generics costing less than 10 cents per tablet.

In the early 20th century John D. Rockefeller sponsored mass drug administration to control helminth infection in the American South, and similar efforts began in the Caribbean. During the 1950s and 1960s several tropical medicine specialists started programs for other infections and locations. Among them was Frank Hawking, father of physicist Stephen Hawking, who in 1967 published the results of a study in Brazil in which he treated LF by add-

PHOTO RESEARCHERS, INC. (*assassin bug*); LUCY READING-IKKANDA (*map*)

ing diethylcarbamazine to cooking salt. In 1988 Merck & Co. began one of the first public-private partnerships for the mass treatment of river blindness. Various such partnerships have since been established, and today they reach tens of millions of people annually.

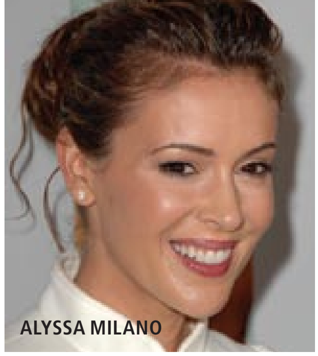
Through the delivery of extremely low cost treatments, these partnerships—in collaboration with WHO, health ministries in low-income countries, and several multinational pharmaceutical companies—have managed to control or eliminate river blindness in 11 African countries, allowing farmers to return to arable lands they had abandoned because of high rates of blindness in their communities. Similarly, treatment programs have eliminated LF in more than a dozen previously endemic countries and reduced the prevalence of schistosomiasis by up to 80 percent in eight African countries. Measured narrowly in financial terms, the internal rates of return for these programs have ranged as high as 30 percent.

One Pill to Cure Them All

Despite these enormous successes, we still have a long way to go to provide complete drug coverage for the billion or more people with NTDs. WHO estimates that treatment programs reach fewer than 10 percent of people suffering from intestinal infections and schistosomiasis.

Better organization and technology are part of the answer. WHO and other organizations have studied the simultaneous administration of many NTD drugs, and they are moving quickly to provide these drugs as a single package (sometimes referred to as a rapid impact package), which can cost as little as 50 cents annually. A number of African countries have already begun to integrate programs that target individual NTDs into a single program. Bundling reduces costs and the strain on otherwise overburdened health systems, as well as providing an opportunity to fold in other interventions, among them the delivery of antimalaria bed nets, childhood immunizations and nutritional supplements such as vitamin A.

Although the integration of NTD-control programs has been largely successful so far, it has also encountered some operational challenges, including an increased workload for community drug distributors and the lack of availability of some of the NTD drugs in certain places. Health workers have had to be vigilant in looking for signs of drug resistance.



ALYSSA MILANO

HOW TO HELP

The neglected tropical diseases represent an enormous challenge, but because treatment is so inexpensive, individuals can make a difference. Luminaries ranging from Bill Clinton to actress Alyssa Milano have lent their time and support to the Global Network.

One step is to join the Just 50 Cents Campaign, the network's grassroots fundraising and awareness campaign. A donation of just 50 cents can provide a person with treatment for the seven most common NTDs for an entire year. Visit: *www.globalnetwork.org/just50cents*

➥ MORE TO EXPLORE

Control of Bancroftian Filariasis by Cooking Salt Medicated with Diethylcarbamazine. Frank Hawking and Ruy João Marques in *Bulletin of the World Health Organization,* Vol. 37, No. 3, pages 405–414; 1967. Available online at **www.ncbi.nlm.nih.gov/pmc/articles/PMC2554262**

Forgotten People, Forgotten Diseases: The Neglected Tropical Diseases and Their Impact on Global Health and Development. Peter J. Hotez. ASM Press, 2008.

Rescuing the Bottom Billion through Control of Neglected Tropical Diseases. Peter J. Hotez et al. in *Lancet,* Vol. 373, No. 9674, pages 1570–1575; May 2, 2009. Available online at **tinyurl.com/yh5qbeq**

Ultimately, these NTD-control programs will need more money. The U.S. and British governments have committed more than $400 million over the next few years to support integrated NTD control, but estimates suggest that controlling NTDs in the 56 endemic countries will require $2 billion to $3 billion for the next five to seven years. To make the case for better funding, some of the major public-private partnerships came together in 2006 to form the Global Network for NTDs, which works closely with WHO and its regional offices. Hosted by the Sabin Vaccine Institute, the network receives support from the Gates foundation and other private donors and works to support treatment programs for NTDs around the world through advocacy, policy and logistical efforts.

The Sabin Vaccine Institute has also established an international product development partnership to produce new vaccines for hookworm infection and schistosomiasis. A hookworm vaccine is now entering clinical trials, which is welcome news because of concerns that one of the drugs now in use for mass treatment is showing high failure rates, a sign that the parasite has become resistant. Sabin works with a spectrum of Brazilian research and development institutes and the Brazilian government. Brazil has the largest number of cases of these helminth infections in the Americas; these NTDs were originally introduced from the endemic areas of West Africa by the slave trade, making them living vestiges of slavery.

If fighting NTDs is so obvious and so cheap, why has it taken so long to act in a systematic way? That is not an easy question to answer. In the Millennium Development Goals for sustainable reduction of poverty, launched in 2000, the NTDs were lumped in an "other diseases" category, and it is hard to get people excited about "other diseases." Moreover, the NTDs debilitate more than they kill, so that the big donor countries have chosen to focus primarily on HIV/AIDS, tuberculosis and malaria, which are fatal unless treated. Other development programs, viewing NTDs as a symptom rather than the disease, have preferred to concentrate on what they see as the underlying problems, such as poor sanitation, lack of access to clean water, and poverty in general. Those are laudable aims, but the empirical reality is that NTD drugs are the single most cost-effective way to improve the health, education and well-being of the world's poor right now. ■

STEVE GRANITZ *Getty Images (Milano)*; DON FARRALL *Getty Images (quarters)*

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85354140
See HarborFreightusa.com/sciamerican for additional SUPER COUPONS
SUPER COUPON!
3000 LB. CAPACITY LIGHTWEIGHT ALUMINUM RACING JACK
U.S. GENERAL
Item 91039 shown
$59.99
LOT NO. 91039/67408
REG. PRICE $99.99
SAVE $40
68035260
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These valuable coupons are only good when presented at your nearest Harbor Freight Tools store. Offer Ends 4/15/10.
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SUPER COUPON!
LOT NO. 67256
MULTIFUNCTION POWER TOOL
CHICAGO Electric Power Tools
$34.99
REG. PRICE $59.99
SAVE 41%
31260250
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SUPER COUPON!
CENTRAL MACHINERY INDUSTRIAL
10" INDUSTRIAL BENCH TABLE SAW
Stand sold separately.
$69.99
REG. PRICE $149.99
SAVE $80
LOT NO. 97896
49721152
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SUPER COUPON!
1-1/2 HP BRIDGE TILE SAW WITH STAND
LOT NO. 97360
CHICAGO Electric Power Tools
Diamond blade sold separately.
$169.99
REG. PRICE $299.99
SAVE $130
32681347
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SUPER COUPON!
CENTRAL PNEUMATIC
3 GALLON 100 PSI OILLESS PANCAKE AIR COMPRESSOR
$39.99
REG. PRICE $74.99
LOT NO. 95275
SAVE 46%
76709708
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SUPER COUPON!
9 volt DC battery included.
NON-CONTACT LASER THERMOMETER
CEN-TECH
SAVE 55%
LOT NO. 96451
$26.99
REG. PRICE $59.99
DANGER
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HARBOR FREIGHT TOOLS - LIMIT 1
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SUPER COUPON!
1500 WATT DUAL TEMPERATURE HEAT GUN (572°/1112°)
Item 96289 shown
CHICAGO Electric Power Tools
$7.99
REG. PRICE $19.99
SAVE 60%
LOT NO. 96289/66001
78460011
HARBOR FREIGHT TOOLS - LIMIT 1
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SUPER COUPON!
29 PIECE TITANIUM NITRIDE COATED DRILL BIT SET
DRILL MASTER
$9.99
SAVE 64%
LOT NO. 5889
REG. PRICE $27.99
77625630
HARBOR FREIGHT TOOLS - LIMIT 1
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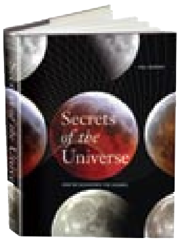
Cosmic Revelations ▪ Bird-Watching ▪ Medieval Manuscripts

BY KATE WONG

SECRETS OF THE UNIVERSE: HOW WE DISCOVERED THE COSMOS

by Paul Murdin. University of Chicago Press, 2009 ($49)



Astronomer Paul Murdin traces the history of astronomical discoveries—from the shape of Earth to the cosmic microwave background to the origin of the elements. Pictured at the right is the N49 supernova remnant in the Large Magellanic Cloud. Supernovae play a key role in distributing the elements made in stars.

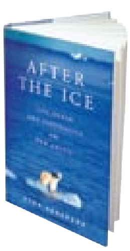
THE CASE FOR PLUTO: HOW A LITTLE PLANET MADE A BIG DIFFERENCE

by Alan Boyle. Wiley, 2009 ($22.95)

Science writer Alan Boyle chronicles the rise and fall of embattled Pluto—from its serendipitous discovery in 1930 to its hotly debated downgrade to nonplanet in 2006—and in so doing reveals just how intertwined science, politics and culture really are.

AFTER THE ICE: LIFE, DEATH AND GEOPOLITICS IN THE NEW ARCTIC

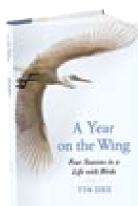
by Alun Anderson. Smithsonian, 2009 ($26.99)



Ice is vanishing from the Arctic so fast that no one can keep up, asserts journalist Alun Anderson. Aiming to provide a big picture sketch of the region, he examines the science, politics and business of the Arctic and considers who stands to gain and lose from this transformation.

A YEAR ON THE WING: FOUR SEASONS IN A LIFE WITH BIRDS

by Tim Dee. Free Press, 2009 ($24)



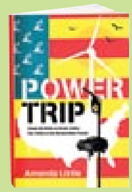
In this lyrical memoir, radio producer and writer Tim Dee draws on 40 years of avian observation to compose an account of a year in the lives of birds. Along the way he explores humanity's fascination with these creatures and their journeys on the wing.

THIS WILL CHANGE EVERYTHING: IDEAS THAT WILL SHAPE THE FUTURE

edited by John Brockman. Harper Perennial, 2009 ($14.99)

John Brockman, literary agent and founder of the online science salon Edge.org, has rounded up more than 150 luminaries to reflect on ideas that are poised to change the world in their lifetimes. Among the contributors are Nobel laureate physicist Frank Wilczek on the quantum world, biologist Paul Ewald on infectious disease and psychologist Sherry Turkle on robot companions.

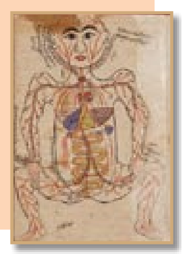
ALSO NOTABLE



- **Power Trip: From Oil Wells to Solar Cells—Our Ride to the Renewable Future** by Amanda Little. Harper, 2009 ($25.99)
- **The Tangled Bank: An Introduction to Evolution** by Carl Zimmer. Roberts & Company, 2009 ($59.95)
- **Mr. Jefferson and the Giant Moose: Natural History in Early America.** by Lee Alan Dugatkin. University of Chicago Press, 2009 ($26)
- **Treasures of the Earth: Need, Greed, and a Sustainable Future** by Saleem H. Ali. Yale University Press, 2009 ($30)
- **Ambassadors from Earth: Pioneering Explorations with Unmanned Spacecraft** by Jay Gallentine. University of Nebraska Press, 2009 ($34.95)
- **Great Plains: America's Lingering Wild** by Michael Forsberg. University of Chicago Press, 2009 ($45)
- **Dazzled and Deceived: Mimicry and Camouflage** by Peter Forbes. Yale University Press, 2009 ($27.50)
- **Blood and Guts: A History of Surgery** by Richard Hollingham. Thomas Dunne Book, 2009 ($27.99)
- **Department of Mad Scientists: How DARPA Is Remaking Our World, from the Internet to Artificial Limbs** by Michael Belfiore. Smithsonian, 2009 ($26.99)
- **The Lives of the Brain: Human Evolution and the Organ of Mind** by John S. Allen. Belknap Press, 2009 ($39.95)

EXHIBITS

- **Moving beyond Earth, a new permanent exhibition about spaceflight, opens November 19 at the National Air and Space Museum in Washington, D.C.**
- **Migrations of the Mind: Manuscripts from the Lawrence J. Schoenberg Collection. November 17, 2009–April 18, 2010, at the Getty Center in Los Angeles.**



"VEIN MAN," 14th-century Persia

NASA AND THE HUBBLE HERITAGE TEAM (STSCI/AURA) (*supernova*); COURTESY OF THE LAWRENCE J. SCHOENBERG COLLECTION ("*Vein Man*")

Careful What You Wish For

The potential problems with more public interest in science

BY STEVE MIRSKY

In October a blog post circulated widely in the science journalism community. Larry Husten mused at CardioBrief.org about the potential benefits to society if only mainstream newspapers covered science with as much dedication as they cover baseball. Indeed, it might be wonderful. But as a big sports fan, I know that there could be unexpected consequences of heightened media interest in science. For example, imagine all-science talk radio:

"Aaaaand good afternoon, everybody, how are your vital signs today?! Mike and the Mad Scientist with you here on QED radio, simulcast on the Nobel TV Network! How are you, Michael?"

"Fine, Mad Sci, good, the new issues of *Nature* and *Science* are out, lots to discuss, including an update on the state of the Mars rovers. Spirit has a bum wheel and has been on the disabled list, but NASA has some tricks that might get it back in the field."

"And they published the genome of the horse! I hope that comes in handy at the Belmont, Michael."

"Don't bet on it, Sci. Listen, they've had the human genome sequenced for, what, 10 years, 12 years they've had the human genome sequenced and they're still giving you and me the same meds, not personalized meds, and they've had the genome sequenced for, what, 10 years, 12 years."

"Good point, Michael, excellent point. Whaddya say, let's go to the phones and hear what science fans out there have on their minds today. Morris from Rego Park, you're on QED."

"Hi, Sci, hi, Mike, first time long time."

"What's on your mind today, Morris?"

"I wanted to float a trade by you guys. How about Harvard trades Steven Pinker and Noam Chomsky for Sean Carroll and a postdoc to be named later?"

"Which Sean Carroll ya talking about, Morris buddy? There's the physicist Sean Carroll at Caltech, and there's the evolutionary biologist Sean Carroll at Wisconsin–Madison, and you can't just call up and float a trade like that without saying which Sean Carroll, can ya, Michael?!"

"That's a problem, Sci, and then there's a bigger problem—Noam Chomsky isn't at Harvard, he's at M.I.T. Chomsky's at M.I.T. Pinker's at Harvard. He used to be at M.I.T., Pinker, Pinker used to be at M.I.T., but now he's at Harvard. Chomsky's at M.I.T., he's at M.I.T., so you can't put the package together in the first place, because Chomsky's at M.I.T."

"There you have it, Mo, you gotta do a little more homework before you call in, a little more housework. Here we go, Jeremy from Manhattan." (*The* Twilight Zone *theme plays in the background, as it does whenever Jeremy calls in.*) "Hello, Jeremy."

"Evolution's just a theory! Global warming's a hoax!"

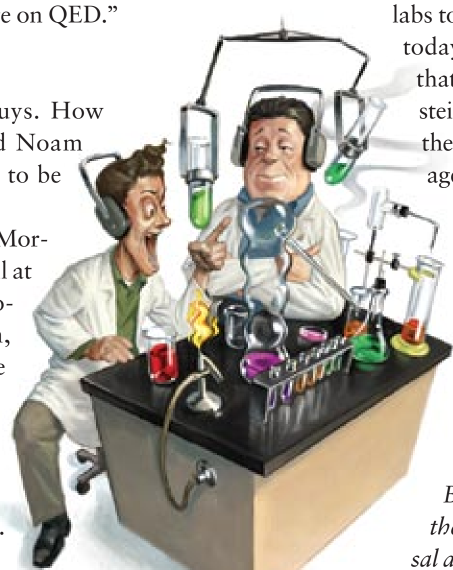
"And goodbye, Jeremy. Jeremy's meniscus is touching the bottom of the graduated cylinder there. Short Hal from Queens on the line, what's up, Short Hal?"

"Not much, Sci, how are your liver enzyme levels today?"

"You're a wise guy, Short Hal. Short Hal's a hepatologist in his spare time, what's on your mind, Hal?"

"Well, Sci, I'm talking to my friend, and he says that grad students are doing all kind of performance-enhancing substances, stuff like Mountain Dew, double espressos. And I just don't know if you can compare the results they're getting with the stuff that the old-timers did without these kinds of enhancers."

"Hal, this is Mike, listen, you think Heisenberg wasn't on massive doses of caffeine? He did his best work, when, in his early 20s? You think he was sleeping more than, what, two hours a night, three hours a night? Don't kid yourself, there was stuff they did back then, maybe not Mountain Dew, but they had ways to keep working all night. I'll tell you what they didn't have back then, they didn't have competitors coming in from all over the world to their labs to compete with them. If anything, these kids today, they're on average better. I'm not saying that the best ones are better than, say, your Einsteins or your Feynmans, but I'd say on average the average ones are better today than the average ones were back then, pound for pound."



"Michael, time for the atomic clock update with Burgess Shale, right after this word from Beckman Instruments. If your analytical balance botches your breakthroughs, better buy a Beckman. We'll be right back." (*The Nobel Network's camera picks up Mike and Mad Sci browsing the* Proceedings of the National Academy of Sciences *and* Physical Review Letters, *while the Irving Berlin song* He Ain't Got Rhythm, *starting at the lyric "With a problem scientific, he's colossal and terrific," plays them off . . .*) ■

PHOTOGRAPH BY FLYNN LARSEN; ILLUSTRATION BY MATT COLLINS