WILDFIRES: Understanding the West's Infernos

SCIENTIFIC AMERICAN

RADIOACTIVE TERROR: Preparing for "Dirty Bomb" Attacks

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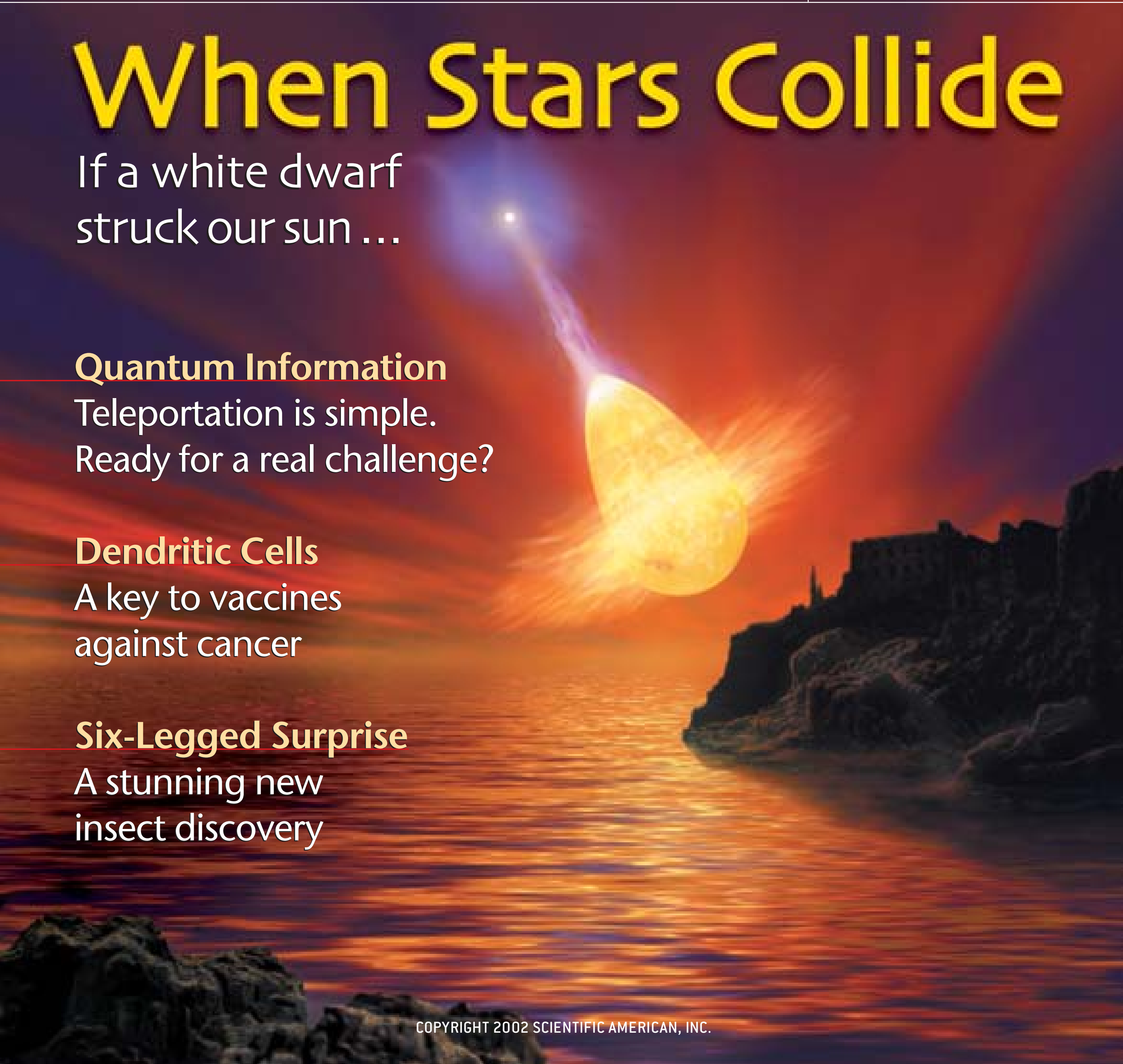
If a white dwarf struck our sun . . .



Quantum Information
Teleportation is simple. Ready for a real challenge?

Dendritic Cells
A key to vaccines against cancer

Six-Legged Surprise
A stunning new insect discovery

november 2002

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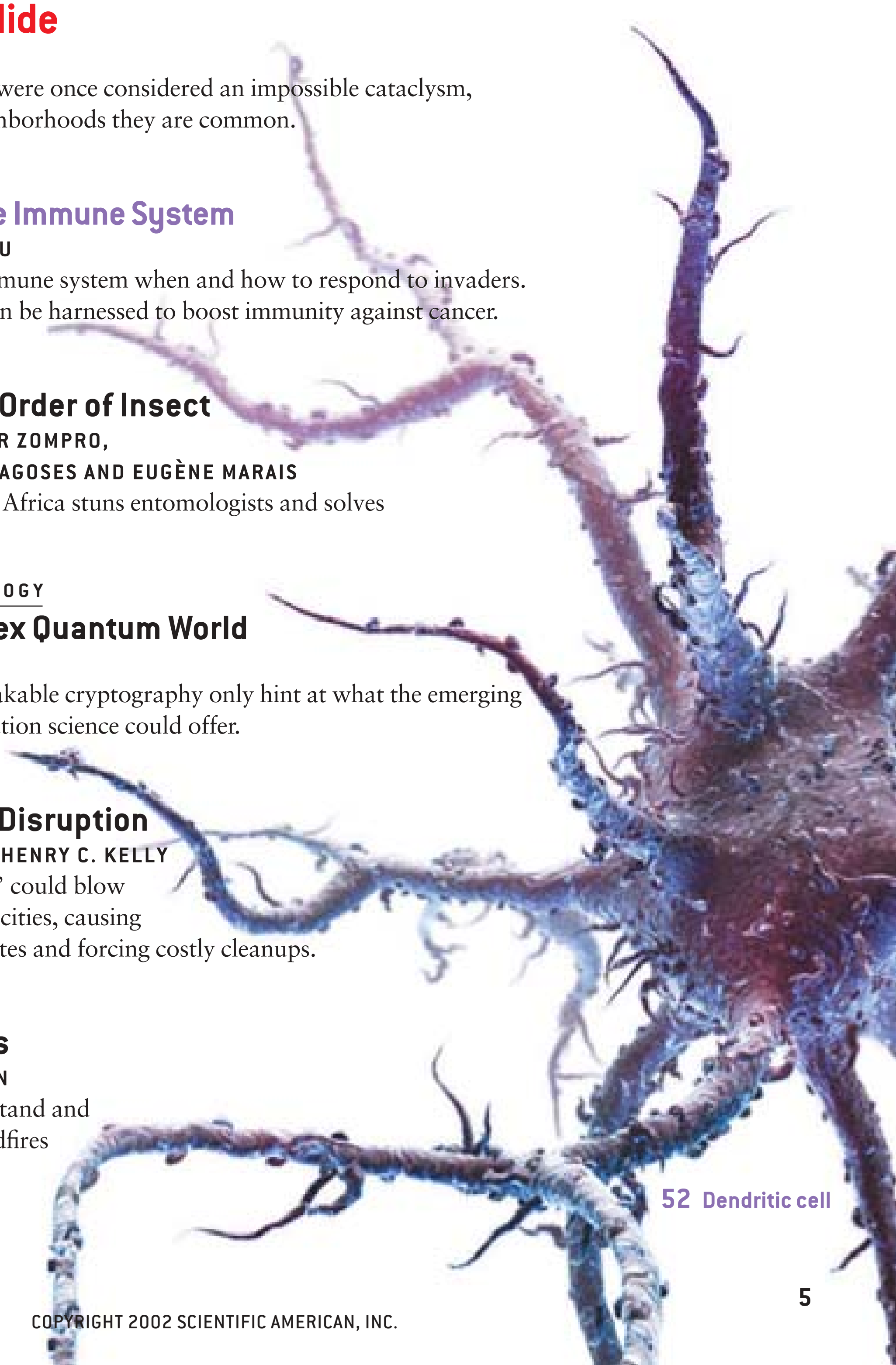

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Cover image by Don Dixon

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Land of Fire

As you read this, the horrific 2002 wildfire season is drawing to a close. And in what has become an annual ritual, many are asking, "Why are things so bad?" This summer more than six million acres burned, thousands of people had to flee for their lives, and the cost of battling those blazes could hit $1.5 billion.

Smokey Bear may have done too good a job. Decades of well-intentioned fire suppression, combined with recent droughts, have left vast tracts of wildland littered with tinder-dry brush and matchsticklike trees. Of 470 million acres of federally managed forests, 190 million or so are said to be at risk of catastrophic fire. Various efforts are now under way to remove excessive brush, and a growing number of people are endorsing the idea of thinning Western forests.


BATTLING the burn.

DOUGLAS GANTENBEIN

Igniting a new debate, President George W. Bush recently announced a plan to remove forest-floor fuels for "free," by letting loggers cut larger, more commercially valuable trees in exchange. Many argue about the appropriate levels of thinning, how it might be accomplished and even whether it's a good idea at all. But at least everyone agrees that research will improve the prevention and management of conflagrations [see "Burning Questions," by Douglas Gantenbein, on page 82].

All the efforts to handle forest fires must proceed from a simple realization: fire is a fact of life in Western ecosystems, in more ways than one. Western forests are supremely adapted to coexist with natural, lightning-sparked burns. Before they were quashed by Smokey, these fires had cyclically swept up brush and debris every few years. The thick bark of native Ponderosa pines, for example, insulated the trees from damage. In fact, some varieties of pinecones won't release seeds without exposure to fire's heat.

So the efforts to hack away underbrush and to phase out routine fire suppression are welcome. But they are also incomplete. The root cause of the problem is not an overly zealous desire to save trees but frenetic development. The conifer-covered slopes of the West are magnetic for homesteaders. Builders slip more and more houses among the picturesque trees, creating what fire managers call the urban-wildland interface. According to the National Interagency Fire Center in Boise, Idaho, fire-susceptible areas hold 10 times as many homes today as 25 years ago.

Although houses can be built using noncombustive materials and modified with other fire-smart practices, they nonetheless create a need for fire suppression that never used to exist. In certain areas, the situation has become untenable: natural fires cannot be left to run their course, the underbrush builds up, and eventually the forest explodes in an uncontrollable blaze.

It is hardly the first time that humans, in our desire to be close to nature, have destroyed the very thing we seek. Fortunately, new policies can reduce the cost in lives, property and environmental conditions. As state and local planners consider what and how to build, they must recognize the inevitability of fire in the same way that other regions prepare for floods, earthquakes or hurricanes. Communities such as Malibu, Calif., already have strict building codes in place. Insurance companies can require more discrimination from their clients in site choices.

Stronger steps, including bans on building in fire-prone areas, may eventually prove necessary. Some people might regard preventive measures as overbearing government interference. But unless we start making these hard trade-offs, we may find ourselves continuing to fiddle while the West burns.

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FEATURED THIS MONTH

Visit **www.sciam.com/explore_directory.cfm** to find these recent additions to the site:

Alone in the Universe?

The Search for Extraterrestrial Intelligence (SETI) continues to disappoint. Of the candidate radio signals that have been detected since scientists first started listening for alien civilizations more than four decades ago, not one has been verified as a real ET transmission. But might these candidates represent ET signals that eluded verification because they were corrupted or modified en route to Earth, in much the same way that a twinkling star's light brightens and fades? In fact, distant radio sources can twinkle, or vary in intensity, dramatically as they pass through interstellar gas clouds. ET transmission variability could also result from a phenomenon known as gravitational microlensing.

Phytoplankton to the Rescue

In an effort to reduce global levels of the greenhouse gas carbon dioxide, a number of companies are pursuing projects designed to make the oceans bloom with CO_2-absorbing phytoplankton. It's a clever solution in theory but one whose real-world benefits are uncertain. Critics charge that even if the plan works, the effects will not be substantial enough to actually mitigate climate change. More worrisome, the scheme could create toxic algal blooms, leading to new problems.

ASK THE EXPERTS

How do Internet search engines work?

Javed Mostafa, an expert on computer and information science at Indiana University, explains.
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Letters

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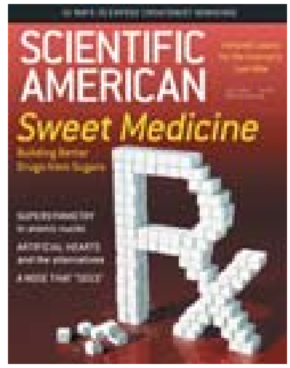


"JOHN RENNIE IS A FOOL, and not very bright," begins one of the most colorful responses to his article "15 Answers to Creationist Nonsense" in the July 2002 issue. After asserting that "the very fact that we exist is evidence of a Supreme Being that created all things," the letter suggests that Rennie should be "flogged, stoned, drawn and quartered, and spat upon." Some of the hundreds of anti-evolution correspondents insisted that creationists no longer really made the silly argument "If men descended from monkeys, why are there still monkeys?"; others . . . well, repeated that argument. Rennie is grateful for the many promises of prayers for his soul (he'll need them for other reasons) but suspects that the glee of those writing that he will be in for a rude surprise on Judgment Day betrays a sinful lack of mercy.

More letters on this article and other heresies from the July 2002 issue follow.

CREATIONISM COMMENTARY

One thing is certain from "15 Answers to Creationist Nonsense"—evolution is a religion to you. As a young-Earth Christian, I find all the answers to the meaning of life in the Bible. Even if I were not a Christian, I would find the theories of evolution insane. God gave men the brains to develop computers and all the amazing inventions we enjoy today.

It seems that the more we learn, the more hardened evolutionists become in their rebellion against God. If the genetic code discovery does not prove intelligent design, nothing will convince evolutionists.

Boris F. Rice, Sr.
Houston

Growing up in Oklahoma at the center of the Bible Belt, I read a Christian textbook that claimed Satan put fossils into the ground to deceive us. Other explanations for fossils included the proposition that dinosaurs lived before Adam and Eve, when Earth was inhabited by angels, including Satan before his fall.

The will of creationists to postulate whatever explanations are necessary to support their beliefs cannot be underestimated. Consequently, the debate between creationism and evolution is not always a debate over truth. Science cannot persuade those who, having rejected science, do not acknowledge the rules of scientific thought.

Lisa Lindeman
Bowie, Md.

In any effort to teach evolution, instructors must give students a clear understanding of the nature of science: its realm, mechanisms, rules and limitations. These are seldom adequately addressed in any textbook. When teachers do devote adequate time to these topics and then provide experiences for students to explore the critical elements of evolution, they encounter much less resistance. Such classroom-tested lessons and strategies are available on the Evolution and the Nature of Science Institutes Web site: www.indiana.edu/~ensiweb

Larry Flammer
Evolution and the Nature of Science Institutes
San Jose, Calif.

The validation of evolutionary theory consists not in its correspondence with human intelligence but with what is physically observed. This is the sole tenet of true science—that human theory and conjecture must match observation. Therein lies the true validation (and genius) of evolutionary theory.

The creationism arguments are detrimental to scientific thought not only because they are void of empirical evidence but because they betray logic and philosophical thought in general. The tragic irony is that if creationists were successful in proving their theories, they would deprive themselves of the intended relationship to their religion: faith.

Paul Tyma
via e-mail

The greatest service that scientists can do for the advancement of science in the face of creationism may not involve a frontal assault—which will be interpreted by creationists as an attack on their faith, not on their science. Rather the greatest service may well be to help people of faith understand that faith and science are two quite different ways of observing the same universe but that they cannot be substituted one for the other, nor can either be used to judge the other.

Jordan L. Stedman
Shoreline, Wash.

Today's debate is not primarily over scientific facts but over what true science actually is. John Rennie points out that "a central tenet of modern science is methodological naturalism—it seeks to explain the universe purely in terms of observed and testable natural mechanisms"—which of course is an a priori assumption that there is no supernatural. Many scientists, however—individuals the likes of Copernicus, Galileo, Newton and Pascal—did not want to limit the scope of science artificially by assuming naturalism. Instead they successfully used knowledge outside of "testable natural mechanisms" to inform their work.

Paul R. Payne
Orlando, Fla.

You cite Richard Hardison's computer program that produced Shakespeare's *Hamlet* from randomly generated letters in four and a half days. But Hardison's program and his accomplishment are examples of purposeful creation, not evolution.

Chris Newbill
Richland, Wash.

RENNIE REPLIES: As Stedman notes, too many religious people perceive evolution studies and other fields of science as trying to prove that God doesn't exist—which is not the intent of science. Unfortunately, out of fear or ignorance, many creationists do aim to undermine evolution and other science by throwing out adherence to methodological naturalism. Payne is mistaken: methodological naturalism is not an a priori denial of the supernatural (that would be philosophical naturalism). Rather science avoids supernatural explanations for the logical reason that unless the supernatural can be tested empirically, it's impossible to deduce what it is or isn't doing. Copernicus, Newton et al. were religiously devout scientists, and their faith may have inspired their thinking, but no enduring part of their scientific contributions is anything but naturalistic. For example, Newton doubted that gravitational principles could adequately explain planetary movements. He thought an Intelligent Designer was needed to keep them in their orbits. He was wrong.

Many readers raised Newbill's objection, but I didn't present the computer program as an example of natural selection. I was rebutting the misleading mathematical argument that complex structures could not evolve by chance. What the program demonstrates is that selection acting on the products of random generation can arrive at a solution extremely quickly even when the odds against it seem astronomically high.


NAUTILUS SHELL: Designed or evolved?

By the way, as I should have noted, evolutionary biologist Richard Dawkins independently created a program that acts like Hardison's, which he described in his book The Blind Watchmaker. *Dawkins and Hardison both wrote their programs in 1984, and both programs select for phrases from* Hamlet *("Methinks it is like a weasel" for Dawkins; "To be or not to be" for Hardison), yet they were each unaware of the other's work! Further proof of the power of coincidence, or of some divine power working to reveal and promote evolution?*

PLIGHT OF PH.D.s

The issue at hand in Rodger Doyle's "Filling the Pipeline" [By the Numbers] is not simply the falling number of Ph.D.s but the lack of opportunities for them after graduation. To draw new students into the pipeline, one must offer them something at the end. As things stand, the promise given by the academic community rings hollow.

Thomas R. M. Ulrich
Boston

HEADPHONES FOR ASTRONAUTS

There is a simple, low-cost solution to excessive equipment noise on the International Space Station ["Orbital Shouting," by James Oberg; News Scan]: commercially available noise-canceling headphones, such as those used by veteran air travelers.

Jeff Schoenwald
Salt Lake City

SLEEPLESS IN LOS ALAMOS

Although we were not doing an experiment on sleep deprivation such as the one described in the Ask the Experts column, we have some related experience. In May 2000 Bob Clark, Bill Rogan and I were continuously awake for one hour short of 10 days doing live radio coverage of the Cerro Grande fire, which ultimately consumed nearly 48,000 acres and 400 homes in Los Alamos. We found that we were not only functional but also able to convey information to our audience right to the end. We may have had periods of "microsleep," but we were unaware of them. My memory of what occurred was virtually nonexistent when we finished. It was only after listening to what we recorded that I remembered what happened and when.

Mark M. Bentley
General Manager, KRSN-AM 1490
Los Alamos, N.M.

ERRATA The Jurassic period ended 144 million, not 65 million, years ago ["15 Answers to Creationist Nonsense"].

Stephen Y. Chou received his undergraduate degree from the University of Science and Technology of China in Hefei, not the University of Science and Technology in Beijing ["Breaking the Mold," Innovations].

LAYNE KENNEDY *Corbis*

50, 100 & 150 Years Ago

FROM SCIENTIFIC AMERICAN

Langley Succeeding ■ Edison Wrong ■ Agassiz Deluded

NOVEMBER 1952

POLIO TARGETED—"The discovery of a way to grow poliomyelitis virus in tissue culture—made three years ago by John F. Enders, Thomas H. Weller and Frederick C. Robbins at the Children's Hospital in Boston—has given a tremendous impetus to the study of this disease. It means the end of the 'monkey era' in poliomyelitis research and opens the way to a much wider attack on the problem. Tissue-culture methods have provided virologists with a simple *in vitro* method for testing a multitude of chemical and antibiotic agents."

SLEEP—"The Mammoth Cave experiment enabled the author and a colleague to change their sleep cycles at will in surroundings constant in temperature and darkness and free from disturbances of the normal cycle of life [*see illustration*]. The cerebral cortex can prolong the waking state, but not beyond limits. Sixteen hours of wakefulness in 24 is probably near the physiological limit of tolerance over the long run for most of us. But the proportion, not the duration, of sleeping time is what counts. A person can adjust himself to a routine of staying up 18 hours and sleeping nine, or being awake 12 hours and sleeping six."

NOVEMBER 1902

POWERED FLIGHT—"What is popularly known as the 'flying machine' is literally a machine, without gas to support it, in no way resembling a balloon, and which its inventor, Samuel Pierpont Langley, has called the aërodrome (signifying 'air runner'). The aërodrome is hundreds of times heavier than the air, and owes its support to another principle—that is, to the *rapidity* with which it runs over the air, like a skater on thin ice. The present models weigh about 30 pounds, one-fourth of which is contained in the engine and machinery. This and other models have repeatedly flown distances of over half a mile, at speeds of from 20 to 30 miles per hour."

PREDICTIONS—"At the opening of the Copenhagen Exhibition, a letter was read from Thomas A. Edison: 'I believe that within thirty years nearly all railways will discard steam locomotives and adopt electric motors, and that the electric automobile will displace the horse almost entirely. In the present state of science, there are no known facts by which one could predict any commercial future for aerial navigation.'"

CAVE LIVING: In sleep-cycle experiments, some adapt well, some do not (1952)

FISH TALK—"One of the most remarkable sound-producing fish it has ever been my good fortune to listen to was a Haemulon of the Gulf of Mexico—one of the wide-mouthed, highly colored grunts so common on the reef. The moment I took one of these fishes from the water it began to grunt: 'Oink-oink-oink'; now with one prolonged 'o-i-n-k'; all the while it rolled its large eyes at me in a comical manner. The impression was created that it represented a very primitive attempt at vocal communication among fishes."

NOVEMBER 1852

AGAINST NATURE—"Prof. Agassiz, the eminent philosopher, says: 'The extinct animals found in the lowest geological strata, it has been imagined by philosophers, were the first created, but this supposition is overturned by modern science, which discloses the fact *the lowest strata* contain *radiata, molusca, articulata,* and *vertibrata.* The plan which pervades the animal kingdom at the present day is the same which was displayed at the first introduction of animals upon this earth. The same thought which planned the arrangement of animals now living is the same which has laid them from *the beginning.*'"

RINGS OF SATURN—"Of what substance are the rings of Saturn composed? A strict soldier of the nebular hypothesis should stick to his theory by asserting that the planet and rings were once in a fluid state, and the planet cooled, contracted, and shrunk from the rings. The inner ring at least is, in all likelihood, aqueous. Lieut. Matthew F. Maury says that 'the belt of equatorial rains encircles the earth. Were the clouds which overhang this belt luminous, and could they be seen by an observer from one of the planets, they would present an appearance not unlike the rings of Saturn.'"

news SCAN

RESEARCH INTEGRITY

Reality Check

ALLEGED FRAUD GETS PHYSICISTS THINKING ABOUT MISCONDUCT **BY JR MINKEL**

The physics community's collective jaw dropped this past summer when allegations of fraud were raised against two of their own. With one investigation only just completed and the other being appealed, physicists hesitate to pass judgment. Nevertheless, some regard these episodes as a wake-up call for a field that has considered fraud within its ranks a freak occurrence. "My colleagues and I sit around at lunch saying, 'Could this happen in my group?'" says Marc A. Kastner, chair of the physics department at the Massachusetts Institute of Technology.

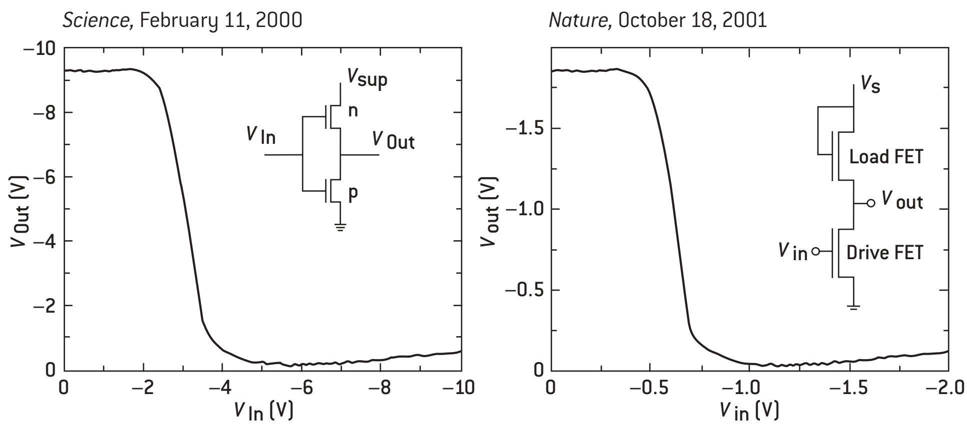
It's in the nature of experimental science to catch major inaccuracies, be they honest or deliberate. Although few groups may check minor results, scores may set out immediately to reproduce a big breakthrough. The trouble was, nobody could reproduce the results coming from teams led by Jan Hendrik Schön of Bell Laboratories and Victor Ninov of Lawrence Berkeley National Laboratory.

Over the past two years, Schön was lead author on a series of astonishing papers reporting high-temperature superconductivity and molecule-scale electrical switching in thin films of organic materials. Such findings suggested one approach for fabricating better transistors. Murmurs about the Nobel Prize gave way to confusion as months dragged on and the results weren't reproduced. Researchers noted suspiciously identical segments of graphs, leading Bell Labs to convene a panel of investigators. Its September 25 report concludes that Schön manipulated and misrepresented data but clears his co-authors. (Schön has been fired.)

Ninov, an established nuclear physicist, along with 14 collaborators, claimed in 1999 to have spotted nuclei of elements 116 and 118 in a shower of high-energy particle collisions. Several of Ninov's colleagues began growing suspicious when independent verification never came and only Ninov could find traces of these nuclei in the data. Lawrence Berkeley fired him after an internal investigation, but he has appealed the decision. Ninov

ELEMENTAL MESS: The Berkeley gas-filled separator (*next to technician*) sifts out heavy ions from other reaction products. It generated the data that Victor Ninov claims contain signs of elements 116 and 118.

ROY KALTSCHMIDT *Lawrence Berkeley National Laboratory*



TOO PERFECT? The noise profiles—the squiggles on the bottom of the curves—as they appeared in two journal articles are nearly identical, even on differently scaled axes. Graphs from possibly 20 different papers by Jan Hendrik Schön displayed such unusual similarities, arousing suspicions of other researchers.

also refused to join the other authors in a formal retraction published in the July 15 *Physical Review Letters*. Doubts then arose about data he analyzed in the discovery of elements 110 and 112 in Europe in 1995 and 1996. (The existence of those elements, and element 116, has been confirmed.)

Some physicists still say that fraud is tough to get away with and that anyway the "system" works, if slowly, at uncovering it. Biologists "said exactly the same thing in the early 1980s," notes Nicholas H. Steneck, a historian at the University of Michigan at Ann Arbor, "and they turned out to be wrong," misjudging the safeguards against error. Since that time, they've taken a hard look at the way they publish data, educate young researchers and spell out guidelines for responsible behavior. Physicists would be prudent to do the same, Steneck remarks. Concern in Congress also led ultimately to the creation of the Office of Research Integrity within the Department of Health and Human Services. The National Science Foundation has an equivalent, the Office of the Inspector General.

A few physicists see additional steps in the works for their field. "I think it's going to change the culture," says Thomas A. Weber, director of the NSF's materials science division and a former Bell Labs employee. He predicts that graduate schools may begin requiring ethics courses.

To some, the onus of ensuring integrity falls on the co-authors. Collaborators have to trust one another, but the research group is the first line of defense against inaccuracy, deliberate or not, some physicists maintain. "That's what's so stunning to me," comments Peter D. Bond, a nuclear physicist at Brookhaven National Laboratory: if there really was fraud, "the other experimenters bought into it." Co-authors need to be held accountable, insists Robert L. Park of the American Physical Society. "When you put your name on an article as a co-author, you are expected to be certifying that you think it's correct," he asserts. In cases of egregious misconduct, he says, co-authors should be questioned publicly about why they didn't catch the problem.

Specialization within a group can make it hard to check one another's work. But experts agree that one person should never have sole responsibility for data collection or analysis, as seems to have occurred in the recent cases. This is less of an issue for high-energy accelerator experiments, which can have hundreds of members and elaborate cross checks in place to avoid mistakes. The leaders of several nuclear physics collaborations, which are much smaller, say that trust of longtime colleagues is key in their field but that independent data analyses are still possible. Academic and industrial researchers in the condensed-matter field also claim that when things are going well, the interaction of younger group members with senior scientists or research managers makes it difficult to falsify results.

Many are wary of advocating potentially cumbersome systemic changes. Investigating misconduct allegations swiftly and fairly may be a sufficient deterrent, and shocks like the Shön and Ninov episodes should tighten up traditional safeguards. But even if these cases blow over, nobody really knows how common misconduct is in the physical sciences. If the worst turns out to be true, Weber observes, then "we were probably very naive."

JR Minkel, based in New York City, works part-time for the American Physical Society.

PUBLISHING WITHOUT PERISHING

Science journals could play a stronger role in enforcing ethics. The American Physical Society, publisher of the *Physical Review* journals, is reexamining its guidelines for conducting independent investigations of misconduct. The APS currently looks into any indications brought forward by editors, reviewers or scientists and alerts the relevant institution, explains editor in chief Martin Blume. If an institution doesn't respond or isn't involved, the society performs its own inquiry.

Many physicists believe that beefing up peer review would be too burdensome. But one step forward, proposes Paul M. Grant, a science fellow at the Electric Power Research Institute in Palo Alto, Calif., would be for institutions to acknowledge peer review as a positive element and factor it into promotion decisions. Reviewers might then have greater incentive to be thorough, he says.

GEOPHYSICS

Headed South?

EARTH'S FADING FIELD COULD MEAN A MAGNETIC FLIP SOON BY SARAH SIMPSON

Birds and compasses know north from south because, like a giant bar magnet, the earth's magnetic field has two poles that line up closely with the planet's axis of rotation. That's simple physics.

Less widely known is that this global dipole has been diminishing precipitously for the past 150 years and at this rate could disappear entirely sometime early in the next millennium. With the world's protective magnetic shield severely disabled, intensified doses of cosmic and solar particles could knock out satellites—the least of humanity's concerns under this deadly shower of radiation.

The good news is that any disappearance of the dipole will be temporary, the halfway point along a southward swing that would leave compass needles pointing toward Antarctica rather than the frozen North. Magnetic minerals trapped inside ancient rocks have recorded hundreds of these so-called polarity reversals in the past 500 million years. But no known pattern exists in the timing or duration of these events, making them impossible to predict.

Most geophysicists have long assumed that a 2,200-kilometer-thick layer of molten iron swirling deep inside the core creates the planet's self-sustaining field. But until about six years ago, no one had written computer code sufficiently complex to simulate core motion and its magnetic effects. Now several programs can simulate not only motion but even polarity reversals, some of which require only 1,200 years—a wink of geologic time.

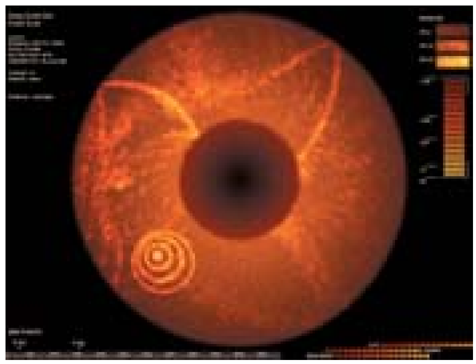
Other investigators have seen real-world hints of why the reversals might occur. Earlier this year Gauthier Hulot of the Paris Geophysical Institute and his colleagues used satellite measurements to track changes in the field's behavior near the top of the core. Far below the southern tip of Africa they found a small region where the magnetic field lines point peculiarly toward the center of the earth instead of toward the surface, as do the dominant lines in that region. A clump of similar patches exists near the North Pole.

Hulot's team argues that the growth of these reversed patches, presumably eddies that are working against the primary motion of the core, can explain the current decline in the dipole field. What is more, the rampant growth of such patches has caused full-blown reversals in some computer simulations.

As for what life would be like at a time of flip-flopping polarity, Paramount Pictures's new geophysical thriller *The Core* suggests that birds will lose their way and that humans will live under frequent radiation alerts. In the movie, world governments unite to build a manned craft that can burrow through 2,900 kilometers of solid mantle rock and survive the core's scorching heat—comparable to that at the surface of the sun. The mission: to set off nuclear explosions that could revive the core's natural flow and fight the magnetic field's tendency to reverse.

With current technology falling far short of this Jules Verne–esque solution, scientists can offer other reassurances: The shrinking dipole doesn't guarantee an imminent reversal. Only a random few of the field's myriad natural fluctuations actually mushroom into an all-out switch. Recent computer simulations also indicate that the planet's peripheral magnetic fields, which constitute only 10 percent of the total, may get stronger as the dominant dipole field weakens.

Most comforting of all may be that no major species extinctions correlate with past polarity reversals. As geophysicist Joseph L. Kirschvink of the California Institute of Technology says, "If there is a biological effect, we're evolved for it."



EARTH SLICE, HOLLYWOOD-STYLE: In *The Core,* a cross section of the earth is imaged, showing a magnetic-field disturbance (*concentric rings*) in the mantle.

PARAMOUNT PICTURES

MAGNETIC MEMORIES

Iron-rich minerals within lava and other molten rocks align freely with the earth's magnetic field. Once a rock solidifies, the minerals retain their magnetic memory as long as the rock doesn't heat up again. Such records, discovered throughout the world, reveal that polarity flip-flops are far from predictable.

Known reversals: About 1,000

Most recent: 780,000 years ago

Slowest: 10,000 years

Fastest: 1,000 years*

Typical lag between reversals: 200,000 years

Longest lag between reversals: 50 million years

**Controversial evidence indicates that magnetic north traveled as much as three degrees a day during a brief span about 16 million years ago.*

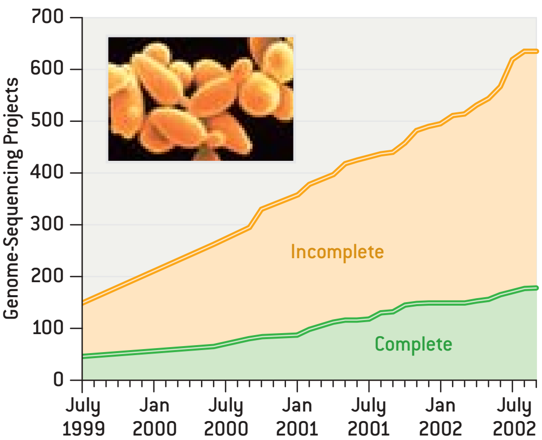
news SCAN

BIOTECH

Stringing Along

THE KEY TO EXPLORING GENOMES IS MORE GENOMES **BY KEN HOWARD**

Readers could be forgiven for stifling a yawn on learning that yet another genome has been sequenced. After tracking down most of the human base pairs by 2000, scientists have continued to use high-throughput sequencing machines to complete upward of 100 other genetic blueprints; the next few years will see some 600 more. And amid the proud announcements are general statements indicating that the information will be a boon to medical science. Yet an individual curious to know how the genomes have been helpful might well ask "Where's the beef?" even before the bovine genome is done.



DNA RISING: The number of completed genomes, such as that of the baker's yeast *Saccharomyces cerevisiae* (*inset*), keeps increasing.

A jaded public, however, may be just what geneticists want. "I'm hoping we can go back to being scientists and get beyond the hype of the human genome," comments Chad Nusbaum, co-director of genome sequencing and analysis at the Whitehead Institute–Massachusetts Institute of Technology Center for Genome Research. "Analysis is what's important, not the sequencing." This is perhaps most true for nonvertebrates, which represent most whole genomes that have been sequenced. Bacterial genomes, approximately 70 of which have been done, "are no longer of broad interest," explains Robert H. Waterston, director of the Genome Sequencing Center at the Washington University School of Medicine. "Generally these new genomes are not going to add anything broadly to the concept of what a bacterial genome contains," although they are important to researchers studying specific bacteria, he notes.

Many researchers say it's time to regard the sequencing of genomes as standard practice rather than as high-profile projects in themselves. Biochemist Russell F. Doolittle of the University of California at San Diego likens the switch to the replacement of exploration by Lewis and Clark with the Coast and Geodetic Survey. Groundbreaking and romantic adventure gave way to the more workaday pursuit of recording all geography onto maps. These maps then became integral parts of the geologists' and engineers' toolboxes.

One payoff so far in knowing the human sequence is in the diagnosis of infectious diseases. Microbiologist David A. Relman of Stanford University exposes human cell lines to infectious agents and catalogues how cells respond to the attacks: different pathogens activate different sets of genes. Matthew L. Meyerson, a pathologist at the Dana-Farber Cancer Institute in Boston, sequences samples of infected human tissue and then, using the human genome as a reference, tells the computer to hunt for nucleic acid sequences that do not match and therefore are most likely to be those of the pathogen. Later he searches a database of pathogen genomes to identify the microbe or determine if it is new. Categorizing types of cancers and other diseases through genetic markers has also gotten a boost from access to the human sequence.

The real benefits, however, will come from comparing different genomes, many scientists say. With nonhuman genomes, such comparisons have led biologists to "bump into discoveries," according to David J. Lipman, director of the National Institutes of Health's National Center for Biotechnology Information. Researchers working for Nusbaum, for instance, studied the sequences of four species of budding yeast, including *Saccharomyces cerevisiae*. They found that a previous computational prediction for one gene on *S. cerevisiae* was attributed to the wrong strand. They suspect that about 10 percent of the yeast's genetic regions may be misattributed. Nusbaum sees the results as an argument for building up the number of sequenced mammals: "If you need four genomes to understand a small, information-dense genome like *Saccharomyces*, I think you need a lot more to get a full understanding of a big mammalian genome."

Richard K. Wilson, co-director of Washington University's Genome Sequencing Center, estimates that the current number of ge-

UNLOCKING EVOLUTION AT BASE PAIRS

The emerging collection of sequenced genomes is giving scientists the power to read evolution's notebook. "We're a little like Darwin; we're collecting data sets and cataloguing," comments Edward M. Rubin, acting director of the U.S. Department of Energy's Joint Genome Institute. Comparing whole sequences, researchers say, reveals how genomes change over time—which genes are deleted and which are conserved—and how rates of evolutionary change differ from species to species. Darwin's trip to the Galápagos enabled him to glean "fundamental insights to how organisms change," Rubin says. "You don't get there from bringing back one or two genes. You need a much larger data set. We're collecting specimens like mid-19th-century scientists."

SCIMAT/SCIENCE SOURCE/PHOTO RESEARCHERS, INC. (*inset*) nomes represents only a tenth of what will be sequenced within the next decade. The mouse sequence will surely make a splash with its publication, slated for later this year, as will the rat genome, estimated to be done by spring 2003. An informal survey of genomic researchers pegs the DNA of the chimp, chicken, cow and dog as mammalian sequences to look forward to in the near future.

And what will the collection of genomes look like years from now, after biologists, drug developers, agribusiness and others have weighed in on the selection process? It will probably include many of the disease-causing pathogens, economically important crops and animals, model organisms and vertebrates relevant to the human genome. And if you live long enough, Doolittle quips, everything will be sequenced—after all, the sequencing "machines have to be fed."

Ken Howard is based in San Francisco.

PHYSICS

Revising Relativity

PHYSICISTS TRY TO OUTDO EINSTEIN BY GRAHAM P. COLLINS

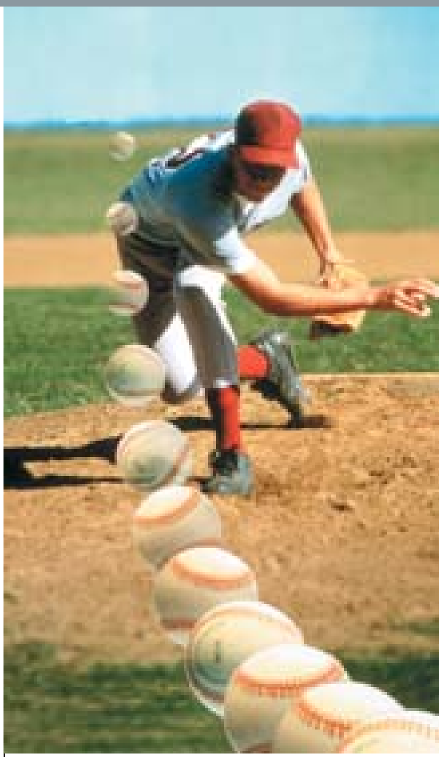
Einstein's theory of special relativity turned 97 this year and is one of the most hale and hearty sets of laws in physics. Allied with quantum mechanics, it forms the foundation on which the Standard Model of particle physics is built. When reconciled with gravity, it mutates into general relativity, the theory governing black holes, the expansion of the universe, and the fine details of GPS satellite trajectories. Although cranks frequently claim to have extended or repealed relativity, rarely have qualified theorists dared to tinker directly with its basic structure. Recently, however, a small group of physicists have suggested that a fundamental overhaul of relativity is in order.

The basic change proposed is to introduce a second "scale" to the theory in addition to *c,* the speed of light in a vacuum. The constancy of *c* for all observers is the bedrock of relativity. When relative velocities of objects approach *c*, strange effects such as time dilation and length contraction become obvious.

Quantum gravity has its own special scale: the Planck energy, which is defined uniquely by *c* in conjunction with the magnitude of quantum effects and the strength of the force of gravity. For an elementary particle, the Planck energy is huge beyond anything ever observed in cosmic rays or created at an accelerator. When particles have energies comparable to the Planck energy, the existing theories of physics should break down and an as yet undetermined theory of quantum gravity should take over, manifesting weird phenomena such as a "foaminess" of spacetime itself. This prediction poses a puzzle for relativity, because observers with different relative motions will disagree about when a particle reaches the Planck regime. How can one observer see the particle traversing ordinary, smooth, continuous spacetime while another sees it skipping across a quantum foam?

In late 2000 Giovanni Amelino-Camelia of the University of Rome proposed a revision of relativity in which a minimum-length scale is added. (An extremely small distance called the Planck length corresponds to the Planck energy.) Because the theory has two absolute scales, *c* and the Planck length, Amelino-Camelia dubbed it a "doubly special" relativity theory. In a world ruled by the modified equations, very short wavelengths approaching the Planck length become increasingly immune to the effects of length contraction. The change also causes extremely short wavelength light to travel slightly faster than *c*. The changes wrought by the theory might be tested by observations of ultrahigh-energy cosmic rays or by studies of gamma rays by the orbital telescope GLAST, to be launched in 2006.

The variation in the speed of light is eliminated in a newer doubly special theory concocted by Lee Smolin of the Perimeter Institute



GLOBUS, HOLWAY & LOBEL *Corbis*

WHEN BASEBALLS ARE DOUBLY SPECIAL

The threshold energy for strange new double-relativistic effects applies only to elementary particles, not to composite objects built from them. Expressed as a mass, the Planck energy is just 20 micrograms. A baseball far exceeds that mass without showing any bizarre trans-Planckian behavior. Only for a fastball traveling exceedingly close to the speed of light would the baseball's constituent particles have Planck-scale energies and exhibit new double-relativistic effects.

for Theoretical Physics in Waterloo, Ontario, and João Magueijo of Imperial College, London. Their theory changes how a particle gains energy and momentum as it is boosted to higher energy. Smolin and Magueijo predict that an accelerated particle's energy will approach the Planck energy asymptotically in the same way that the velocity of an accelerated massive particle approaches *c*. The changes to physics in Smolin and Magueijo's theory are smaller than in Amelino-Camelia's model and hence are unlikely to be experimentally tested anytime soon. A whole class of additional doubly special theories also exist.

The modifications of energy and momenta are better understood than the effects on distance. Imagine somehow using a Planck-length ruler to measure a baseball bat. A moving observer will see the bat contracted by relativity, but the tiny ruler should be unaffected if the Planck length is invariant. The ruler lengths must not add up by ordinary arithmetic. Energies add up in a similarly complicated fashion.

Quantum gravity theorist Steven Carlip of the University of California at Davis says that doubly special relativity is an interesting idea, but he suspects that "they are looking for too simple a solution to a complicated problem" in quantum gravity. "But," he adds, "I hope I'm wrong."

RADIO

Fine Tuning

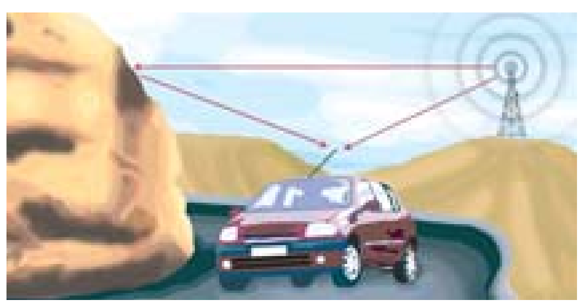
IC CHIPS BRING DIGITAL QUALITY TO CONVENTIONAL RADIOS BY STEVEN ASHLEY

On long road trips, it's frustrating to have your favorite Coltrane jam or Mozart suite begin to crackle and fade away—or worse, to hear Pink apparently singing harmony with Pink Floyd. Weak, intermittent radio reception and interfering channels are familiar banes for motorists, but Motorola says it has an alternative to hitting the tuner's "seek" button yet again, one that can lock onto and pull in a station even when it's more noise than signal.

The engineers at Motorola's Semiconductor Products Sector in Austin, Tex., have developed a set of silicon chips that apply sophisticated digital processing to standard analog signals, enabling software code rather than analog circuitry to do the tuning, explains Steven R. Tremmel, operations manager for digital radio and digital audio at Motorola. Called Symphony Digital Radio, the system relies on algorithms running at the rate of 1,500 million instructions per second on Symphony's 24-bit semiconductor chip set. The device converts any incoming AM or FM signal into an intermediate frequency that can be filtered and conditioned by digital signal processors. The result can be near-CD-quality sound from analog radios, given a sufficiently strong signal.

The Motorola system represents an early example of a new class of what the electronics industry calls software or software-defined radios, a technology that derives tremendous flexibility by using digital code in place of fixed hardware to accomplish functional tasks. This algorithmic approach to radio was originally applied to military communications systems.

Tremmel says that the programmable aspect of the design means that both low- and high-end radio models can share substantially the same chips from the Symphony family. Manufacturers will be able to distinguish their products based on the kind of software they load into the chips. They might install, for instance, movie-soundtrack-decoding functions



MIXED SIGNALS: Multipath distortion occurs when transmissions reflected off objects interfere with the direct signal.

ALICIA CALLE

RADIO DAZE: DEFINING DIGITAL

When it comes to radio, there's digital, and then there's digital. Most people are familiar with digital tuners, which lock onto broadcast waves with the help of a quartz crystal. "Digital radio" can refer to the satellite and terrestrial broadcasts that pump out 1's and 0's rather than the traditional sine waves of an oscillating electromagnetic field. Receiving such broadcasts requires higher-cost digital equipment. Internet users might think of digital radio as the broadcasts they hear downloading from a station's Web site. Finally, "digital" can pertain to software-defined radios, which rely on integrated chips and algorithms to handle some of the radio's traditional hardware functions but work with analog transmissions. Motorola's Symphony system falls into this category.

(such as Dolby or dts), spatial soundfield or bass enhancers, or the capability to work with various peripheral devices. Consumers may also be able to upgrade the software features after purchase.

One of the most interesting attributes of Symphony is its ability to improve reception on the road. It can essentially eliminate multipath distortion, the biggest problem for mobile systems. Radio signals can reach cars along many pathways. One path is a direct line from the antenna, but other transmissions might reflect off nearby buildings or mountains. Often the reflected signals interfere with the direct one, causing annoying clicks and pops as one drives along. When the Symphony radio is configured for dual antennas (as some luxury autos have installed in them), the chip set combines the two signals in a way that minimizes multipath distortion, says Motorola systems manager Jeremy Ho.

The system can also reduce so-called adjacent-channel interference—noise coming from a neighboring frequency. The Symphony chip set can lock onto the desired frequency even if the noise is 11 decibels louder. Its software automatically adjusts the size of its band filter to suppress nearby transmissions and isolate the target signal.

A key aspect of Symphony, however, is that it will not significantly boost the cost of car radios, Motorola insists. The company expects to earn its profit by selling makers a larger fraction of the internal workings of each radio set. South Korea's Hyundai Autonet has announced that it will incorporate the technology into its automotive sound systems, and Motorola says that other firms have signed on to purchase them as well. The technology is expected to appear in premium car radios by December 2003—so on your next long holiday drive to visit the relatives, you might actually hear *Dark Side of the Moon* in its entirety this time.

BIOLOGY

Bug Blast

JET PACKS ON COCKROACHES ADVANCE THE CAUSE OF ROBOTICS BY CHARLES CHOI

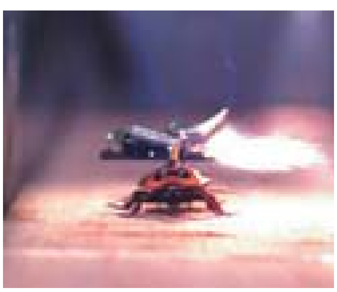
Detonating explosives strapped to cockroaches might seem excessive, but it actually has nothing to do with any insecticidal tendencies of engineers. Rather the experiment tested a mathematical system to explain how insects and their simple nervous systems carry out high-speed balancing acts.

The false death's head roach, *Blaberus discoidalis,* is amazingly nimble, able to run over obstacles three times its height without slowing from its eight-inch-per-second pace. Such unusually fast, complex reflexes led biologist Robert J. Full of the University of California at Berkeley to believe that the roach's nervous system isn't acting alone in maintaining the pace. With Princeton University mathematicians, Full devised a simple mechanical model in 1998 that treated the roach's legs like springs that help to keep the critter stable without the need for nerve impulses to do the job.

Proving their model has been challenging. The scientists needed jolts powerful enough to knock the roaches off balance but brief enough to test within a single roach stride, which can last as little as 50 milliseconds. After trying out spring-loaded projectiles, magnets and strings, biologist Devin L. Jindrich, now at Harvard University, hit on the idea of mini cannons: inch-long plastic tubes filled with gunpowder, ball bearings and flint shavings. Cannons glued onto the roaches' backs and activated via electrical wires fired 10-millisecond-long bursts.

Digital-camera recordings revealed that when jostled by explosives, the roaches regained their footing before even taking their next step. This speedy recovery challenges or beats a roach's fastest nerve responses and reinforces the mathematical model. Full and his engineer colleagues have already used the data to improve a breadbox-size robot bug named RHex, which can scrabble at 10 feet a second over rough terrain. The model, Full says, has helped liberate a huge amount of computing power that would otherwise be spent on balancing.

Charles Choi is based in New York City.



BACKPACK CANNON fires to knock a roach off balance.

DEVIN L. JINDRICH *Harvard University*

BY THE NUMBERS

Calculus of Happiness

ASSESSING SUBJECTIVE WELL-BEING ACROSS SOCIETIES **BY RODGER DOYLE**

Research beginning in the 1960s has found that among the correlates of happiness across societies are security, gender equality, absence of class inequity, modernity and low militarization. One of the most recent and extensive efforts to explore these links was conducted by political scientists Ronald F. Inglehart of the University of Michigan at Ann Arbor and Hans-Dieter Klingemann of the Social Science Research Center in Berlin. Through personal interviews in which tens of thousands were questioned, they assessed subjective well-being in 64 countries during the 1990s. Their measure of well-being is based on answers to two questions: "How satisfied are you with your life as a whole?" and "Taking all things together, would you say that you are very happy, quite happy, not very happy, not at all happy?" The answers are given equal weight in the subjective well-being scores displayed on the map.

The scores show a correlation between subjective well-being and economic development. Above about $13,000 of gross domestic product per capita, however—roughly half the American level—additional income does not seem to enhance reported well-being.

There is a correlation between subjective well-being and democracy. As Inglehart and Klingemann point out, however, democracy does not always make people happy. As examples, they cite Weimar Germany and the former communist countries. In fact, the extraordinarily low level in most ex-communist countries apparently reflects not so much low income as the turmoil following the dissolution of the Soviet empire. The evidence suggests that well-being in these countries was considerably higher before the dissolution.

Inglehart and Klingemann theorize that although democracy contributes to happiness, the primary causal effect is in the other direction: high levels of well-being legitimize democracy and promote its survival. Lack of democracy does not necessarily lead to unhappiness, as is demonstrated by authoritarian China, which has a higher level of well-being than democracies such as India or South Africa, perhaps because of its rapid economic growth.

Particular religious traditions may play a role just as important as economic development. This proposition is suggested by the higher level of well-being in the historically Protestant cultures of Scandinavia as compared with Catholic countries such as Italy and Spain. Western countries as a group have higher well-being scores than non-Western nations, but to what extent this is influenced by religion is not clear.

Among the correlates of happiness on an individual level are good health, extraversion, and professional or managerial occupation. The divorced and widowed are less happy than the never married, who in turn are less happy than the married. Old and young are equally happy. To judge by the experience of Holocaust survivors, early trauma leads to later unhappiness. Contrary to what some pessimists believe, most people almost everywhere who live above a bare subsistence level are happy.

Rodger Doyle can be reached at rdoyle2@adelphia.net

MORE TO EXPLORE

The Pursuit of Happiness. David G. Myers and Ed Diener in *Scientific American,* Vol. 274, No. 5; May 1996.

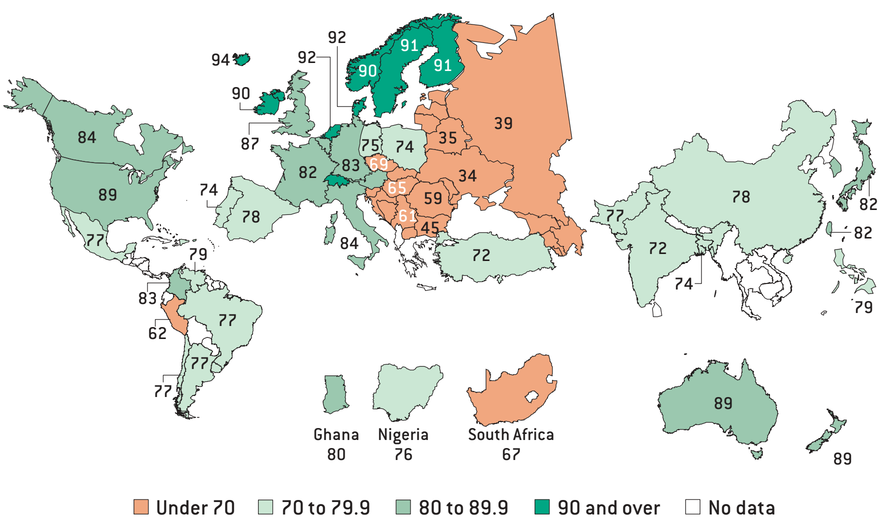
Handbook of Quality-of-Life Research. M. Joseph Sirgy. Kluwer Academic Publishers, 2001.

The High Price of Materialism. Tim Kasser. MIT Press, 2002.

World Database of Happiness: www.eur.nl/fsw/research/happiness/

World Values Survey: http://wvs.isr.umich.edu/

SUBJECTIVE QUALITY OF LIFE



SOURCE: "Genes, Culture, Democracy and Happiness," by Ronald Inglehart and Hans-Dieter Klingemann, in Subjective Well-Being across Cultures. MIT Press, 2000 (available at http://wvs.isr.umich.edu/papers/genes.html). The highest score possible is 100. Data are for the early to mid-1990s.

RODGER DOYLE

DATA POINTS: FIT TO PRINT

Bad news from weak science gets the column inches, at least in the U.K. Researchers from the University of Bristol and the University of Bern looked at 1,193 medical journal articles and determined which ones were accompanied by press releases and subsequently picked up by two newspapers. Notably, the papers were not inclined to describe results from randomized trials, which generate the strongest kind of scientific evidence.

Percent of journal articles given a press release: 43
Percent reported on by a newspaper: 7

Percent of journal articles describing
Good news: 44.7
Bad news: 37.5
Observational studies: 37.2
Randomized trials: 24.7

Percent of newspaper stories reporting on
Good news: 37.0
Bad news: 51.9
Observational studies: 58.0
Randomized trials: 6.2

Percent of items that focused on women's health in
Journals: 12.1
Press releases: 18.0
Newspapers: 30.9

SOURCE: British Medical Journal, *July 13, 2002. Journal articles were culled from the* BMJ *and the* Lancet; *newspapers were the* Times *and the* Sun.

SOCIOLOGY

In Sickness and in Health

No time for a checkup? Try sending your spouse instead. He or she predicts your own health as strongly as your level of education or income does. Brigham Young University political scientist Sven Wilson analyzed data from more than 4,700 couples in their 50s gathered during the 1992 Health and Retirement Study. He found that sickly men were much more likely to have sickly wives than healthy men were. Only 2 percent of very healthy men had wives in poor health, and just 5 percent had spouses in fair health. In comparison, 13 percent of the ill men had sick wives, and 24 percent had wives in fair health. Several factors contribute to the correlation: people tend to marry those with like backgrounds, and couples are more likely to make similar choices about diet, smoking and drinking. Their shared environments and stresses may also play a role. Wilson's study, published in the September *Social Science and Medicine,* suggests that health care concerns should focus on households, not just individuals. *—JR Minkel*

BIOLOGY

So Happy Together

Like Kafkaesque co-workers, cells can sit side by side their entire lives and never open up to one another. When membranes do fuse, the process may prove of life-or-death importance, such as in the case of egg fertilization or viral infection. The details of how these ultrathin cell skins link up have eluded investigators' best observations. By chance, when scientists at Brookhaven National Laboratory and Rice University shined x-rays at pancake stacks of dehydrating membranes, the resulting images of their atomic structures revealed hourglass shapes joining the surfaces. Biologists have long conjectured that short-lived objects, known as stalks, stretch to form bridges through which molecules such as DNA flow. The data confirm that theory and could help improve gene therapy and drug-delivery techniques. The researchers wrote up their results in the September 13 *Science.* *—Charles Choi*

MEMBRANES FUSE when sperm meets egg.

GENETICS

Gay Flies

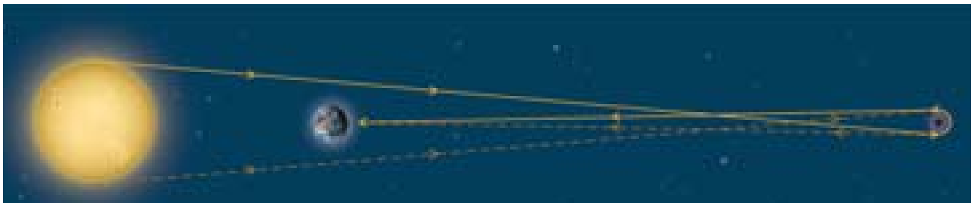
A flick of a thermostat made male fruit-fly wings and hearts go aflutter for other males. Prior studies hinted that *Drosophila*'s sexual preferences were genetically fixed, but the precise brain circuitry involved remained unclear. Neuroscientist Toshihiro Kitamoto of the Beckman Research Institute at the City of Hope in Duarte, Calif., and his colleagues implanted in the flies a heat-sensitive mutant gene that targeted specific neurons, including taste-sensing cells on the head and legs. When warmed to 30 degrees Celsius (86 degrees Fahrenheit), the mutant gene disrupted neurotransmitter activity, and males began courting males, even attempting copulation. The flies resumed heterosexual courtship when temperatures cooled. Kitamoto suspects that the taste nerves normally suppress homosexual behavior after detecting male antiaphrodisiac pheromones. The scientists report their findings in the September 18 online edition of the *Proceedings of the National Academy of Sciences.* *—Charles Choi*

COURTING MALE fruit flies form a ring.

D. PHILLIPS *Photo Researchers, Inc.* (*top*); TOSHIHIRO KITAMOTO (*bottom*); ILLUSTRATION BY MATT COLLINS

ASTRONOMY

Doing a 180



LOOP-D-LOOP: Sunlight could swing around a black hole and return to Earth.

If you were to shine a flashlight into a black hole, what would you see? The hole's intense gravity would bend some of the rays right back to you, so you'd see a dim, distorted image of your flashlight. Astronomers long regarded this extreme example of gravitational lensing as a mere curiosity—it is a homework problem in one standard graduate-level relativity textbook—but two physicists argue that it might just be visible. Daniel E. Holz of the University of California at Santa Barbara and John A. Wheeler of Princeton University say that the sun could serve as the flashlight. A black hole near the solar system would produce a very dim image of the sun in the night sky. The image, which would appear for several hours and recur once a year, might be picked up by ongoing searches for gravitational microlensing. It would provide the strongest-ever test of Einstein's theories under the extreme conditions of a black hole. The paper is published in the October 10 *Astrophysical Journal* and is also at arXiv.org/abs/astro-ph/0209039 —*George Musser*

MATERIALS SCIENCE

Charging Up Diamonds

On paper, diamond is an ideal semiconductor. It has the same crystal structure as silicon but could carry stronger electric fields and operate at wider bandwidths and higher temperatures. In practice, the natural kind is just not pure enough; those that would wow even the most meticulous appraiser would have too many microscopic imperfections that would prevent charges from freely roaming. Diamonds made artificially—through the deposition of vaporized carbon onto a substrate—are better, but they have not achieved the requisite purity and size. Now by carefully controlling the environmental conditions during deposition, Swedish and U.K. researchers have fabricated artificial sparklers with a charge mobility nearly twice as high as seen before. In an encouraging sign for carbon electronics, the highly mobile positive charges even outpaced the electrons in the semiconductors silicon carbide and gallium nitride. Higher mobility translates roughly into lower losses and faster switching times in semiconductor devices, says lead author Jan Isberg of Uppsala University in Sweden, whose paper appears in the September 6 *Science*. —*JR Minkel*

UNBEATABLE BRILLIANCE, but not good enough for circuits—yet.

ALICIA CALLE (*top*); L. CLARKE *Corbis* (*bottom*)

BRIEF POINTS

- Unlike aspirin and ibuprofen, acetaminophen doesn't reduce inflammation. That may be because it works on a newly discovered target, the COX-3 enzyme—a variation of COX-1, which anti-inflammatories go after.

  Proceedings of the National Academy of Sciences, September 13, 2002

- An August 30 court ruling allows scientists to examine the 9,200-year-old Kennewick Man. The decision overturns a U.S. Department of the Interior's decision in September 2000 to return the bones, unstudied, to Native American tribes.

  www.friendsofpast.org/

- Oxygen isn't always the bad guy when it comes to cell damage. In bacteria, a protein called AlkB relies on oxygen (and iron) to knock off methyl groups that can wreck DNA and lead to tumors.

  Nature, September 12, 2002

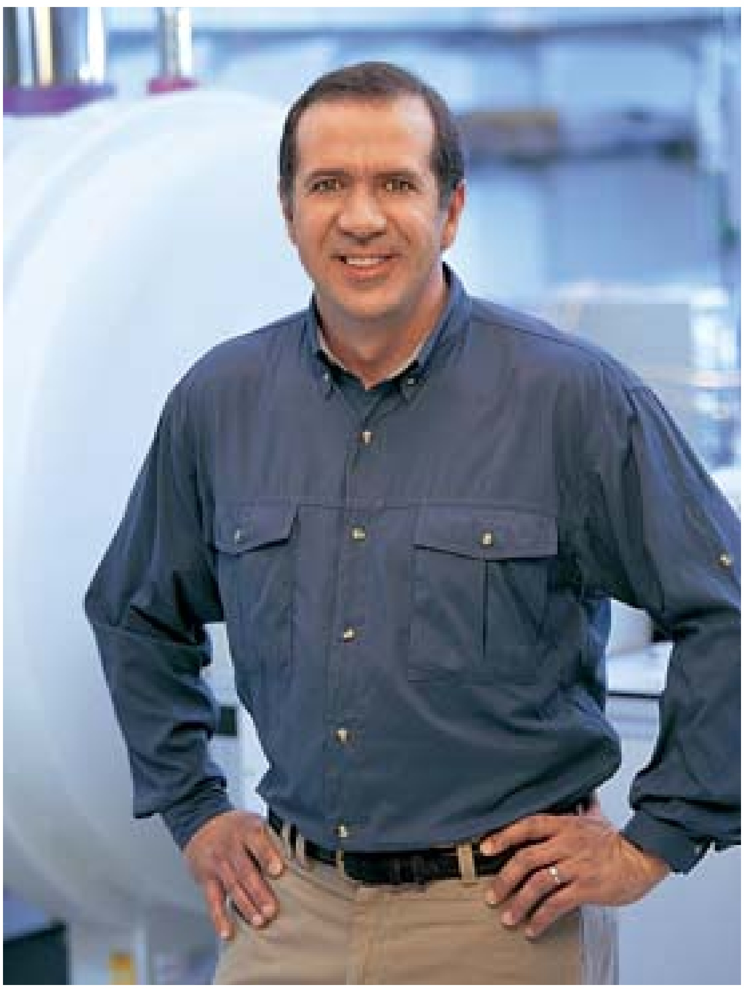
- Metal shavings and chips from machining actually consist of nanocrystals. They may provide a cheap, plentiful source of the tiny crystals, which are costly and difficult to make but can be four times as strong as the metal in bulk form.

  Journal of Materials Research, October 2002

The Universal Biosensor

A drug company tries to make a detector that can find nearly any biopathogen By GARY STIX

Chance is often the best inventor. Isis Pharmaceuticals never set out to become a maker of sensors for biological weapons. The company, based in Carlsbad, Calif., is best known for its work in developing antisense therapies, the use of small pieces of DNA-like molecules that bind to messenger RNA (a copy of a gene) to block synthesis of an encoded protein. Its research led to the formation of a division called Ibis Therapeutics, which develops chemicals other than DNA that would interfere with RNA.



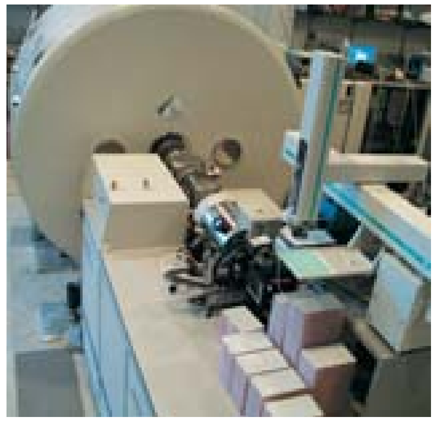
COURTESY OF ISIS PHARMACEUTICALS

INSPIRATION for Ibis Therapeutics's broad-scan biodetector came when company president David J. Ecker realized that a method used to screen for potential RNA-binding drugs might provide a means of looking for pathogens.

Along the way, Ibis discovered a method of screening pathogens that might lead to a universal detector for biological weapons—even perhaps nefarious, as yet to be invented bioengineered strains of pathogens. The road to a universal biosensor began in the mid-1990s, when Ibis started looking for chemicals with a low molecular weight that would bind to and block the activity of RNA, the same mechanism used by many antibiotics. The Defense Advanced Research Projects Agency (DARPA) funded some of the research because of its interest in finding new drugs to counter the microorganisms used in biowarfare. Conventional high-throughput screening—conducting a multitude of tests to measure the interaction of drug candidates with different enzymes—is ineffective for drugs that would work by binding to RNA. So Ibis began to explore the possibility of using mass spectrometry to determine when a small molecule binds to RNA.

The company refined a technique called electrospray ionization, as well as mass spectrometry, to extract RNA and the bound drug candidate from an aqueous solution intact and then suspend those molecules in a vacuum, where they can be weighed. As the methods proved themselves, Ibis president David J. Ecker came to the realization that pulling out the RNA alone, without the bound molecule, would provide the makings of an extraordinary sensing system.

After RNA from a cell is weighed with the spectrometer—each cell has multiple types of the molecule—these very precise measurements, accurate down to the mass of a few electrons, can be correlated with a database that contains information about RNA weights for a given pathogen. Each weight in the database table corresponds to the weight of the exact number of letters, or nucleotides, for a particular RNA. As long as information about the nucleotide composition is in the database, the system, called TIGER (triangulation identification for genetic evaluation of risks), can identify any bacterium, virus, fungus or protozoan. Before the RNA is weighed, another critical step is necessary: the polymerase chain reaction must make copies of stretches of DNA or RNA that are found in all cellular organisms (or, for viruses, in whole families of them).



MICROBIAL SCALE: The TIGER system uses a mass spectrometer to gauge the weight of a microorganism's RNA.

COURTESY OF ISIS PHARMACEUTICALS

Six months before last year's anthrax attacks, Ibis and partner SAIC, a contract research house, received a $10-million DARPA grant extending over two years to do a feasibility study for TIGER. The goal of the program is to develop a system that can detect the 1,500 or so agents known to infect humans. This approach differs fundamentally from the way other biodetectors are designed. Most systems use an antibody or a piece of DNA as a probe to bind to a protein or nucleic acid in a pathogen. These tests are limited to detecting a small subset of the universe of pathogenic agents. And an antibody probe for, say, anthrax needs to make a match with the exact strain of the specific bacterium it is targeting.

With TIGER, if information about a pathogen is not in its database—because it is a newly evolved strain or a specially bioengineered bug—the software can flag any genetic likeness it has with other microorganisms. "The database will say, 'I've never seen this before, but it's very similar to *Yersinia pestis* [plague],'" Ecker says. The detector would not, however, be able to pick up some genetic alterations of a microorganism—for instance, a gene for a toxin put in an otherwise harmless microbe.

Although biosensors were never part of Ibis's business plan, about half of its 35 employees are now on the TIGER team. Work at the company continues on sequencing the relevant genes to extract the needed RNA signatures for populating the databases—or obtaining this information from sequencing efforts under way worldwide. One of the biggest challenges the researchers still face is how to tell one piece of RNA from among thousands of specimens in a complex sample, such as a ball of dirt. "That requires very complex signal processing," Ecker says. The problem that Ibis had encountered was one that radar engineers deal with constantly. In fact, this was the reason behind the collaboration with SAIC, which produced culture shock when Ibis's molecular biologists began to work with SAIC's radar engineers. "We spent the better part of a whole year figuring out how to communicate with each other," Ecker remarks.

According to Ecker, it would have been easy to detect the anthrax in the letter sent to Senator Tom Daschle of South Dakota in October 2001, because the envelope contained no other biological material. Finding a small amount mixed in with other organic molecules is much harder; researchers are still laboring to improve the signal-processing capabilities. The extent to which TIGER can read pathogen signatures in complex samples will determine how effective the technology is. "The question is how far can we ultimately push it," Ecker says.

In April, Nobelist Joshua Lederberg, a scientific adviser to Ibis, hosted a conference at the Rockefeller University to explore ways in which various government agencies could adapt TIGER to their particular needs. If tests prove successful, Ecker foresees a detector eventually in every hospital, clinic and surveillance center, which could report back to a central monitoring site. How many of these systems would be deployed would depend in part on society's fear level about biowarfare—each of the mass spectrometers alone could cost $200,000. "Although TIGER is an extremely powerful tool, it is a big, cumbersome and expensive machine. Plus, it does not give results in real time," notes Rocco Casagrande, a biologist with Surface Logix, a drug-discovery company that has done work in biodetection [see "Technology against Terror," by Rocco Casagrande; Scientific American, October].

Ecker's optimism about the technology, though, extends beyond bioweapons. The detection system can be used to look not only for biopathogens but for any kind of disease-causing organism. Ecker believes that it could enable laboratories to forgo many of the time-consuming processes needed to determine if a particular microorganism is present—whether that bug is measles, anthrax or a newly emerging infectious disease. "If my vision holds, this could supersede a lot of what takes place in infectious microbiology," he says. "There would be no need to culture things anymore." Thus, a bioweapon sensor could become a universal disease sentinel. SA

If information about a pathogen is not in its database, TIGER might say, "I've never seen this before, but it's very similar to the plague bacterium."

Selling the Free Lunch

Perpetual motion has changed its name but not its methods By GRAHAM P. COLLINS

In recent decades crackpot inventors have focused on a variant of perpetual-motion machines known as free-energy devices or over-unity generators. These contraptions supposedly output more power than they take in, generally by drawing on an implausible font of energy hitherto unknown to science. The motionless electromagnetic generator discussed last month is a good example [see "There's No Stopping Them," by Graham P. Collins; Staking Claims]. At first it appears to be based on misconceptions about magnets, but it turns out the inventors have published a physics paper describing a "higher symmetry electrodynamics" that would allow infinite energy to be extracted from the vacuum by their device.

Limitless energy is more marketable than mere perpetual motion. Many over-unity promoters are outright scam artists, putting on public appearances to drum up investment money or to sell franchises and making it onto TV news shows with gullible hosts.

Perpetual motion holds a special place in the world of patents. Until 1880, a miniature working model was required for a U.S. patent to be approved. With the industrial revolution in full swing, that requirement became impractical to administer and the rule was rescinded—with the notable exception of perpetual-motion devices.

Yet "working" models of over-unity devices have occasionally fooled technically trained people at the U.S. patent office and elsewhere. A common trap for the unwary is that measuring electrical power with a meter is a difficult operation when there are sharp spikes of voltage or current or even just when the voltage and current are out of phase. In an infamous case that dragged on for years in the courts during the 1980s, Joseph W. Newman sued the patent office to try to reverse the rejection of his Energy Generation System Having Higher Energy Output Than Input. A court-appointed "special master" concluded that tests at universities had verified the excess power output, and it took new court-ordered tests by the National Bureau of Standards (what is now NIST) to establish that the machine's efficiency never exceeded 80 percent.

Currently a mechanical engineering professor at Rowan University is conducting a NASA-funded study to build and test a Black Light Rocket Engine. The Black Light process is the brainchild of Randell L. Mills, a medical doctor, whose Grand Unified Theory of Classical Quantum Mechanics holds that in a hydrogen atom the electron can drop to a state lower than the lowest state allowed by quantum mechanics, which would release vast amounts of energy. Mills's patent for extracting this energy was granted in February 2000.

The same month that news of the Rowan study broke, the American Physical Society, rather like King Canute trying to command the tide, issued a statement announcing its concern that "misguided or fraudulent claims of perpetual-motion machines and other sources of unlimited free energy are proliferating. Such devices directly violate the most fundamental laws of Nature, laws that have guided the scientific advances that are transforming our world."

The U.S. patent office may have been stung into action by recent negative publicity and complaints about ludicrous patents. Reportedly, the commissioner of patents will order a reexamination of the motionless electromagnetic generator patent. In August the office announced that patent examiners are to receive "expanded training to build and reinforce their knowledge and skills," which will be tested regularly. Patent office workers can't all be Einsteins, but perhaps now more of them will be Homer Simpsons. As he scolded his daughter Lisa when she built a perpetual-motion device: "In this house, we *obey* the laws of thermodynamics." SA

JOHN McFAUL

Mesmerized by Magnetism

An 18th-century investigation into mesmerism shows us how to think about 21st-century therapeutic magnets   By MICHAEL SHERMER

In an uncritical August 11, 1997, *World News Tonight* report on "biomagnetic therapy," a physical therapist explained that "magnets are another form of electric energy that we now think has a powerful effect on bodies." A fellow selling $89 magnets proclaimed: "All humans are magnetic. Every cell has a positive and negative side to it."

On the positive side, these magnets are so weak that they cause no harm. On the negative side, these magnets do have the remarkable power of attracting the pocketbooks of gullible Americans to the tune of about $300 million a year. They range in scale from coin-size patches to king-size mattresses, and their curative powers are said to be nearly limitless, based on the premise that magnetic fields increase blood circulation and enrich oxygen supplies because of the iron present in the blood.

This is fantastic flapdoodle and a financial flimflam. Iron atoms in a magnet are crammed together in a solid state about one atom apart from one another. In your blood only four iron atoms are allocated to each hemoglobin molecule, and they are separated by distances too great to form a magnet. This is easily tested by pricking your finger and placing a drop of your blood next to a magnet.

Magnetic cures are fantastic flapdoodle and a financial flimflam.

What about claims that magnets attenuate pain? In a 1997 Baylor College of Medicine double-blind study of 50 patients (in which 29 got real magnets and 21 got sham ones), 76 percent in the experimental group but just 19 percent in the control group reported a reduction in pain. Unfortunately, this study included only one 45-minute treatment, did not try other pain-reduction modalities, did not record the length of the pain reduction and has never been replicated.

Scientists studying magnetic therapy would do well to read the 1784 "Report of the Commissioners Charged by the King to Examine Animal Magnetism" (reprinted in an English translation in *Skeptic,* Vol. 4, No. 3). The report was instituted by French king Louis XVI and conducted by Benjamin Franklin and Antoine Lavoisier to experimentally test the claims of German physician Franz Anton Mesmer, discoverer of "animal magnetism." Mesmer reasoned that just as an invisible force of magnetism draws iron shavings to a lodestone, so does an invisible force of animal magnetism flow through living beings.

The experimenters began by trying to magnetize themselves, to no effect. To test the null hypothesis that magnetism was all in the mind, Franklin and Lavoisier deceived some subjects into thinking that they were receiving the experimental treatment with animal magnetism when they really were not, while others did receive the treatment and were told that they had not. The results were clear: the effects were from the power of suggestion alone.

In another experiment (there were 16 altogether), Franklin had Mesmer's representative, Charles d'Eslon, magnetize a tree in his garden: "When a tree has been touched following principles & methods of magnetism, anyone who stops beside it ought to feel the effect of this agent to some degree; there are some who even lose consciousness or feel convulsions." The subject walked around the garden hugging trees until he collapsed in a fit in front of the fourth tree; it was the fifth one that was "magnetized."

One woman could sense "magnetized" water. Lavoisier filled several cups with water, only one of which was supposedly magnetized. After touching an unmagnetized cup she "fell competely into a crisis," upon which Lavoisier gave her the "magnetized" one, which "she drank quietly & said she felt relieved."

The commission concluded that "nothing proves the existence of Animal-magnetism fluid; that this fluid with no existence is therefore without utility; that the violent effects observed at the group treatment belong to touching, to the imagination set in action & to this involuntary imitation that brings us in spite of ourselves to repeat that which strikes our senses." In other words, the effect is mental, not magnetic.

Modern skeptics should take a lesson from this historical masterpiece, which employed the control of intervening variables and the testing of specific claims, without resorting to unnecessary hypothesizing about what was behind the "power." A sad fact is that true believers remain unaffected by contradictory evidence, today as well as in the 18th century. SA

Michael Shermer is publisher of Skeptic *magazine (www.skeptic.com) and author of* In Darwin's Shadow.

BRAD HINES

An Ear to the Stars

Despite long odds, astronomer Jill C. Tarter forges ahead to improve the chances of picking up signs of extraterrestrial intelligence By NAOMI LUBICK

In a photograph hanging outside her office, Jill C. Tarter stands a head taller than Jodie Foster, the actress who played an idealistic young radio astronomer named Ellie Arroway in the film *Contact*. Tarter was not the model for the driven researcher at the center of Carl Sagan's book of the same name, although she understands why people often make that assumption. In fact, she herself did so after reading the page proofs that Sagan had sent her in 1985. After all, both she and Arroway were only children whose fathers encouraged their interest in science and who died when they were still young girls. And both staked their lives and careers on the search for extraterrestrial intelligence (SETI), no matter how long the odds of detecting an otherworldly sign. But no, Tarter says, the character is actually Sagan himself—they all just share the same passion.

JILL C. TARTER: SETI SEARCHER

- Grew up in Scarsdale, N.Y., and is a descendant of Cornell University's founder.
- Most influential cartoon: *Flash Gordon.*
- In the July *Astronomical Journal,* she and two colleagues conclude that there are no more than 10,000 civilizations in the Milky Way at about our level of technological advancement.
- "I just can't ever remember a time when I didn't assume that the stars were somebody else's suns."

In her position as director of the Center for SETI Research at the SETI Institute in Mountain View, Calif., Tarter has recently focused on developing new technology for observing radio signals from the universe. The concept, first presented in the 1950s, is that a technologically advanced civilization will leak radio signals. Some may even be transmitting purposefully.

So far there haven't been any confirmed detections. Amid the radio chatter from natural and human sources, there have been some hiccups and a few heart-stoppingly close calls. On her first observing run at Green Bank Observatory in West Virginia, Tarter detected a signal that was clearly not natural. But it turned out to come from a telescope operator's CB radio.

Tarter's current project is the Allen Telescope Array, consisting of a set of about 350 small satellite dishes in Hat Creek, Calif. The system, which will span about 15,000 square meters and will be one of the first radio-telescope arrays built specifically for SETI projects, is funded by private investors. Its observing speed will be 100 times as fast as that of today's equipment, and it will expand observable frequency ranges.

Tarter has often been a lone and nontraditional entity in her environment. Her interest in science, which began with mechanical engineering, was nurtured by her father, who died when she was 12. As with most other female scientists of her generation, Tarter says, a father's encouragement was "just enough to make the difference about whether you blew off the negative counseling" that girls interested in science often got. Her mother worried about her when she departed in the

OLIVIER LAUDE

1960s from their suburban New York home for Cornell University, when women there were still locked in their dorms overnight. She was the only female student in the mechanical engineering department. (Tarter is a descendant of Ezra Cornell, the university's founder, although at the time her gender meant that she would not receive the family scholarship.)

"There's an enormous amount of problem solving, of homework sets to be done as an engineering student," Tarter recalls. Whereas male students formed teams, sharing the workload, "I sat in my dorm and did them all by myself." Puzzling out the problems alone gave her a better education in some ways, she says, but "it was socially very isolating, and I lost the ability to build teaming skills."

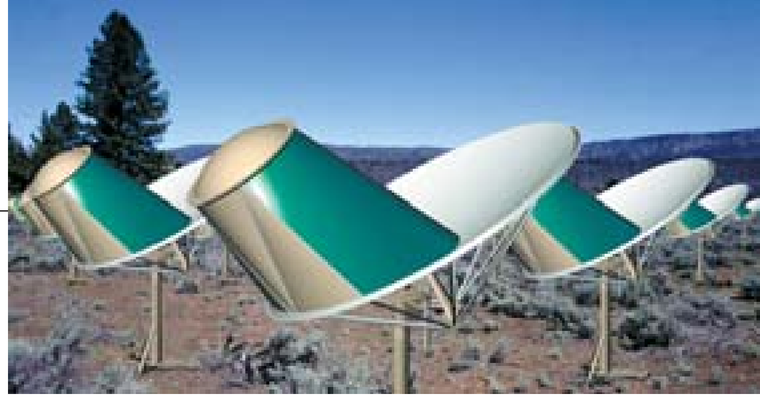
Her independence and eventual distaste for engineering led her to do her graduate work in physics at Cornell, but Tarter soon left for the University of California at Berkeley to pursue a doctorate in astronomy. While working on her Ph.D., which she completed in 1975, Tarter was also busy raising a daughter from her first marriage, to C. Bruce Tarter, who has directed Lawrence Livermore National Laboratory for the past eight years. The two had married in Tarter's junior year of college and moved to Berkeley together. Tarter's postdoctoral work there was on brown dwarfs, a term she coined in the 1970s for what was then a hypothetical planetlike body (only recently have they been observed directly).

By chance, an ancient computer led Tarter to SETI. She had programmed a signal-processing machine as a first-year graduate student. When astronomer Stuart Boyer acquired the computer from a colleague several years later for a SETI project—lack of funds forced Boyer into looking for handouts—he approached Tarter, because someone remembered that she had used it.

To persuade her to join the project, Boyer placed a copy of a report on her desk called Project Cyclops, a NASA study conducted by Bernard M. Oliver of Stanford University on possible system designs for detecting extraterrestrial life. Tarter read the hefty volume cover to cover in one night. Hooked on the idea of SETI, she would work with Frank Drake, who in 1960 conducted Ozma, the first American SETI project, and with William "Jack" Welch, who taught her radio astronomy and would become her second husband in 1978. Astronomer John Billingham hired her to join the small group of SETI researchers at NASA, a group that Tarter helped to turn into the SETI Institute in 1984. She became director of SETI's Project Phoenix in 1993, so named because it was resurrected after Congress removed its funding.

The SETI project has always seemed to be NASA's astronomical stepchild, Tarter explains, partly because of the "little green men" associations. But the congressional rejection of the search for intelligent life paradoxically gave new life to its pursuit.

Operating outside the confines of NASA's bureaucracy, Tarter says, the SETI Institute runs like a nonprofit business. The current funding for projects has come from venture capitalists—wealthy scientific philanthropists such as Paul G. Allen and



ALLEN TELESCOPE ARRAY (based on artist's conception) will begin working in 2005. Each antenna has a shroud to block ground reflections.

LY LY *SETI Institute*

Nathan P. Myhrvold, both formerly at Microsoft. Some contributors also serve with scientists on a board that supervises SETI's business plan, procedures and results.

Tarter's efforts to push SETI forward with private financing impress even skeptics of the enterprise. Benjamin M. Zuckerman, a radio astronomer who began his career with SETI, is blunt in his disbelief in both the search for and the existence of extraterrestrial intelligence. Still, he finds Tarter's work exceptional and notes that by keeping the public interested in SETI, Tarter has enabled astronomers to continue esoteric work.

Tarter, too, has been able to overcome her solo work tendencies. Her SETI collaborators say she has been an indomitable and tireless team leader. Yet a bout with breast cancer in 1995 may have been a defining moment of her ability to delegate authority. Radiation and chemotherapy treatment required that she step down temporarily as Phoenix project manager and cut back on her travel, thereby forcing her to assign tasks to others. She picked up her grueling pace of going to observatories and attending meetings—not to mention consulting for the movie version of *Contact*—as soon as her therapy ended.

The SETI Institute's Allen Telescope Array, to start up in 2005, will be Tarter's largest contribution to instrumentation yet. Thanks to advances in computers and telecommunications, the cost of the array is much lower than that of past setups. For instance, each dish of the Very Large Array in Socorro, N.M., cost $1 million, whereas the SETI Institute paid only $32,000 per dish for the Allen array. Each dish measures 6.1 meters wide and will be set up in a carefully selected, random pattern. The U.C. Berkeley Radio Astronomy Lab and NASA will co-manage it.

The small dishes will be more mobile than the 305-meter-wide stationary dish at Arecibo, Puerto Rico, where Tarter currently does most of her observing. The Allen array will hear frequencies from 0.5 to 11.2 gigahertz, a span 20 times as wide as what most radio telescopes can detect, and results will be high-resolution images of the sky, with thousands more stars observed at once than by Project Phoenix. Plus, the institute will be able to give time to other observers—instead of competing for it elsewhere.

Tarter strongly believes in the search for extraterrestrial intelligence, although unlike Ellie Arroway, she seems to accept that a momentous signal may not come in her lifetime. Meanwhile she is happy to push the technological boundaries of the earth's listening posts and is already planning even larger telescopes for future Arroways to use. SA

Naomi Lubick is based in Palo Alto, Calif.

IMPACT CRASH SHOCK SMASH INTO RAM

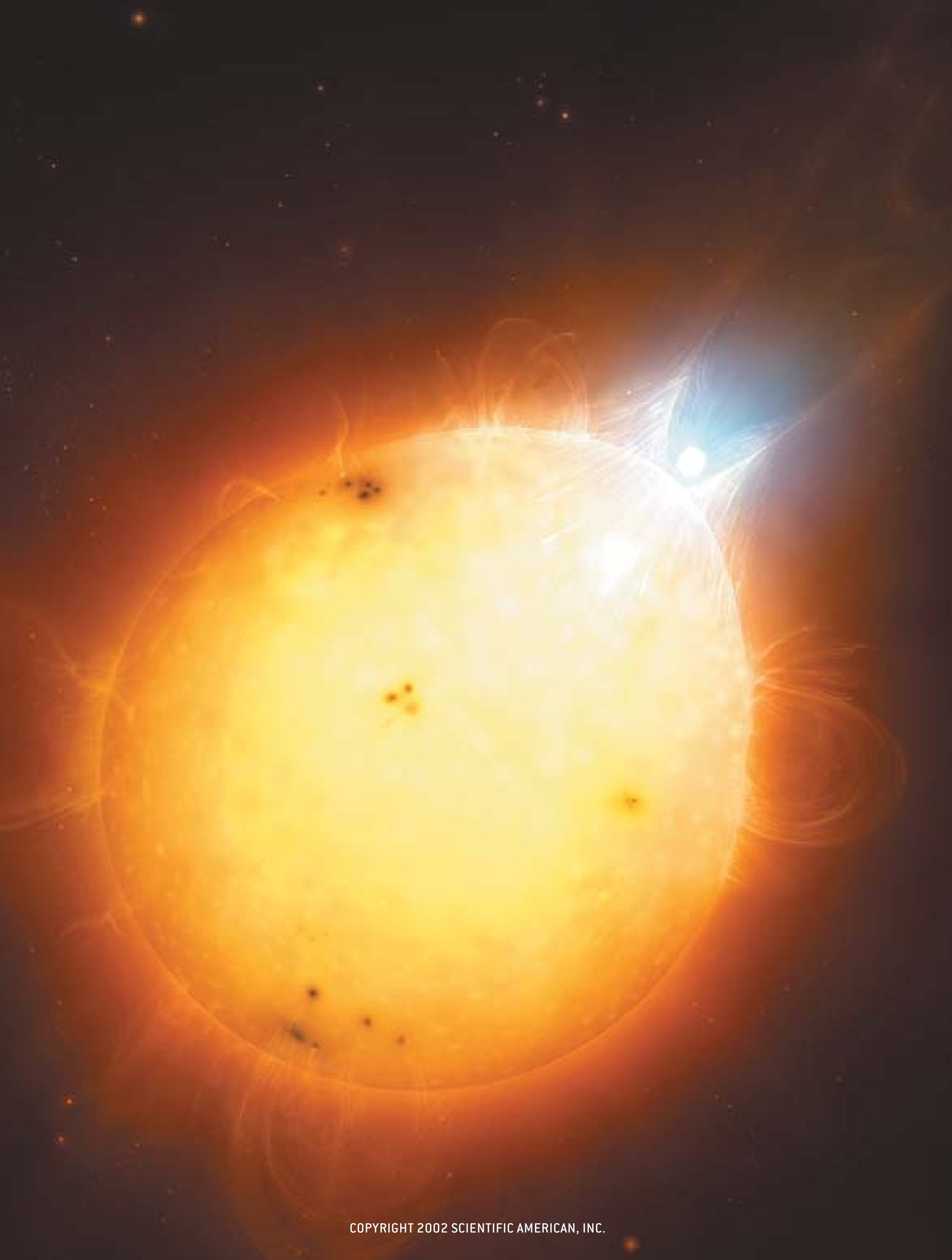
WHEN STARS COLLIDE

VIOLENT BLOW SMACK JOLT

THIS IS NOT A SIGHT you would ever want to see. If a white dwarf star hit the sun, it would trigger a calamitous series of events—despite the fact that the dwarf is barely a hundredth the sun's diameter. As the dwarf approached, it would suck matter toward it and distort the sun into a pear shape. Thankfully, such a collision is unlikely. But similar events occur regularly in denser parts of the galaxy, such as globular star clusters.

WHEN TWO STARS SMASH INTO EACH OTHER, IT CAN BE A VERY PRETTY SIGHT (AS LONG AS YOU'RE NOT TOO CLOSE BY). THESE OCCURRENCES WERE ONCE CONSIDERED IMPOSSIBLE, BUT THEY HAVE TURNED OUT TO BE COMMON IN CERTAIN GALACTIC NEIGHBORHOODS

BY MICHAEL SHARA



Of all the ways for life on Earth to end, the collision of the sun and another star might well be the most dramatic. If the incoming projectile were a white dwarf—a superdense star that packs the mass of the sun into a body a hundredth the size—the residents of Earth would be treated to quite a fireworks show. The white dwarf would penetrate the sun at hypersonic speed, over 600 kilometers a second, setting up a massive shock wave that would compress and heat the entire sun above thermonuclear ignition temperatures.

It would take only an hour for the white dwarf to smash through, but the damage would be irreversible. The superheated sun would release as much fusion energy in that hour as it normally does in 100 million years. The buildup of pressure would force gas outward at speeds far above escape velocity. Within a few hours the sun would have blown itself apart. Meanwhile the agent of this catastrophe, the white dwarf, would continue blithely on its way—not that we would be around to care about the injustice of it all.

For much of the 20th century, the notion that stellar collisions might be worth studying seemed ludicrous to astronomers. The distances between stars in the neighborhood of the sun are just too vast for them to bump into one another. Other calamities will befall the sun (and Earth) in the distant future, but a collision with a nearby star is not likely to be one of them. In fact, simple calculations carried out early in the 20th century by British astrophysicist James Jeans suggested that not a single one of the 100 billion stars in the disk of our galaxy has ever run into another star.

But that does not mean collisions are uncommon. Jeans's assumptions and conclusion apply to the environs of the sun but not to other, more exotic parts of the Milky Way. Dense star clusters are a veritable demolition derby. Within these tight knots of stars, observers in recent years have discovered bodies that are forbidden by the principles of ordinary stellar evolution—but that are naturally explained as smashed-up stars. Collisions can modify the long-term evolution of entire clusters, and the most violent ones can be seen halfway across the universe.

Overview/*Stellar Collisions*

- This is one of those cases in which the textbooks need to be revised. The conventional wisdom that stars can never hit each other is wrong. Collisions can occur in star clusters, especially globular clusters, where the density of stars is high and where gravitational interactions heighten the odds of impact.
- The leading observational evidence for collisions is twofold. Globular clusters contain stars called blue stragglers that are best explained as the outcome of collisions. And globulars contain an anomalously high number of x-ray sources—again the likely product of collisions.

A Star-Eat-Star World

THE 1963 DISCOVERY of quasars was what inspired skeptical astronomers to take stellar collisions seriously. Many quasars radiate as much power as 100 trillion suns. Because some brighten or dim significantly in less than a day, their energy-producing regions must be no larger than the distance light can travel in a day—about the size of our solar system. If you could somehow pack millions of stars into such a small volume, astronomers asked, would stars crash? And could this jostling liberate those huge energies?

By 1970 it became clear that the answer to the second question was no. Nor could stellar slam dancing explain the narrow jets that emanate from the central powerhouses of many quasars. The blame fell instead on supermassive black holes. (Ironically, some astronomers have recently proposed that stellar collisions could help feed material into these holes.)

Just as extragalactic astronomers were giving up on stellar

MARK A. GARLICK (*preceding page*)

collisions, their galactic colleagues adopted them with a vengeance. The Uhuru satellite, launched in 1970 to survey the sky for x-ray-emitting objects, discovered about 100 bright sources in the Milky Way. Fully 10 percent were in the densest type of star cluster, globular clusters. Yet such clusters make up only 0.01 percent of the Milky Way's stars. For some reason, they contain a wildly disproportionate number of x-ray sources.

To express the mystery in a different way, consider what produces such x-ray sources. Each is thought to be a pair of stars, one of which has died and collapsed into a neutron star or a black hole. The ex-star cannibalizes its partner and in doing so heats the gas to such high temperatures that it releases x-rays. Such morbid couplings are rare. The simultaneous evolution of two newborn stars in a binary system succeeds in producing a luminous x-ray binary just once in a billion tries.

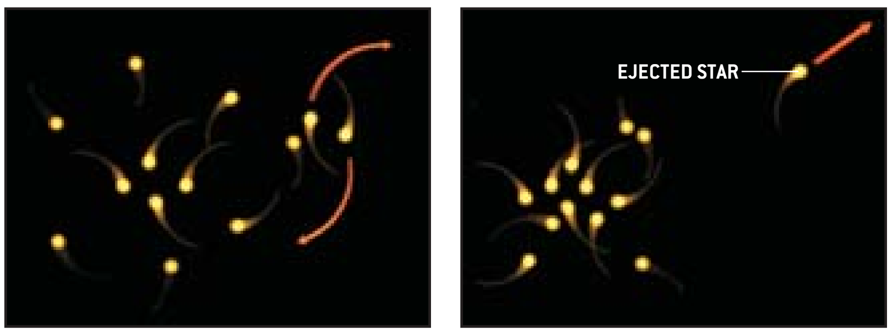
What is it about globulars that overcomes these odds? It dawned on astronomers that the crowded conditions in globulars could be the deciding factor. A million stars are crammed into a volume a few dozen light-years across; an equivalent volume near the sun would accommodate only a hundred stars. Like bees in a swarm, these stars move on ever changing orbits. Lower-mass stars tend to be ejected from the cluster as they pick up energy during close encounters with more massive single and double stars, a process referred to as evaporation because it resembles the escape of molecules from the surface of a liquid. The remaining stars, having lost energy, concentrate closer to the cluster center. Given enough time, the tightly packed stars will begin to collide.

Even in a globular, the average distance between stars is much larger than the stars themselves. But Jack G. Hills and Carol A. Day, both then at the University of Michigan at Ann Arbor, showed in 1975 that the probability of impact is not a simple matter of a star's physical cross section. Because the stars in a globular cluster move at a lackadaisical (by cosmic standards) 10 to 20 kilometers a second, gravity has plenty of time to act during close encounters. Without gravity, two stars can hit only if they are aimed directly at each other; with gravity, each star pulls on the other, deflecting its path. The stars are

PROCESSES THAT MAKE COLLISIONS MORE LIKELY

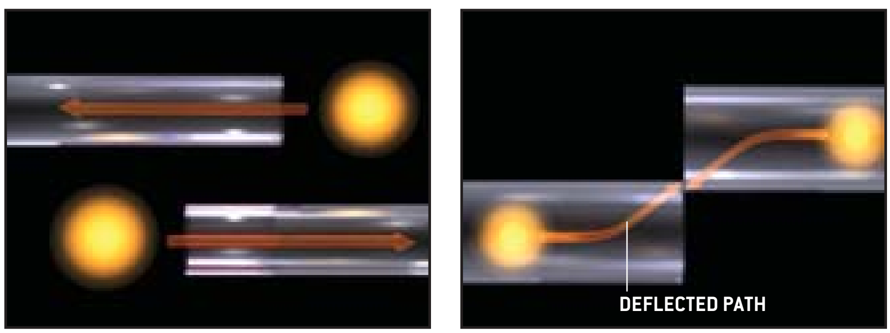
EVAPORATION

STARS IN A GLOBULAR CLUSTER zip around like bees in a swarm. Occasionally three or four come close to one another. Their close encounter redistributes energy and can fling one of the stars out of the cluster altogether. The remaining cluster members huddle together more tightly. If enough stars are ejected, the ones left behind begin to collide. This process typically occurs over billions of years.



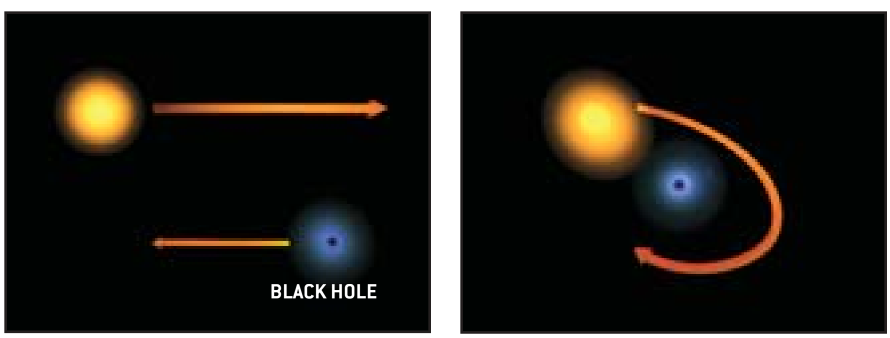
GRAVITATIONAL FOCUSING

IN THE COSMIC SCHEME of things, stars are small targets for impacts. Each sweeps out a very narrow region of space, and at first glance it appears that two such regions are unlikely to overlap. But gravity makes stars into larger targets by deflecting the paths of any approaching objects. In effect, each star actually sweeps out a region many times its own size, greatly increasing the probability of overlap and collision.



TIDAL CAPTURE

BLACK HOLE or neutron star makes an even smaller target than a normal star. But it can exert powerful tidal forces that bend a passing star out of shape. The distortion dissipates energy and can cause the two bodies to go into orbit. A collision between the two is then just a matter of time, as successive close passages rob ever more orbital energy.



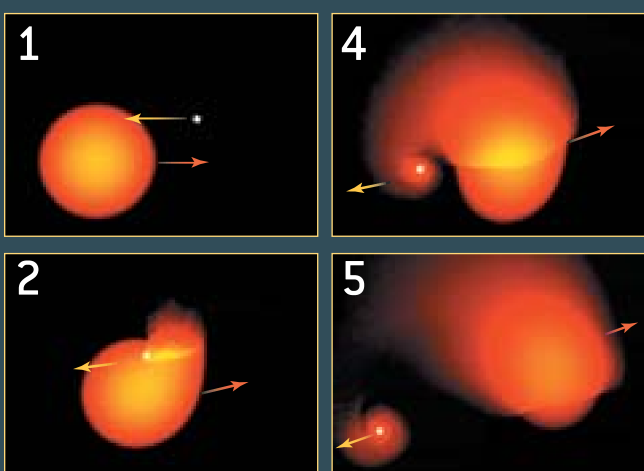
ALFRED T. KAMAJIAN

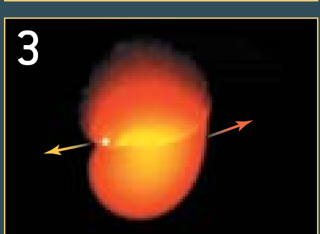
Having an Impact

	SUPERGIANT	RED GIANT	MAIN SEQUENCE	BROWN DWARF	WHITE DWARF	NEUTRON STAR	BLACK HOLE
BLACK HOLE	black hole + disk + white dwarf	black hole + disk + white dwarf	black hole + disk	black hole + disk	black hole + disk	black hole + disk	black hole
NEUTRON STAR	neutron star or black hole + disk + white dwarf	neutron star or black hole + disk + white dwarf	neutron star or black hole + disk	neutron star or black hole + disk	neutron star or black hole + disk	neutron star or black hole + disk	
WHITE DWARF	white dwarf + white dwarf	white dwarf + white dwarf	white dwarf	white dwarf or neutron star	neutron star or white dwarf		
BROWN DWARF	brown dwarf + white dwarf	brown dwarf + white dwarf	main sequence	main sequence or brown dwarf			
MAIN SEQUENCE	main sequence + white dwarf	main sequence + white dwarf	main sequence				
RED GIANT	white dwarf + white dwarf	white dwarf + white dwarf					
SUPERGIANT	white dwarf + white dwarf						

STARS COME IN seven basic types, with black holes being the most dense and supergiants the least. Our sun is a main-sequence star. This table lists the outcomes of the 28 different pairings. In many cases, a collision can have more than one possible outcome, depending on impact speed, angle and other parameters. The results here assume deeply penetrating collisions at modest speeds. Two such collisions are shown below.

WHITE DWARF HITS RED GIANT





WHITE DWARF STAR takes a month to penetrate the bloated red giant. It escapes unscathed and spirits away some of the giant's gas. The giant, however, falls apart, although its core remains intact and becomes another white dwarf. (The full movie is available at www.ukaff.ac.uk/movies/collision.mov)

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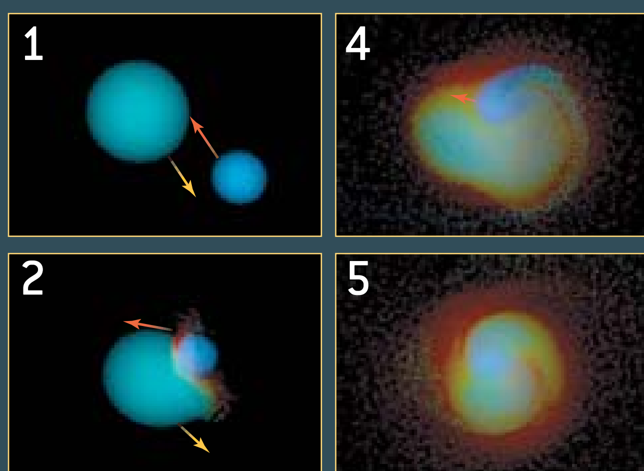

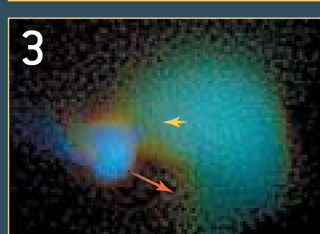

TWO ORDINARY STARS of unequal mass have struck off-center. The smaller one is less massive but denser, so it stays intact for longer. Over the course of an hour, it burrows into the larger star. A single, rapidly spinning star results. Some mass is lost to deep space. (The full movie is available at www.sciam.com)

MATTHEW BATE *University of Exeter (bottom left)*; JOSHUA BARNES *University of Hawaii (bottom right)* transformed from ballistic missiles with a preset flight path into guided missiles that home in on their target. A collision becomes up to 10,000 times more likely. In fact, half the stars in the central regions of some globular clusters have probably undergone one or more collisions over the past 13 billion years.

Around the same time, Andrew C. Fabian, James E. Pringle and Martin J. Rees of the University of Cambridge suggested that a grazing collision or a very near miss could cause two isolated stars to pair up. Normally a close encounter of two celestial bodies is symmetrical: they approach, gather speed, swing past each other and, unless they make contact, fly apart. But if one is a neutron star or a black hole, its intense gravity can contort the other, sapping some of its kinetic energy and preventing it from escaping, a process known as tidal capture. The neutron star or black hole proceeds to feast on its ensnared prey, spewing x-rays.

If the close encounter involves not two but three stars, it is even more likely to produce an x-ray binary. The dynamics of three bodies is notoriously complex and sometimes chaotic; the stars usually redistribute their energy in such a way that the two most massive ones pair up and the third gets flung away. The typical situation involves a loner neutron star that comes a little too close to an ordinary binary pair. One of the ordinary stars in the binary is cast off, and the neutron star takes its place, producing an x-ray source. The bottom line is that three-body dynamics and tidal capture lead to a 1,000-fold increase in the rate at which x-ray sources form in globular clusters, neatly solving the puzzle raised by Uhuru.

Crash Scene

WHAT HAPPENS WHEN TWO STARS smack into each other? As in a collision involving two vehicles, the outcome depends on several factors: the speed of the colliding objects, their internal structures, and the impact parameter (which specifies whether the collision is head-on or a sideswipe). Some incidents are fender benders, some are total wrecks, and some fall in between. Higher-velocity and head-on collisions are the best at converting kinetic energy into heat and pressure, making for a total wreck.

Although astronomers rely on supercomputers to study collisions in detail, a few simple principles govern the overall effect. Most important is the density contrast. A higher-density star will suffer much less damage than a tenuous one, just as a cannonball is barely marked as it blows a watermelon to shreds. A head-on collision between a sunlike star and a vastly denser star, such as a white dwarf, was first studied in the 1970s and 1980s by me and my colleagues Giora Shaviv and Oded Regev, both then at Tel Aviv University and now at the Technion–Israel Institute of Technology in Haifa. Whereas the sunlike star is annihilated, the white dwarf, being 10 million times as dense, gets away with only a mild warming of its outermost layers. Except for an anomalously high surface abundance of nitrogen, the white dwarf should appear unchanged.

The dwarf is less able to cover its tracks during a grazing collision, as first modeled by me, Regev, Noam Soker of the University of Haifa at Oranim and the University of Virginia, and Mario Livio of the Space Telescope Science Institute. The disrupted sunlike star could form a massive disk in orbit around the dwarf. No such disks have yet been shown to exist, but astronomers might be mistaking them for mass-transferring binary stars in star clusters.

When the colliding stars are of the same type, density and size, a very different sequence of events occurs. The case of two sunlike stars was first simulated in the early 1970s by Alastair G. W. Cameron (then at Yeshiva University and now at the University of Arizona) and Frederick G. P. Seidl of the NASA Goddard Institute for Space Studies. As the initially spherical stars increasingly overlap, they compress and distort each other into half-moon shapes. Temperatures and densities never climb high enough to ignite disruptive thermonuclear burning. As a few percent of the total mass squirts out perpendicular to the direction of stellar motion, the rest mixes together. Within an hour, the two stars have fused into one.

It is much more likely that two stars will collide somewhat off-axis than exactly head-on; it is also more likely that they will have slightly different rather than identical masses. This general case has been studied in detail by Willy Benz of the University of Bern in Switzerland, Frederic A. Rasio of Northwestern University, James C. Lombardi of Vassar College and their collaborators. It is a beautiful mating dance that ends in the perpetual union of the two stars.

The object that results is fundamentally different from an isolated star such as our sun. An isolated star has no way of replenishing its initial allotment of fuel; its life span is preordained. The more massive the star is, the hotter it is and the faster it burns itself out. Given a star's color, which indicates its temperature, computer models of energy production can predict its life span with high precision. But a coalesced star does not follow the same rules. Mixing of the layers of gas during the collision can add fresh hydrogen fuel to the core, with a rejuvenating effect rather like tossing twigs on a dying campfire. Moreover, the object, being more massive than its progenitors, will be hotter, bluer and brighter. Observers who look at the star and use its color and luminosity to deduce its age will be wrong.

For instance, the sun has a total life span of 10 billion years, whereas a star twice its mass is 10 times brighter and lasts only 800 million years. Therefore, if two sunlike stars merge halfway through their lives, they will form a single hot star that is five billion years old at the moment of its creation but looks as though it must be younger than 800 million years. The lifetime

THE AUTHOR

MICHAEL SHARA wanted to be an astronomer from age seven. His earliest interest came from observing binary stars with surplus World War II binoculars. Today he is curator and chair of the department of astrophysics at the American Museum of Natural History in New York City. Before joining the museum, he put in 17 years at the Space Telescope Science Institute, where he oversaw the peer-review committees for the Hubble Space Telescope. Shara's research interests include stellar collisions, novae and supernovae, and the populations of stars that inhabit star clusters and galaxies. Nowadays he observes with Hubble and ground-based instruments.

IN THE AFTERMATH of the collision between the sun and a white dwarf, the sun explodes as a giant thermonuclear bomb, leaving a gaseous nebula. A few percent of the sun's mass collects in a disk around the white dwarf, which continues on its way. Earth survives, but the oceans and atmosphere boil away. No longer held by the gravity of a central star, the planets all fly off into interstellar space and wander lifelessly around the galaxy.

remaining to this massive fused star depends on how much hydrogen fuel was thrown to its center by the collision. Usually this lifetime will be much shorter than that of each of its parents. Even in death the star distinguishes itself. When it dies (by swelling to become a red giant, a planetary nebula and finally a white dwarf), it will be much hotter than other, older white dwarfs of similar mass.

Got the Blues

IN A GLOBULAR CLUSTER, massive merged stars will stand out conspicuously. All the members of a globular are born at roughly the same time; their temperature and brightness evolve in lockstep [see "Rip Van Twinkle," by Brian C. Chaboyer; SCIENTIFIC AMERICAN, May 2001]. But a coalesced star is out of sync. It looks preternaturally young, surviving when others of equal brightness and color have passed on. The presence of such stars in the cores of dense star clusters is one of the most compelling predictions of stellar-collision theory.

As it happens, Allan R. Sandage of the Carnegie Institution of Washington discovered in the early 1950s that globular clusters contain anomalously hot and bright stars called blue stragglers. Over the years, researchers have advanced a dozen or so theories of their origin. But it is only in the past decade that the Hubble Space Telescope has provided strong evidence of a link with collisions.

In 1991 Francesco Paresce, George Meylan and I, all then at the Space Telescope Science Institute, found that the very center of the globular cluster 47 Tucanae is crammed with blue stragglers, exactly where collision theory predicted they should exist in greatest number. Six years later David Zurek of the Space Telescope Science Institute, Rex A. Saffer of Villanova University and I carried out the first direct measurement of the mass of a blue straggler in a globular cluster. It has approximately twice the mass of the most massive ordinary stars in the same cluster—as expected if stellar coalescence is responsible. Saffer and his colleagues have found another blue straggler to be three times as massive as any ordinary star in its cluster. Astronomers know of no way other than a collisional merger to manufacture such a heavy object in this environment.

We are now measuring the masses and spins of dozens of blue stragglers. Meanwhile observers are also looking for the other predicted effects of collisions. For instance, S. George Djorgovski of the California Institute of Technology and his colleagues have noted a decided lack of red giant stars near the cores of globular clusters. Red giants have cross sections thousands of times as large as the sun's, so they are unusually big targets. Their dearth is naturally explained by collisions, which would strip away their outer layers and transform the stars into a different breed.

To be sure, all this evidence is circumstantial. Definitive proof is harder to come by. The average time between collisions in the 150 globular clusters of the Milky Way is about 10,000 years; in the rest of our galaxy it is billions of years. Only if we are extraordinarily lucky will a direct collision occur close enough—say, within a few million light-years—to permit today's astronomers to witness it with present technology. The first real-time detection of a stellar collision may come from the gravitational-wave observatories that are now starting to observe. Close encounters between stellar-mass objects should lead to distortions in the spacetime continuum. The signal is especially strong for colliding black holes or neutron stars [see "Ripples in Spacetime," by W. Wayt Gibbs; SCIENTIFIC AMERICAN, April]. Such events have been implicated in the enormous energy releases associated with gamma-ray bursts. [*Editors' note: An upcoming article will discuss gamma-ray bursts in detail.*]

Collisions are already proving crucial to understanding globulars and other celestial bodies. Computer simulations suggest that the evolution of clusters is controlled largely by tightly bound binary systems, which exchange energy and angular momentum with the cluster as a whole. Clusters can dissolve altogether as near-collisions fling stars out one by one. Piet Hut of the Institute for Advanced Study in Princeton, N.J., and Alison Sills of McMaster University in Ontario have argued that stellar dynamics and stellar evolution regulate each other by means of subtle feedback loops.

The fates of planets whose parent stars undergo close encounters is another recent addition to the topic of stellar collisions. Numerical simulations by Jarrod R. Hurley of the American Museum of Natural History in New York City show that the planets often fare badly: cannibalized by their parent star or one of their planetary siblings, set adrift within the star cluster, or even ejected from the cluster and doomed to tramp through interstellar space. Recent Hubble observations by Ron Gilliland of the Space Telescope Science Institute and his colleagues suggest that stars in a nearby globular cluster do indeed lack Jupiter-size planets, although the cause of this deficiency is not yet known for sure.

Despite the outstanding questions, the progress in this field has been astonishing. The very idea of stellar collisions was once absurd; today it is central to many areas of astrophysics. The apparent tranquillity of the night sky masks a universe of almost unimaginable power and destruction, in which a thousand pairs of stars collide somewhere every hour. And the best is surely yet to come. New technologies may soon allow direct and routine detection of these events. We will watch as some stars die violently, while others are reborn, phoenixlike, during collisions. SA

MORE TO EXPLORE

The First Direct Measurement of the Mass of a Blue Straggler in the Core of a Globular Cluster: BSS 19 in 47 Tucanae. Michael M. Shara, Rex A. Saffer and Mario Livio in *Astrophysical Journal Letters,* Vol. 489, No. 1, Part 2, pages L59–L62; November 1, 1997.

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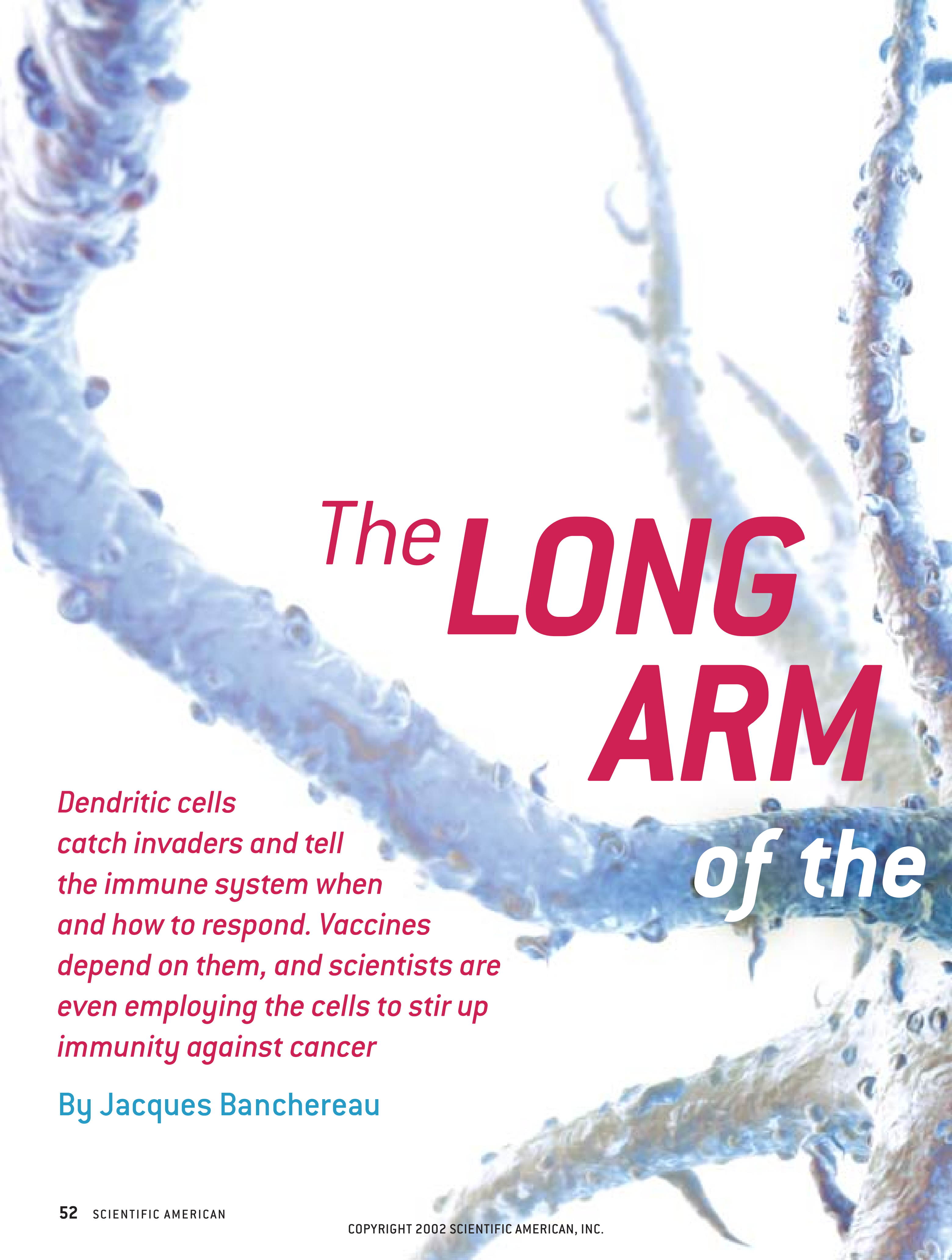
Evolution of Stellar Collision Products in Globular Clusters –II: Off-Axis Collision. Alison Sills, Joshua A. Faber, James C. Lombardi, Jr., Frederic A. Rasio and Aaron Warren in *Astrophysical Journal,* Vol. 548, No. 1, Part 1, pages 323–334; February 10, 2001. **astro-ph/0008254**

The Promiscuous Nature of Stars in Clusters. Jarrod R. Hurley and Michael M. Shara in *Astrophysical Journal,* Vol. 570, No. 1, Part 1, pages 184–189; May 1, 2002. **astro-ph/0201217**

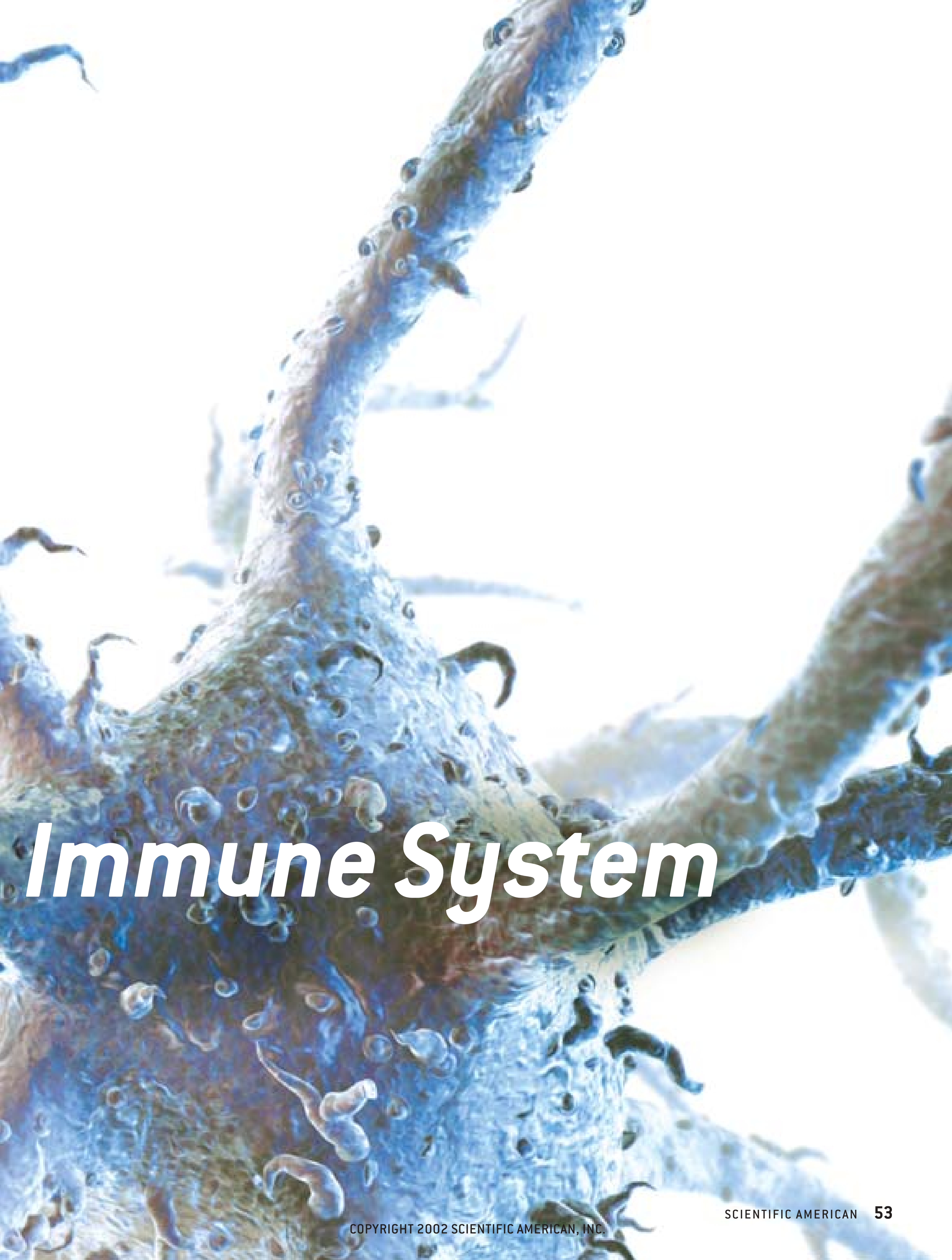
MARK A. GARLICK



The LONG ARM of the

Dendritic cells catch invaders and tell the immune system when and how to respond. Vaccines depend on them, and scientists are even employing the cells to stir up immunity against cancer

By Jacques Banchereau



Immune System

They lie buried—their long, tentaclelike arms outstretched—in all the tissues of our bodies that interact with the environment.

In the lining of our nose and lungs, lest we inhale the influenza virus in a crowded subway car. In our gastrointestinal tract, to alert our immune system if we swallow a dose of salmonella bacteria. And most important, in our skin, where they lie in wait as stealthy sentinels should microbes breach the leathery fortress of our epidermis.

They are dendritic cells, a class of white blood cells that encompasses some of the least understood but most fascinating actors in the immune system. Over the past several years, researchers have begun to unravel the mysteries of how dendritic cells educate the immune system about what belongs in the body and what is foreign and potentially dangerous. Intriguingly, they have found that dendritic cells initiate and control the overall immune response. For instance, the cells are crucial for establishing immunological "memory," which is the basis of all vaccines. Indeed, physicians, including those at a number of biotechnology companies, are taking advantage of the role that dendritic cells play in immunization by "vaccinating" cancer patients with dendritic cells loaded with bits of their own tumors to activate their immune system against their cancer. Dendritic cells are also responsible for the phenomenon of immune tolerance, the process through which the immune system learns not to attack other components of the body.

But dendritic cells can have a dark side. The human immunodeficiency virus (HIV) hitches a ride inside dendritic cells to travel to lymph nodes, where it infects and wipes out helper T cells, causing AIDS. And those cells that become active at the wrong time might give rise to autoimmune disorders such as lupus. In these cases, shutting down the activity of dendritic cells could lead to new therapies.

Overview/*Dendritic Cells*

- Dendritic cells—named for their long arms, or dendrites—exist in many tissues, particularly the skin and mucous membranes. They reel in invaders, chop them into pieces called antigens and display the antigens on their surfaces.
- Antigen-bearing dendritic cells travel to lymph nodes or the spleen, where they interact with other cells of the immune system—including B cells, which make antibodies, and killer T cells, which attack microbes and infected cells.
- Cancer vaccines composed of dendritic cells bearing tumor antigens are now in clinical trials involving humans. Scientists are also hoping to turn off the activity of dendritic cells to combat autoimmune diseases such as lupus.

Rare and Precious

DENDRITIC CELLS are relatively scarce: they constitute only 0.2 percent of white blood cells in the blood and are present in even smaller proportions in tissues such as the skin. In part because of their rarity, their true function eluded scientists for nearly a century after they were first identified in 1868 by German anatomist Paul Langerhans, who mistook them for nerve endings in the skin.

In 1973 Ralph M. Steinman of the Rockefeller University rediscovered the cells in mouse spleens and recognized that they are part of the immune system. The cells were unusually potent in stimulating immunity in experimental animals. He renamed the cells "dendritic" because of their spiky arms, or dendrites, although the subset of dendritic cells that occur in the epidermis layer of the skin are still commonly called Langerhans cells.

For almost 20 years after the cells' rediscovery, researchers had to go through a painstakingly slow process to isolate them from fresh tissue for study. But in 1992, when I was at the Schering-Plough Laboratory for Immunology Research in Dardilly, France, my co-workers and I devised methods for growing large amounts of human dendritic cells from bone marrow stem cells in culture dishes in the laboratory. At roughly the same time, Steinman—in collaboration with Kayo Inaba of Kyoto University in Japan and her colleagues—reported that he had invented a technique for culturing dendritic cells from mice.

In 1994 researchers led by Antonio Lanzavecchia, now at the Institute for Research in Biomedicine in Bellinzona, Switzerland, and Gerold Schuler, now at the University of Erlangen-Nuremberg in Germany, found a way to grow the cells from white blood cells called monocytes.

JEFF JOHNSON (*preceding pages*)

Scientists now know that monocytes can be prompted to become either dendritic cells, which turn the immune system on and off, or macrophages, cells that crawl through the body scavenging dead cells and microbes.

The ability to culture dendritic cells offered scientists the opportunity to investigate them in depth for the first time. Some of the initial discoveries expanded the tenuous understanding of how dendritic cells function.

There are several subsets of dendritic cells, which arise from precursors that circulate in the blood and then take up residence in immature form in the skin, mucous membranes, and organs such as the lungs and spleen. Immature dendritic cells are endowed with a wealth of mechanisms for capturing invading microbes: they reel in invaders using suction cup–like receptors on their surfaces, they take microscopic sips of the fluid surrounding them, and they suck in viruses or bacteria by engulfing them in sacks known as vacuoles. Yong-Jun Liu, a former colleague of mine from Schering-Plough who is now at DNAX Research Institute in Palo Alto, Calif., has found that some immature dendritic cells can also zap viruses immediately by secreting a substance called interferon-alpha.

Once they devour foreign objects, the immature cells chop them into fragments (antigens) that can be recognized by the rest of the immune system [*see illustration on next two pages*]. The cells use pitchfork-shaped molecules termed the major histocompatibility complex (MHC) to display the antigens on their surfaces. The antigens fit between the tines of the MHC, which comes in two types, class I and class II. The two types vary in shape and in how they acquire their antigen cargo while inside cells.

Dendritic cells are very efficient at capturing and presenting antigens: they can pick up antigens that occur in only minute concentrations. As they process antigens for presentation, they travel to the spleen through the blood or to lymph nodes through a clear fluid known as lymph. Once at their destinations, the cells complete their maturation and present their antigen-laden MHC molecules to naive helper T cells, those that have never encountered antigens before. Dendritic cells are the only cells that can educate naive helper T cells to recognize an antigen as foreign or dangerous. This unique ability appears to derive from co-stimulatory molecules on their surfaces that can bind to corresponding receptors on the T cells.

Once educated, the helper T cells go on to prompt so-called B cells to produce antibodies that bind to and inactivate the antigen. The dendritic cells and helper cells also activate killer T cells, which can destroy cells infected by microbes. Some of the cells that have been educated by dendritic cells become "memory" cells that remain in the body for years—perhaps decades—to combat the invader in case it ever returns.

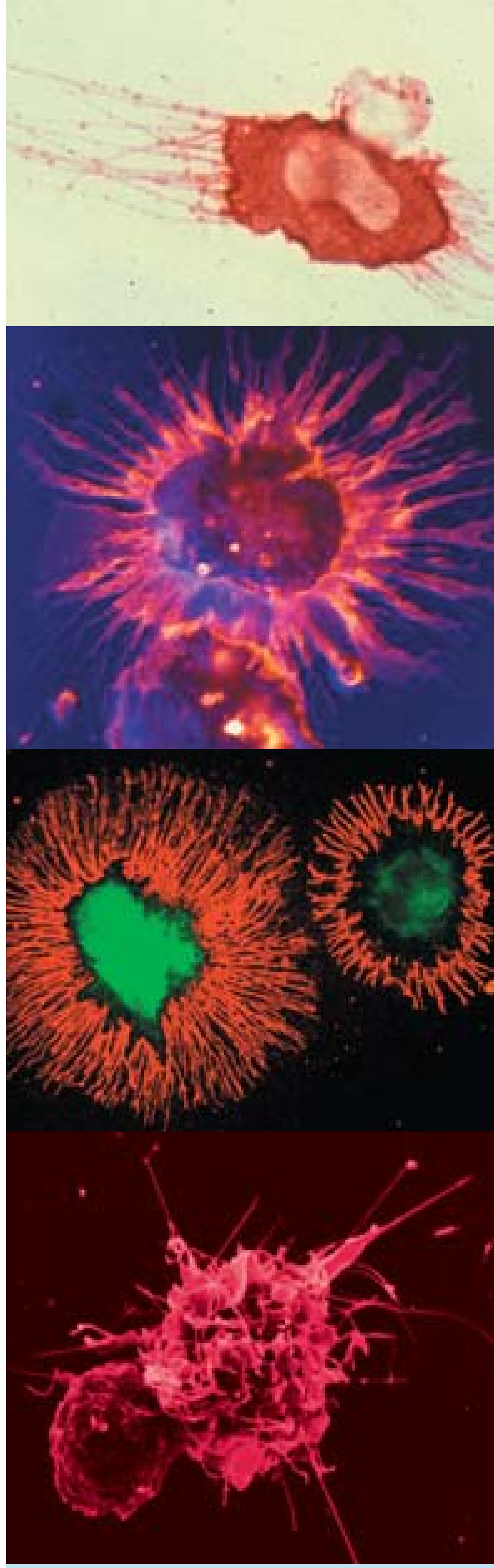
Whether the body responds with antibodies or killer cells seems to be determined in part by which subset of dendritic cell conveys the message and which of two types of immune-stimulating substances, called cytokines, they prompt the helper T cells to make. In the case of parasites or some bacterial invaders, type 2 cytokines are best because they arm the immune system with antibodies; type 1 cytokines are better at mustering killer cells to attack cells infected by other kinds of bacteria or by viruses.

If a dendritic cell prompts the wrong type of cytokine, the body can mount the wrong offense. Generating the appropriate kind of immune response can be a matter of life or death: when exposed to the bacterium that causes leprosy, people who mount a type 1 response develop a mild, tuberculoid form of the disease, whereas those who have a type 2 response can end up with the potentially fatal lepromatous form.

Cancer Killers

ACTIVATING NAIVE helper T cells is the basis of vaccines for everything from pneumonia to tetanus to influenza. Scientists are now turning the new knowledge of the role that dendritic cells play in immunity against microbes and their toxins into a strategy to fight cancer.

Cancer cells are abnormal and as such are thought to generate molecules that

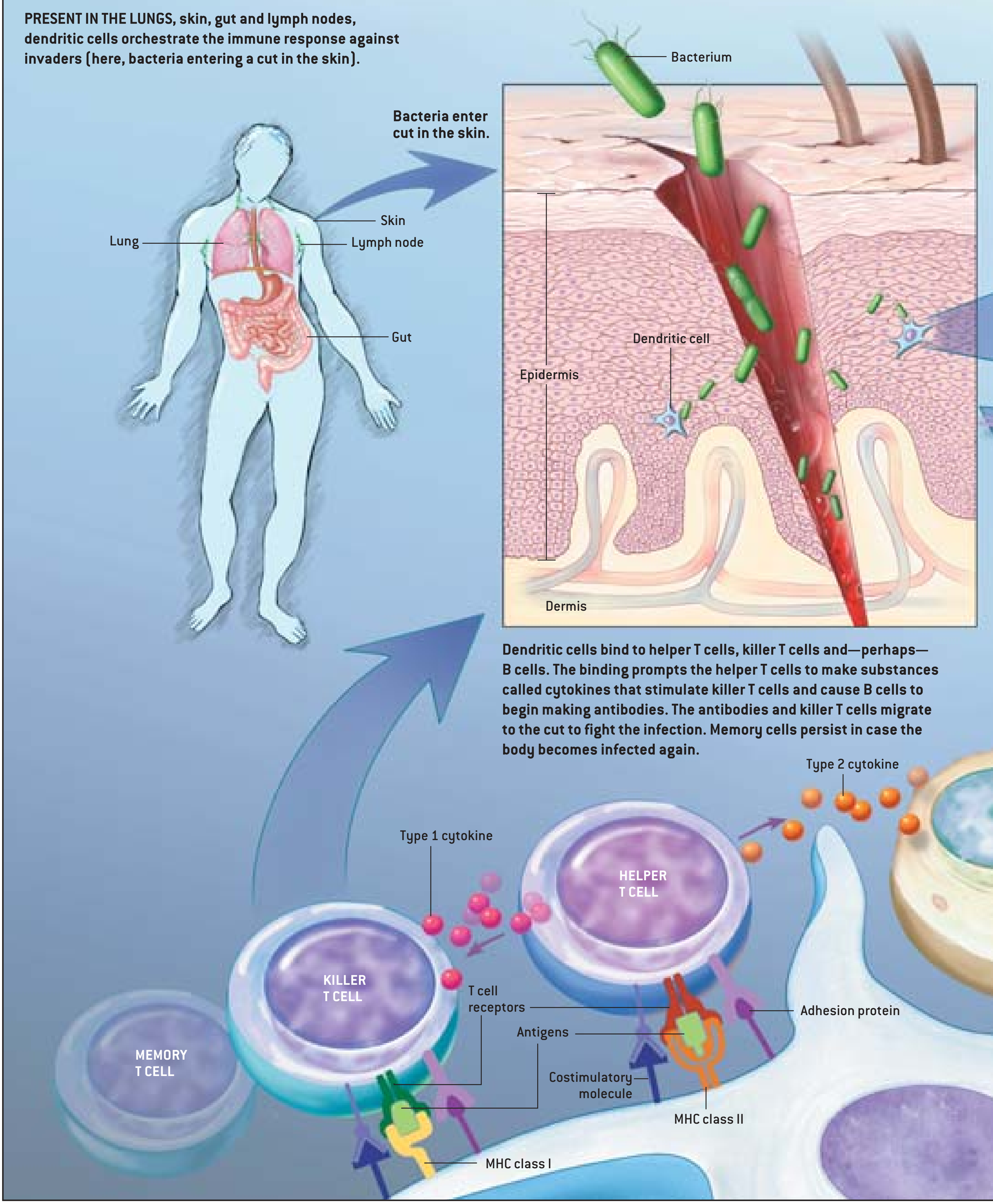


SPIKY ARMS are common to mature dendritic cells from humans (*top* and *top middle*), mice (*bottom middle*) and rats (*bottom*). The rat dendritic cell is interacting with what is probably a helper T cell. Through such interactions, dendritic cells teach the immune system what it should attack. Cells matured in the laboratory, such as the one at the top middle, are being used in cancer vaccines.

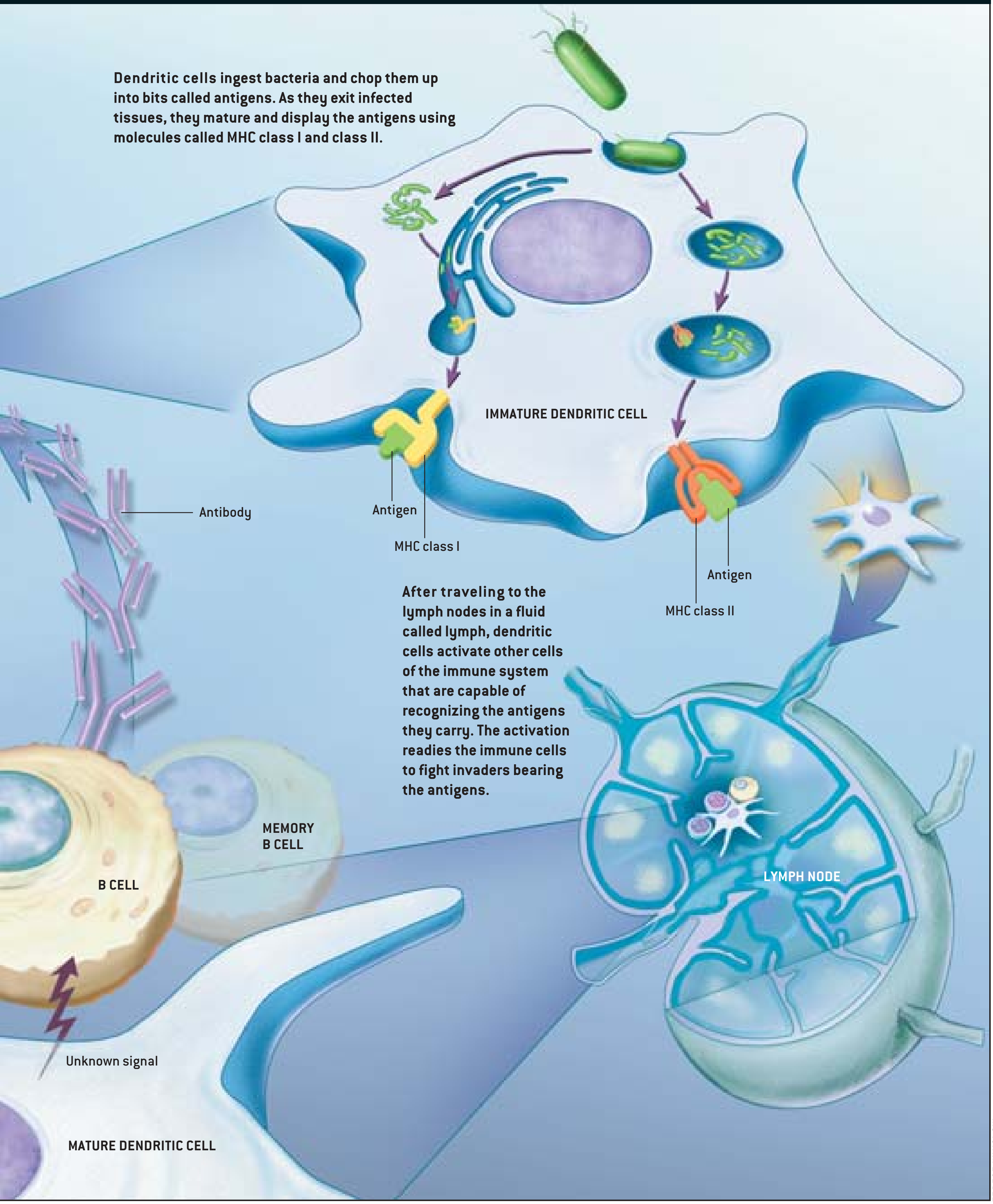
JACQUES BANCHEREAU (*top and top middle*); OLIVIA GRESSER *Marseilles-Luminy Center of Immunology INSERM/CNRS* (*bottom middle*); WILLIAM E. BOWERS, STEVE HALEY AND RICHARD HUNT *University of South Carolina* (*bottom*)

DENDRITIC CELLS AND INFECTION

PRESENT IN THE LUNGS, skin, gut and lymph nodes, dendritic cells orchestrate the immune response against invaders (here, bacteria entering a cut in the skin).



Dendritic cells bind to helper T cells, killer T cells and—perhaps—B cells. The binding prompts the helper T cells to make substances called cytokines that stimulate killer T cells and cause B cells to begin making antibodies. The antibodies and killer T cells migrate to the cut to fight the infection. Memory cells persist in case the body becomes infected again.



Dendritic cells ingest bacteria and chop them up into bits called antigens. As they exit infected tissues, they mature and display the antigens using molecules called MHC class I and class II.

After traveling to the lymph nodes in a fluid called lymph, dendritic cells activate other cells of the immune system that are capable of recognizing the antigens they carry. The activation readies the immune cells to fight invaders bearing the antigens.

TERESE WINSLOW

Dendritic Cell Cancer Vaccines under Development

COMPANY NAME	HEADQUARTERS	STOCK SYMBOL	CANCER TYPE	STATUS*
ML Laboratories	Warrington, England	LSE: MLB	Melanoma	Entering phase I tests
Dendreon	Seattle	Nasdaq: DNDN	Prostate, breast, ovary, colon, multiple myeloma	Phase III (prostate), phase II (prostate, multiple myeloma), phase I (breast, ovary, colon)
Genzyme	Framingham, Mass.	Nasdaq: GZMO	Kidney, melanoma	Phase I (kidney), phase I/II (melanoma)
Immuno-Designed Molecules	Paris	Privately held	Prostate, melanoma	Phase II tests
Merix Bioscience	Durham, N.C.	Privately held	Melanoma	Entering phase I
Oxford BioMedica	Oxford, England	LSE: OXB	Colorectal	Phase I/II
Zycos	Lexington, Mass.	Privately held	DNA-based vaccine against various cancers	Phases I and II

***Phase I tests evaluate safety in a small number of patients; phases II and III assess ability to stimulate the immune system and effectiveness in larger numbers of patients.**

healthy cells don't. If researchers could devise drugs or vaccines that exclusively targeted those aberrant molecules, they could combat cancer more effectively while leaving normal cells and tissues alone—thereby eliminating some of the pernicious side effects of chemotherapy and radiation, such as hair loss, nausea and weakening of the immune system caused by destruction of the bone marrow.

Antigens that occur only on cancerous cells have been hard to find, but researchers have succeeded in isolating several of them, most notably from the skin cancer melanoma. In the early 1990s Thierry Boon of the Ludwig Cancer Institute in Brussels, Steven A. Rosenberg of the National Cancer Institute and their colleagues independently identified melanoma-specific antigens that are currently being targeted in a variety of clinical trials involving humans.

Such trials generally employ vaccines made of dendritic cell precursors that have been isolated from cancer patients and grown in the laboratory together with tumor antigens. During this process, the dendritic cells pick up the antigens, chop them up and present them on their surfaces. When injected back into the patients, the antigen-loaded dendritic cells are expected to ramp up patients' immune response against their own tumors.

Various researchers—including Frank O. Nestle of the University of Zurich and Ronald Levy and Edgar G. Engleman of Stanford University, as well as scientists at several biotechnology companies [*see box above*]—are testing this approach against cancers as diverse as melanoma, B cell lymphoma, and tumors of the prostate and colon. There have been glimmers of success. In September 2001, for instance, my co-workers and I, in collaboration with Steinman's group, reported that 16 of 18 patients with advanced melanoma to whom we gave injections of dendritic cells loaded with melanoma antigens showed signs in laboratory tests of an enhanced immune response to their cancer. What is more, tumor growth was slowed in the nine patients who mounted responses against more than two of the antigens.

Scientists are now working to refine the approach and test it on larger numbers of patients. So far cancer vaccines based on dendritic cells have been tested only in patients with advanced cancer. Although researchers believe that patients with earlier-stage cancers may respond better to the therapy—their immune systems have not yet tried and failed to eradicate their tumor—several potential problems must first be considered.

Some researchers fear that such vaccines might induce patients' immune systems to attack healthy tissue by mistake. For instance, vitiligo—white patches on the skin caused by the destruction of normal pigment-producing melanocytes—has been observed in melanoma patients who have received the earliest antimelanoma vaccines. Conversely, the tumors might mutate to "escape" the immune onslaught engendered by a dendritic cell vaccine. Tumor cells could accomplish this evasion by no longer making the antigens the vaccine was designed to stimulate the immune system against. This problem is not unique to dendritic cells, though: the same phenomenon can occur with traditional cancer therapies.

In addition, tailoring a dendritic cell vaccine to fight a particular patient's tumors might not be economically feasible.

THE AUTHOR

JACQUES BANCHEREAU has directed the Baylor Institute for Immunology Research in Dallas since 1996. The institute aims to manipulate the human immune system to treat cancer as well as infectious and autoimmune diseases. Before 1996 Banchereau led the Schering-Plough Laboratory for Immunology Research in Dardilly, France. He obtained his Ph.D. in biochemistry from the University of Paris. Banchereau holds many patents on immunological techniques and is a member of the scientific advisory board of Merix Bioscience, a biotechnology company based in Durham, N.C.

But many scientists are working to circumvent the costly and time-consuming steps of isolating cells from patients and manipulating them in the laboratory for reinjection.

One approach involves prompting dendritic cell precursors already present in a person's body to divide and start orchestrating an immune response against their tumors. David H. Lynch of Immunex in Seattle (recently acquired by Amgen in Thousand Oaks, Calif.) and his coworkers have discovered a cytokine that causes mice to make more dendritic cells, which eventually induce the animals to reject grafted tumors. Other scientists, including Drew M. Pardoll of Johns Hopkins University, have observed that tumor cells that have been genetically engineered to secrete large amounts of cytokines that activate dendritic cells have the most potential as cancer vaccines.

Shutting Immunity Down

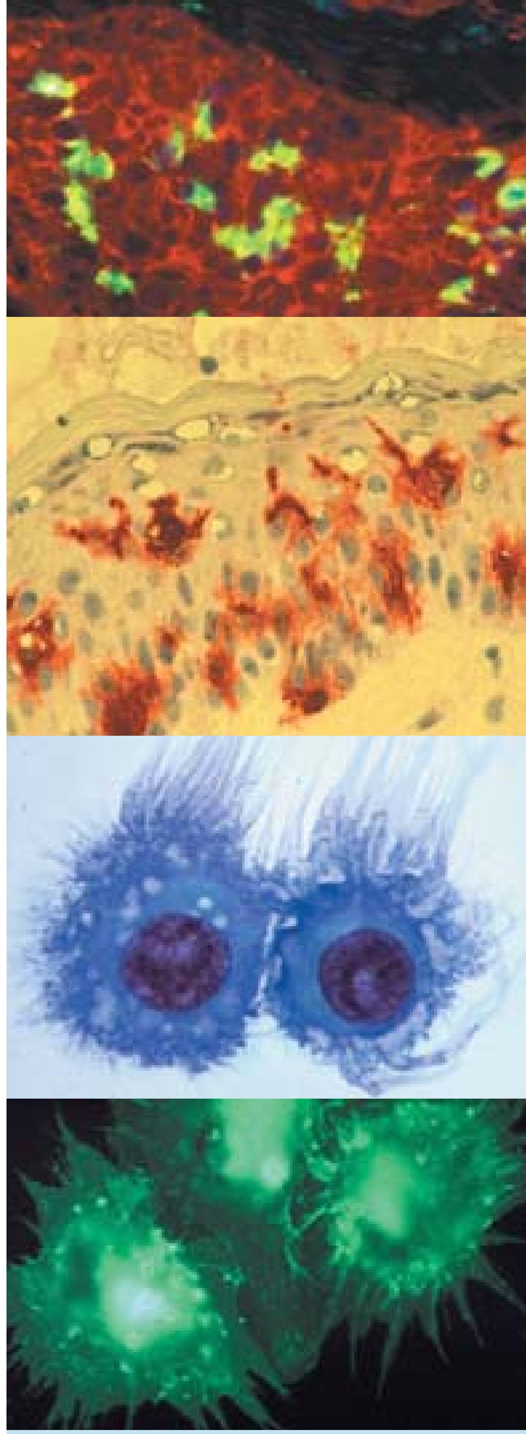
IN THE MEANTIME, other scientists are looking at ways to turn off the activity of dendritic cells in instances where they exacerbate disease instead of fighting it. Usually, in a phenomenon known as central tolerance, an organ in the chest called the thymus gets rid of young T cells that happen to recognize the body's own components as foreign before they have a chance to circulate. Some inevitably slip through, however, so the body has a backup mechanism for restraining their activity.

But this mechanism, termed peripheral tolerance, appears to be broken in patients with autoimmune disorders such as rheumatoid arthritis, type 1 diabetes and systemic lupus erythematosus. Last year my colleagues and I reported that dendritic cells from the blood of people with lupus are unnaturally active. Cells from these patients release high amounts of interferon-alpha, an immune-stimulating protein that causes precursors to grow into mature dendritic cells while still in the bloodstream. The mature cells then ingest DNA, which is present in unusual amounts in the blood of people with lupus, and that in turn causes the individual's immune system to generate antibodies against his or her own DNA. These antibodies result in the life-threatening complications of lupus when they lodge in the kidneys or the walls of blood vessels. Accordingly, we propose that blocking interferon-alpha might lead to a therapy for lupus by preventing dendritic cell activation. A similar strategy might prevent organ transplant recipients from rejecting their new tissues.

A new treatment for AIDS might also rest on a better understanding of dendritic cells. In 2000 Carl G. Figdor and Yvette van Kooyk of the University Medical Center St. Radboud in Nijmegen, the Netherlands, identified a subset of dendritic cells that makes DC-SIGN, a molecule that can bind to the outer coat of HIV. These cells pick up HIV as they regularly prowl the mucous membranes and deep tissues. When they travel to the lymph nodes, they unwittingly deliver the virus to a large concentration of T cells. Drugs that block the interaction between DC-SIGN and HIV might slow the progression of AIDS.

Other infectious diseases—including malaria, measles and cytomegalovirus—also manipulate dendritic cells for their own ends. Red blood cells that have been infected by malaria parasites, for instance, bind to dendritic cells and prevent them from maturing and alerting the immune system to the presence of the invaders. Several groups of researchers are now devising approaches to prevent such microbes from hijacking dendritic cells; some are even seeking to use supercharged dendritic cells to fight the infections.

As we learn more about the molecules that control dendritic cells, we will find ways to harness their therapeutic potential. The increasing number of scientists and corporations working on dendritic cells portends that we will soon be able to maximize the biological power of these cells to treat and prevent the diseases that plague humankind. SA



IMMATURE DENDRITIC CELLS can be stained to show up green in breast cancer tissue (*top*) or red in normal skin (*top middle*). As the cells mature, they make proteins that allow them to stick to one another (*bottom middle*). They also produce forklike receptors (*green dots, bottom*), which they use to show bits of invaders to other immune cells.

JACQUES BANCHEREAU (*top; top middle* and *bottom middle*); MATTHEW L. ALBERT *Rockefeller University* (*bottom*)

MORE TO EXPLORE

Dendritic Cells and the Control of Immunity. Jacques Banchereau and Ralph M. Steinman in *Nature,* Vol. 392, pages 245–252; March 19, 1998.

Dendritic Cells as Vectors for Therapy. Jacques Banchereau, Beatrice Schuler-Thurner, A. Karolina Palucka and Gerold Schuler in *Cell,* Vol. 106, No. 3, pages 271–274; August 10, 2001.

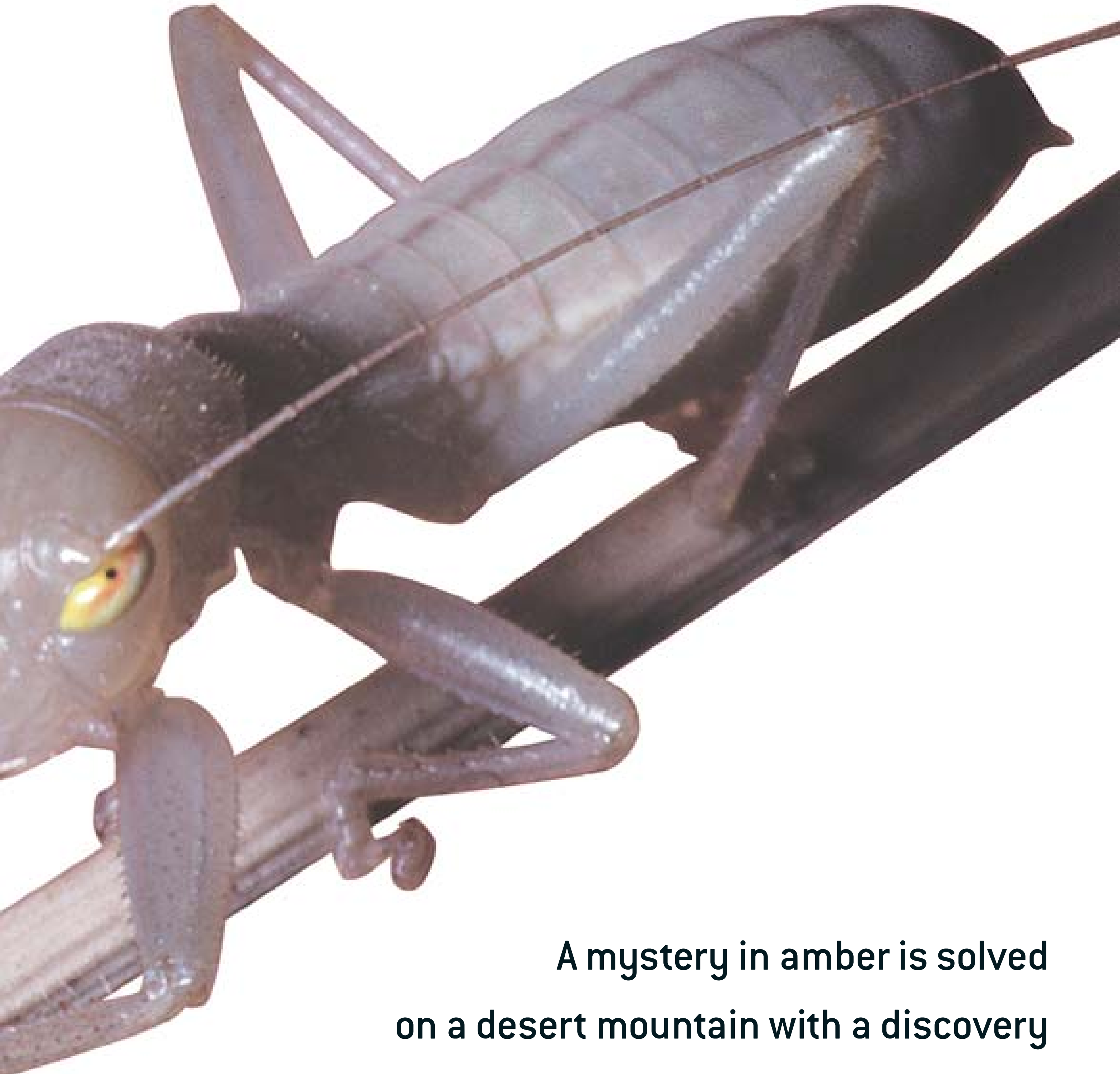
Background information on the immune system and on experimental cancer therapies such as those using dendritic cells can be found on the American Cancer Society's Web site: **www.cancer.org**

By Joachim Adis, Oliver Zompro,
Esther Moombolah-Goagoses and Eugène Marais

Gladiators:

A NEW ORDER OF INSECT

Imagine being the very first person ever to see a butterfly, a beetle or a wasp. Imagine the sense of wonder at a world so wide that it contains not just undiscovered species, genera or families but entire orders of life yet to be named. Carl Linnaeus must have had such a feeling 250 years ago as he was sorting recently discovered plants and animals into the taxonomy he had invented. So probably did E. M. Walker, who in 1914 was the first to describe rock crawlers (Grylloblattodea), bringing the number of orders in the insect class to 30.



A mystery in amber is solved on a desert mountain with a discovery that has stunned entomologists

MYSTERIOUS AMBER FOSSIL preserved this adult male insect for millions of years. The fossil was a critical clue in the discovery of the new Mantophasmatodea order. The insects have evolved; gladiators today have thinner front legs and have heads that are less triangular and more rounded.

Most entomologists thought that was the final total: although there may be millions of insect species still to identify (about 1.2 million have been named so far), for nearly a century we have assumed that every newfound species will fall into just those 30 basic categories. To biologists, the natural world no longer seemed as wide and as wild as it once did. But in June 2001 one of us (Zompro) received bits of amber that would change the way we look at the insect world, giving us a taste of the old joy of discovery—and renewing our awe at the variety of life.

Frozen in Time

THE CHUNKS OF AMBER, from a collection at the University of Hamburg in Germany, were dug up in the Baltic. As the tree sap solidified some 45 million years ago, it had captured several insect larvae that looked utterly different from any Zompro had seen before.

A month later Zompro, who was then working on his doctoral studies at the Max Planck Institute for Limnology in Plön, was visiting the Natural History Museum in London when curator Judith A. Marshall showed him a desiccated bug found in Tanzania in 1950. It was clearly the carcass of an adult male, but no one had been able to identify what manner of insect it once was. Zompro snapped a few pictures and returned to Germany.

A few days later another piece of amber arrived in the mail. This one, from a private collection, entombed a fossilized adult male of some kind. As Zompro examined it under the microscope, he was struck by how much it resembled the exoskeleton he had just seen in London.

Now Zompro knew he was onto something. He showed the new amber fossil to his thesis adviser (Adis), who suggested that he sift through the collections of several European museums for other unidentified bugs of this sort. Hunting in one museum after another, Zompro turned up no matching specimens. But at the Berlin Natural History Museum, he at last struck gold: a little alcohol-filled bottle containing the embalmed body of an adult female insect that looked conspicuously like the mysterious bug in amber.

As Zompro and Adis painstakingly studied these two additional specimens, one prehistoric and the other picked off the ground in Namibia almost a century ago, their excitement grew. At first glance the animals, with their strong hind legs, resembled grasshoppers. But they lacked wings, which most grasshoppers have. Their front legs were studded with thorns, like those that praying mantids use to capture and hold their prey as they eat them alive. But the heads and hind legs of these baffling insects were clearly different from those of a mantis. From above they looked almost like plant-eating walkingsticks. Yet their second body segment was too short for a walkingstick, and their guts contained body parts from other insects, proof of carnivory.

These were no trivial differences, and our collaborators Klaus-Dieter Klass and Niels P. Kristensen found other novel structures inside the insects' bodies. With so many fundamental distinctions in body shape and diet, it took only a few hours to conclude with certainty that these organisms fit in no existing insect order. We would have to create a category for them, one on a par with the flies, the beetles and the termites.

We settled on the scientific name Mantophasmatodea because the animals look like a bizarre cross between a mantis (order Mantodea) and a walkingstick (order Phasmatodea). But among ourselves we took to calling the beasts "gladiators," inspired by their fearsome appearance and the armor that covers them as nymphs.

THE AUTHORS

JOACHIM ADIS, OLIVER ZOMPRO, ESTHER MOOMBOLAH-GOAGOSES and *EUGÈNE MARAIS* collaborated on the discovery of the Mantophasmatodea order. Adis is senior scientist in the tropical ecology working group at the Max Planck Institute for Limnology in Plön, Germany. He is also lecturing professor at the University of Kiel in Germany and at several universities in Brazil. He is affiliated with the Smithsonian Institution as a research entomologist. Since 1975 his work has focused on the ecology and survival strategies of millipedes, spiders and insects in Amazonian wetlands. Zompro is a doctoral student of Adis's at the Max Planck Institute. Since 1980 he has reared more than 130 species of walkingstick and walkingleaf insects. He has specialized in the evolution and ecology of the Phasmatodea order of insects. Moombolah-Goagoses is chief curator of the National Museum of Namibia in Windhoek. Marais is curator of the Namibian National Insect Collection in Windhoek.

THOMAS KUJAWSKI ASA-*Multimedia* (*preceding page* and *above*)

AN ORDER IS BORN

GLADIATORS

ANATOMY OF GLADIATORS shares many characteristics with that of grasshoppers, walkingsticks and mantises. But gladiators are different in critical ways from those and all other insect orders. A new order, Mantophasmatodea, was therefore announced in April. So far it contains at least three living and two extinct species.

INSECT ORDERS

Common Name	***Scientific Name***
Flies	*Diptera*
Twisted-wing parasites	*Strepsiptera*
Scorpionflies	*Mecoptera*
Fleas	*Siphonaptera*
Moths, butterflies	*Lepidoptera*
Caddisflies	*Trichoptera*
Ants, wasps, bees	*Hymenoptera*
Beetles	*Coleoptera*
Lacewings, antlions	*Neuroptera*
Dobsonflies	*Megaloptera*
Snakeflies	*Raphidioptera*
Book lice	*Psocoptera*
Lice	*Phthiraptera*
Bugs	*Heteroptera*
Thrips	*Thysanoptera*
Stoneflies	*Plecoptera*
Webspinners	*Embioptera*
Angel wings	*Zoraptera*
Cockroaches	*Blattodea*
Mantids	*Mantodea*
Gladiators	***Mantophasmatodea***
Termites	*Isoptera*
Earwigs	*Dermaptera*
Rock crawlers	*Grylloblattodea*
Walkingsticks	*Phasmatodea*
Grasshoppers, crickets	*Orthoptera*
Dragonflies	*Odonata*
Mayflies	*Ephemeroptera*
Silverfish	*Zygentoma*
Jumping bristletails	*Archaeognatha*
Aphids, cicadas	*Homoptera*

SIDE VIEW

DEATH GRIPPERS
Spikes on front legs, like those on a mantis, hold prey while it is eaten alive

JUMPING LEGS
They are not as developed as those of a grasshopper

ANIMAL EATERS
Powerful mandibles are evidence of a carnivorous lifestyle. Most grasshoppers and walkingsticks are vegans

TOP VIEW

FLIGHTLESS
Gladiators have no wings; many mantises and most grasshoppers have four

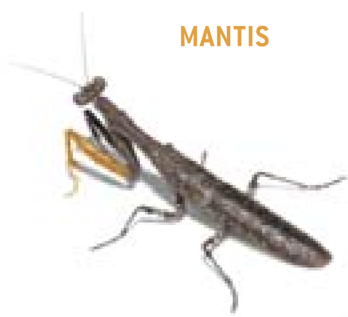
LONG, STRAIGHT BODY
Like a walkingstick

UNEXAGGERATED THORAX
In stick insects the second thorax segment is longer—usually much longer—than the first, and the third segment is merged with the abdomen

HOOKED FEET
Apparently unique to gladiators

WALKINGSTICK

MANTIS



GRASSHOPPER

THOMAS KUJAWSKI *ASA-Multimedia* (*top two photographs*); JOHN MOORE (*bottom row*)

GLADIATORS DON ARMOR in their youth. Nymphs take on the color of the desert rocks that shelter them from predators and the sun.

Although we suspect that the gladiators share a common ancestor with the mantids and stick insects, it will take more work to establish their exact position within the evolutionary tree of insect life. DNA analyses to do just that got under way this past April.

Bug Hunt in the Desert

THE FIRST QUESTION we wanted to answer was: Are gladiators still alive, or did the order pass into extinction since the Tanzanian gladiator was collected half a century ago? Adis e-mailed photographs of the insects to colleagues around the world, asking them to look for similar specimens in their own collections.

A mature gladiator and two larvae turned up at the University of Leeds in England. They had been found in the Brandberg Massif of Namibia sometime between 1998 and 2000. And one of us (Marais) located two animals matching the description. Marais had collected one of them himself in Namibia in 1990; the other was picked up by a Namibian student in 2001.

While Marais was in Germany, he drew up plans with Zompro and Adis to mount an expedition in Namibia to search for living gladiators. On the last day of February 2002, 10 scientists from five countries set out into the tropical Namib Desert. The team made its way to the Brandberg, a circular inselberg that, like an enormous granite pimple, towers 1,800 meters over a barren plain in Erongo province. Locals call it Dâures: Burning Mountain. Remote and protected, the Brandberg is the only home of several endemic animals.

The search began in early March on a high, stony plateau surrounded by tall boulders. Zompro and the other entomologists were all out exploring. John Irish, a Namibian taxonomist, was beating grass bushes with sticks to see what insects might fall out. A few hours into the search, Irish bent down and stared carefully at something in his hand.

"I think I've got something for you, Oliver," he said. In his palm lay a small larva, a gladiator in the second stage of its life. That evening another team member found four more larvae. We could hardly contain our excitement. Unbeknownst to science, this chain of life had remained intact for more than 45 million years!

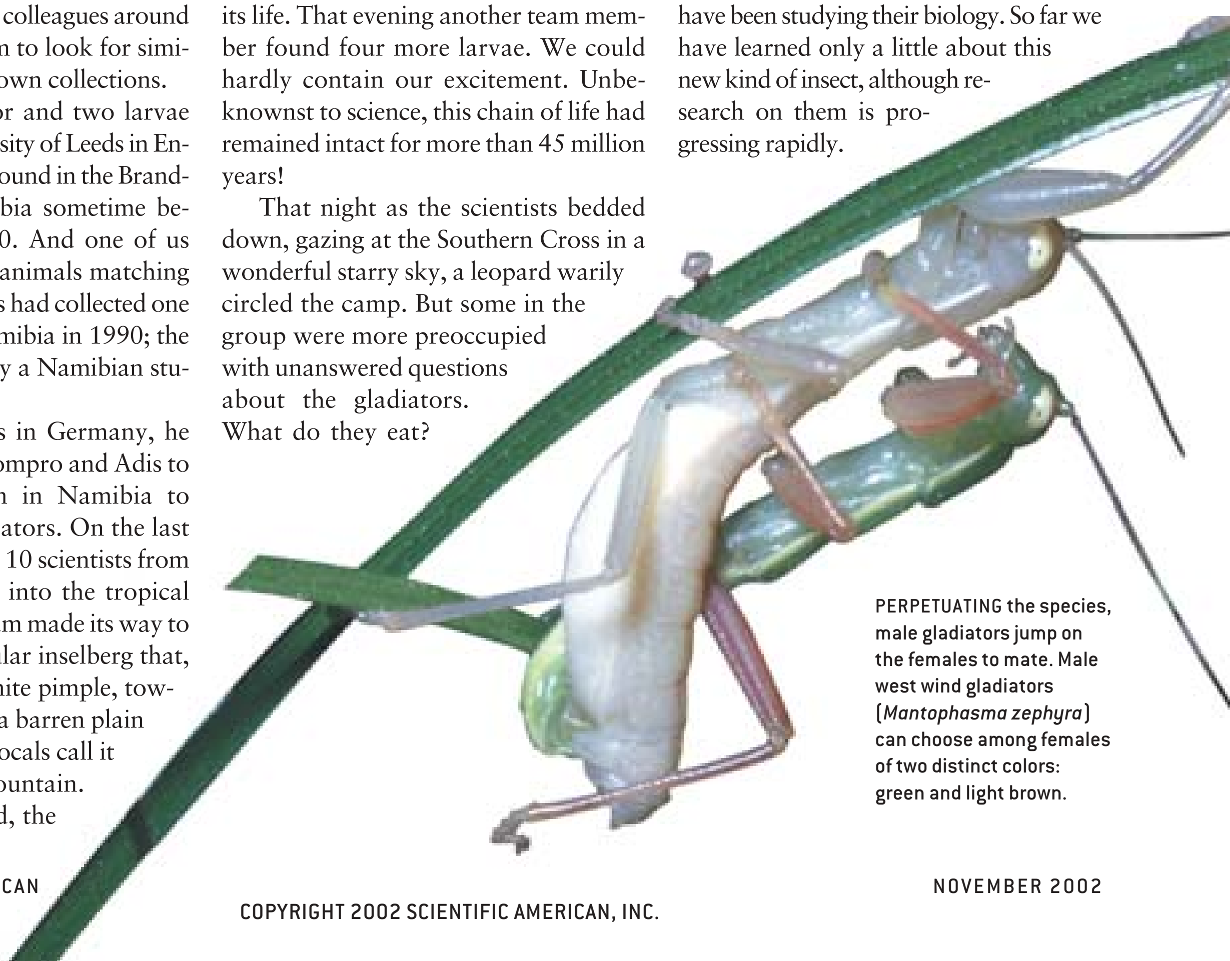
That night as the scientists bedded down, gazing at the Southern Cross in a wonderful starry sky, a leopard warily circled the camp. But some in the group were more preoccupied with unanswered questions about the gladiators. What do they eat? How do they find water? How do they survive flash floods and daily temperature swings of 25 degrees Celsius (40 degrees Fahrenheit)? To answer such questions, we needed to observe how gladiators behave at all stages of their life.

The group wanted to search other parts of the massif—and other nearby mountains—but the weather conspired against a rapid descent. Temperatures over 44 degrees C (110 degrees F) made clambering down the steep slopes arduous. Periodic downpours turned trickling brooks into life-threatening whitewater. But the rains also transformed a landscape of yellow, gray and brown into a verdant expanse of vegetation.

By mid-March, Zompro and his colleagues were into the neighboring mountains. A nocturnal hunt netted yet another species of gladiator; we had now identified four distinct species in the new order. And the next day Zompro was able to make the first observations of how the insects behave in the wild.

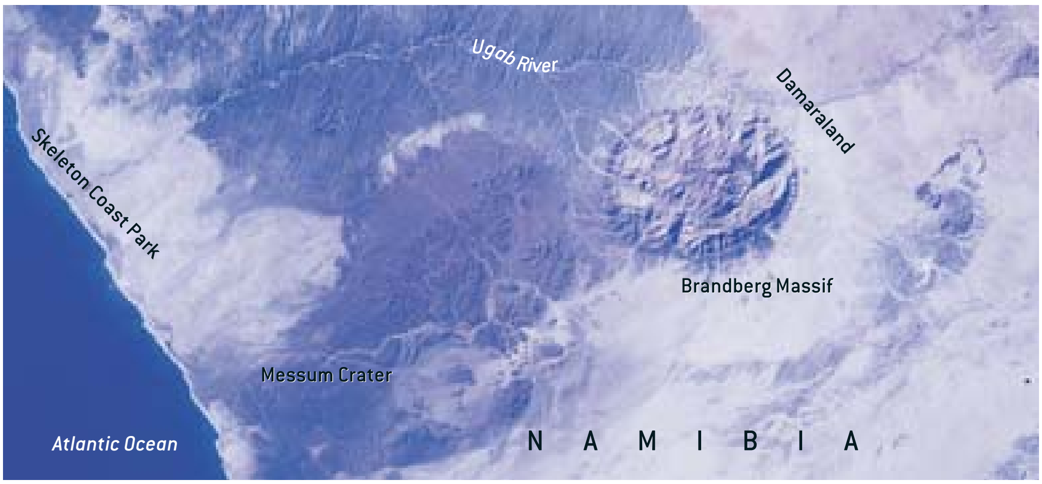
Life as a Gladiator

A DOZEN GLADIATORS were captured alive and taken to Germany, where we have been studying their biology. So far we have learned only a little about this new kind of insect, although research on them is progressing rapidly.



PERPETUATING the species, male gladiators jump on the females to mate. Male west wind gladiators (*Mantophasma zephyra*) can choose among females of two distinct colors: green and light brown.

THOMAS KUJAWSKI *ASA-Multimedia*



EXPEDITION in search of gladiators began in late February. On a tip from Marais, a team of 10 entomologists journeyed by truck and helicopter into the vast, desolate Namib Desert. They began their search on the Brandberg Massif, an isolated mountain (*left*) that is Namibia's tallest. There and in the neighboring mountains of Damaraland, co-author Zompro and the others discovered two living species of gladiators.

THOMAS KUJAWSKI *ASA-Multimedia (photographs)*; LUNAR AND PLANETARY INSTITUTE (*satellite image*)

On the mountainside we saw gladiators hiding in grass tufts and rock crevices during daylight. They were well camouflaged, their body colors blending in with the surrounding plants and rocks. At nightfall they came out to hunt for prey.

Gladiators are carnivorous, and they eat a variety of other insects, some as large as themselves. In the wild we saw them feeding on small moths, silverfish and cockroaches. In captivity they seemed to prefer living flies and crickets. Dead mealworms also suit their tastes.

The animals use their powerful forelegs to wrestle small prey to a standstill. Larger meals they grasp with their middle legs as well (carnivorous grasshoppers use a similar four-handed hunting technique). Big flies are first killed with strong bites to their neck. Then the gladiators devour the flies headfirst. They eat every part of their prey except the wings and legs. We have seen young gladiators, when injured, fall victim to cannibalism.

The larvae grow very fast, molting their skins several times as they mature into adults. They appear to have adapted their entire life cycle to the short rainy season, which in the Brandberg lasts just a few months. It is not yet known how and where female gladiators lay their eggs in the wild.

The unexpected discovery of a new order in the insect kingdom has stunned many entomologists. Some immediately started scanning their collections for more specimens—29 recently turned up in museums in South Africa, and new field studies have found gladiators to be abundant in the Western Cape province.

Other research groups around the world quickly offered to assist in our continuing studies of the gladiators' behavior, life cycle and reproduction. Romano Dallai of the University of Siena in Italy is looking into the shape and structure of the male insect's sperm. Teams led by Michael F. Whiting of Brigham Young University and Roger K. Butlin of the University of Leeds are analyzing the gladiators' DNA. These experiments may by the end of this year give us a clearer picture of where Mantophasmatodea fits within the branches of the insect class, the broadest and bushiest part of the tree of life.

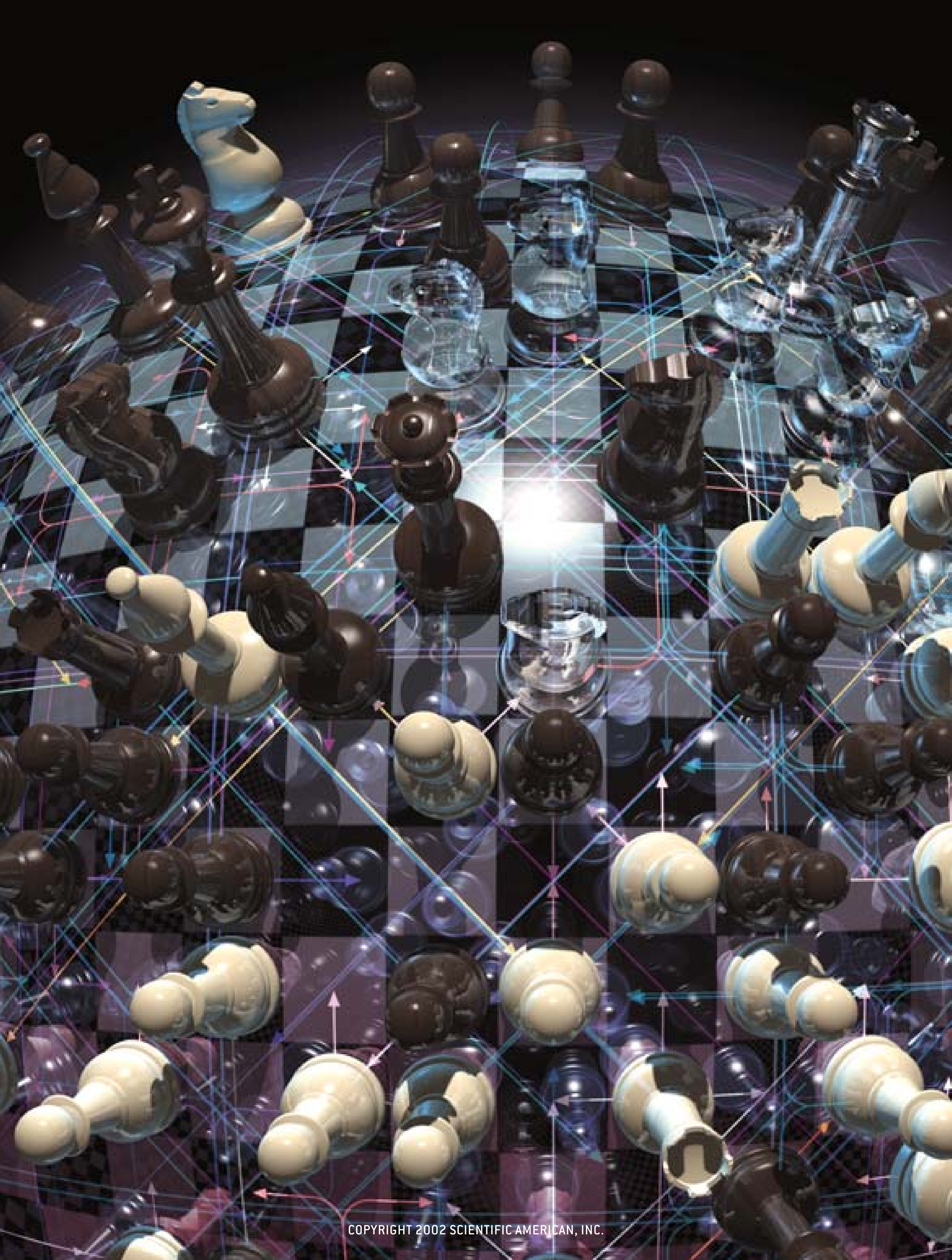
But the fact that the evidence of this new order sat in museums, unnoticed for decades until a chance encounter (and an alert student) put the pieces together, makes us wonder. Are there more orders of insects we have yet to discover? To bug lovers like us, the natural world suddenly seems a bit wider and wilder than we had imagined it to be. SA

MORE TO EXPLORE

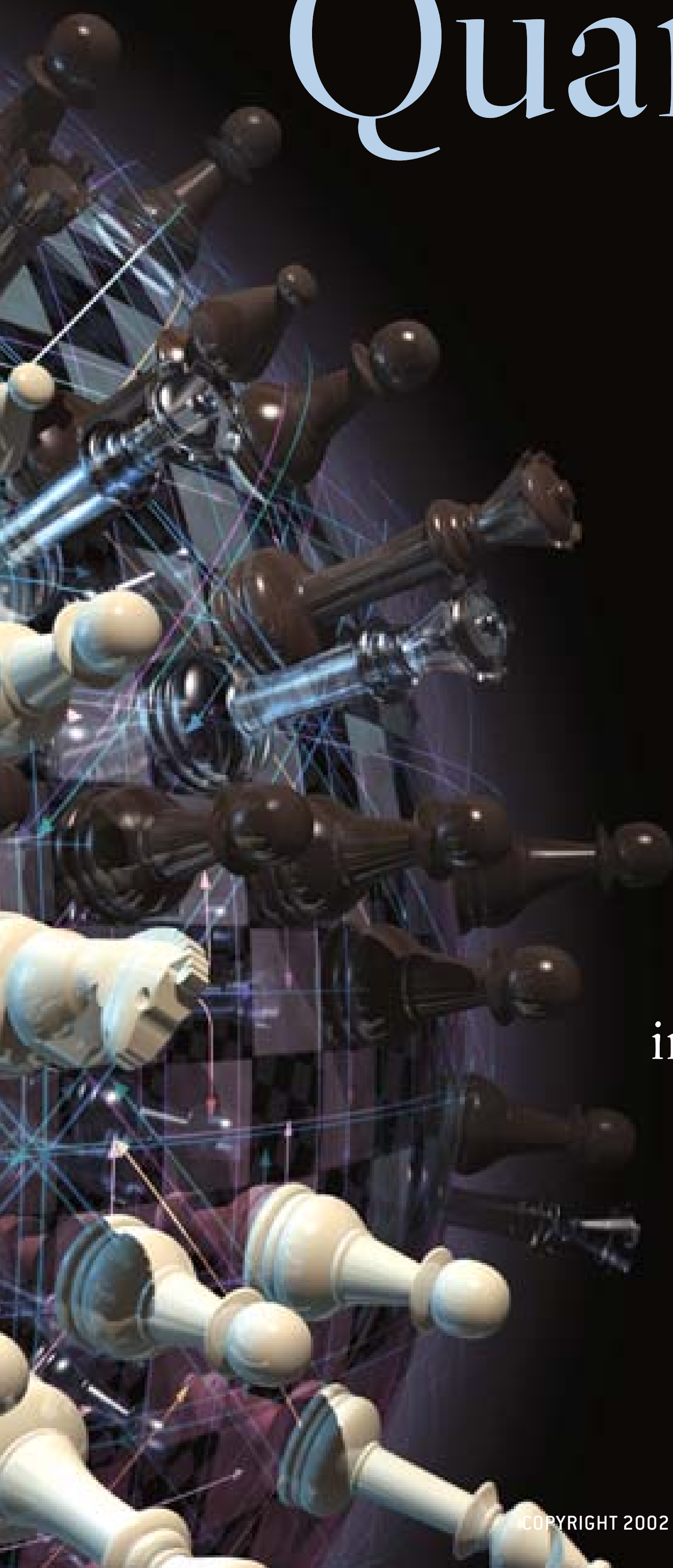
Mantophasmatodea: A New Insect Order with Extant Members in the Afrotropics. Klaus-Dieter Klass, Oliver Zompro, Niels P. Kristensen and Joachim Adis in *Science,* Vol. 296, pages 1456–1459; May 24, 2002.

A Review of the Order Mantophasmatodea (Insecta). O. Zompro, J. Adis and W. Weitschat in *Zoologischer Anzeiger,* Vol. 241 (in press).

Oliver Zompro maintains a Web site on the new order at **www.mantophasmatodea.de**



Rules for a Complex Quantum World



An exciting new fundamental discipline of research combines information science and quantum mechanics

By Michael A. Nielsen

Over the past few decades, scientists have learned that simple rules can give rise to very rich behavior. A good example is chess. Imagine you're an experienced chess player introduced to someone claiming to know the game. You play a few times and realize that although this person knows the rules of chess, he has no idea how to play well. He makes absurd moves, sacrificing his queen for a pawn and losing a rook for no reason at all. He does not truly *understand* chess: he is ignorant of the high-level principles and heuristics familiar to any knowledgeable player. These principles are collective or emergent properties of chess, features not immediately evident from the rules but arising from interactions among the pieces on the chessboard.

Scientists' current understanding of quantum mechanics is like that of a slow-learning student of chess. We've known the rules for more than 70 years, and we have a few clever moves that work in some special situations, but we're only gradually learning the high-level principles needed to play a skillful overall game.

The discovery of these principles is the goal of quantum information science, a fundamental field that is opening up in response to a new way of comprehending the world. Many articles about quantum information science focus on technological applications: research groups "teleport" quantum states from one location to another. Other physicists use quantum states to create cryptographic keys that are absolutely secure from eavesdropping. Information scientists devise algorithms for hypothetical quantum-mechanical computers, much faster than the best known algorithms for conventional, or classical, computers [*see www.sciam.com for past* Scientific American *articles related to these developments*].

These technologies are fascinating, but they obscure the fact that they are a by-product of investigations into deep new scientific questions. Applications such as quantum teleportation play a role similar to the steam engines and other machines that spurred the development of thermodynamics in the 18th and 19th centuries. Thermodynamics was motivated by profound, basic questions about how energy, heat and temperature are related, the transformations among these quantities in physical processes, and the key role of entropy. Similarly, quantum information scientists are fathoming the relation between classical and quantum units of information, the novel ways that quantum information can be processed, and the pivotal importance of a quantum feature called entanglement, which entails peculiar connections between different objects.

Popular accounts often present entanglement as an all-or-nothing property in which quantum particles are either entangled or not. Quantum information science has revealed that entanglement is a quantifiable physical resource, like energy, that enables information-processing tasks: some systems have a little entanglement; others have a lot. The more entanglement available, the better suited a system is to quantum information processing. Furthermore, researchers have begun to develop powerful quantitative laws of entanglement (analogous to the laws of thermodynamics governing energy), which provide a set of high-level principles for understanding the behavior of entanglement and describing how we can use it to do information processing.

Quantum information science is new enough that researchers are still coming to grips with its very nature, and they disagree about which questions lie at its heart. This article presents my personal view that the central goal of quantum information science is to develop general principles, like the laws of entanglement, that will enable us to understand complexity in quantum systems.

Overview/*Quantum Information*

- Information is not purely mathematical. Instead it always has a physical embodiment. In traditional information science the embodiment follows classical, or nonquantum, physics. The burgeoning field of quantum information science puts information in a quantum context.
- The basic resource of classical information is the bit, which is always either a 0 or a 1. Quantum information comes in quantum bits, or qubits (pronounced "cue-bits"). Qubits can exist in superpositions, which simultaneously involve 0 and 1, and groups of qubits can be "entangled," which gives them counterintuitive correlations.
- Quantum computers processing qubits, particularly entangled qubits, can outperform classical computers. Entanglement behaves like a resource, similar to energy, that can be used to do quantum information processing.
- The goal of quantum information science is to understand the general high-level principles that govern complex quantum systems such as quantum computers. These principles relate to the laws of quantum mechanics in the way that heuristics for skillful play at chess relate to the game's basic rules.

Complexity and Quanta

Numerous studies in complexity concentrate on systems such as the weather or piles of sand that are described by classical physics rather than quantum physics. That focus is natural because complex systems are usually macroscop-

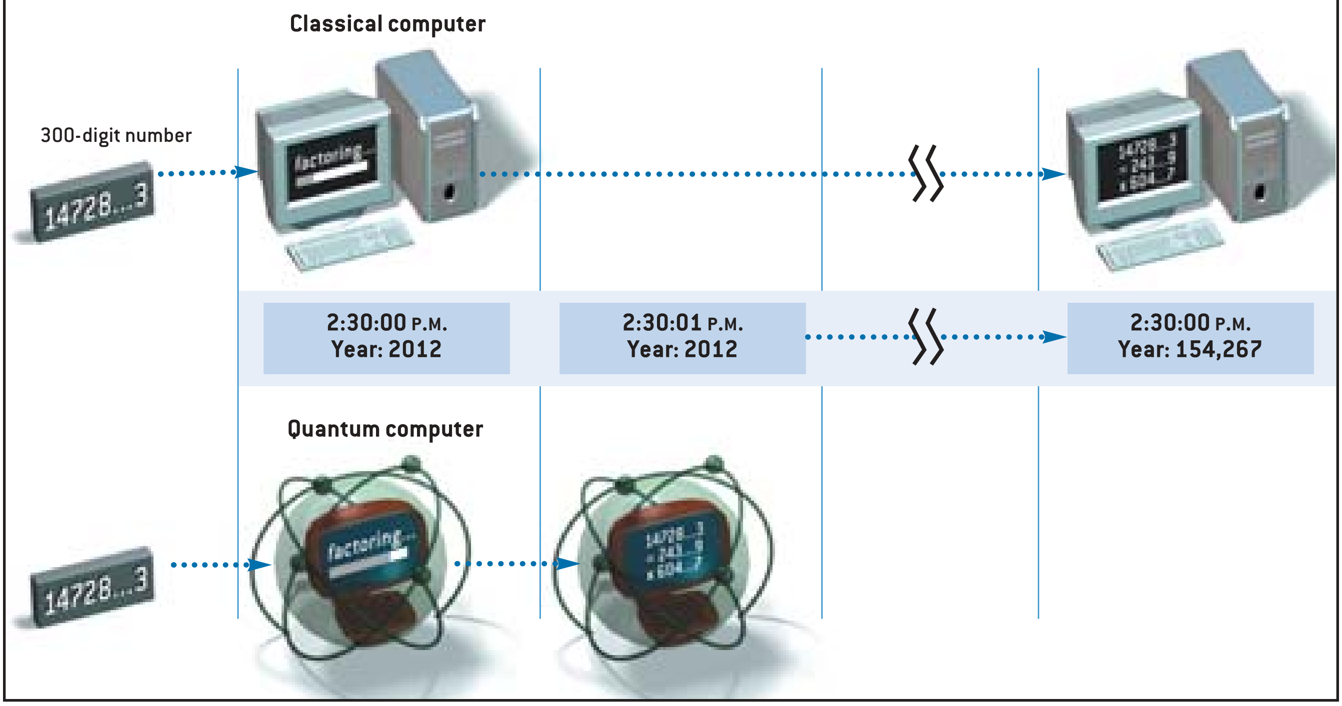
SLIM FILMS (*preceding pages*)

THE FUNDAMENTAL QUESTION

MUCH OF INFORMATION SCIENCE, both classical and quantum, can be summed up by analyzing variants of a basic question:

> *"What quantity of an information resource is needed to perform a specific information-processing task?"*

For example: "How many computational steps are needed to find the prime factors of a 300-digit number?" The best classical algorithm known would take about 5×10^{24} steps, or about 150,000 years at terahertz speed. By taking advantage of innumerable quantum states, a quantum factoring algorithm would take only 5×10^{10} steps, or less than a second at terahertz speed.



ic, containing many constituent parts, and most systems lose their quantum nature as their size is increased. This quantum-to-classical transition occurs because large quantum systems generally interact strongly with their environment, causing a process of decoherence, which destroys the system's quantum properties [see "100 Years of Quantum Mysteries," by Max Tegmark and John A. Wheeler; Scientific American, February 2001].

As an example of decoherence, think of Erwin Schrödinger's famous cat inside a box. In principle, the cat ends up in a weird quantum state, somewhere between dead and alive; it makes no sense to describe it as either one or the other. In a real experiment, however, the cat interacts with the box by exchange of light, heat and sound, and the box similarly interacts with the rest of the world. In nanoseconds, these processes destroy the delicate quantum states inside the box and replace them with states describable, to a good approximation, by the laws of classical physics. The cat inside really is either alive or dead, not in some mysterious nonclassical state that combines the two.

The key to seeing truly quantum behavior in a complex system is to isolate the system extremely well from the rest of the world, preventing decoherence and preserving fragile quantum states. This isolation is relatively easy to achieve with small systems, such as atoms suspended in a magnetic trap in a vacuum, but is much more difficult with the larger ones in which complex behavior may be found. Accidental laboratory discoveries of remarkable phenomena such as superconductivity and the quantum Hall effect are examples in which physicists have achieved large, well-isolated quantum systems. These phenomena demonstrate that the simple rules of quantum mechanics can give rise to emergent principles governing complex behaviors.

Resources and Tasks

WE ATTEMPT TO understand the high-level principles that govern in those rare instances when the quantum and the complex meet by abstracting, adapting and extending tools from classical information theory. Last year Benjamin W. Schumacher of Kenyon College proposed that the essential elements of information science, both classical and quantum, can be summarized as a three-step procedure:

1. Identify a *physical resource*. A familiar classical example is a string of bits. Although bits are often thought of as abstract entities—0's and 1's—all information is inevitably encoded in real physical objects, and thus a string of bits should be regarded as a physical resource.

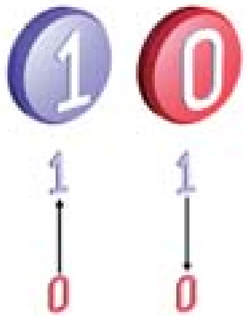
2. Identify an *information-processing task* that can be performed using the physical resource of step 1. A classical example is the two-part task of compressing the output from an information source (for example, the text in a book) into a bit string and then decompressing it—that is, recovering the original information from the compressed bit string.

3. Identify a *criterion for successful completion* of the task of step 2. In our example, the criterion could be that the

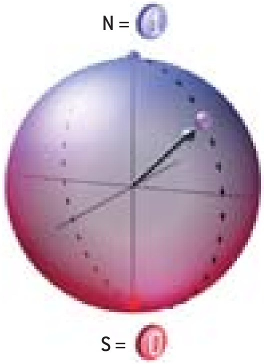
BRYAN CHRISTIE DESIGN

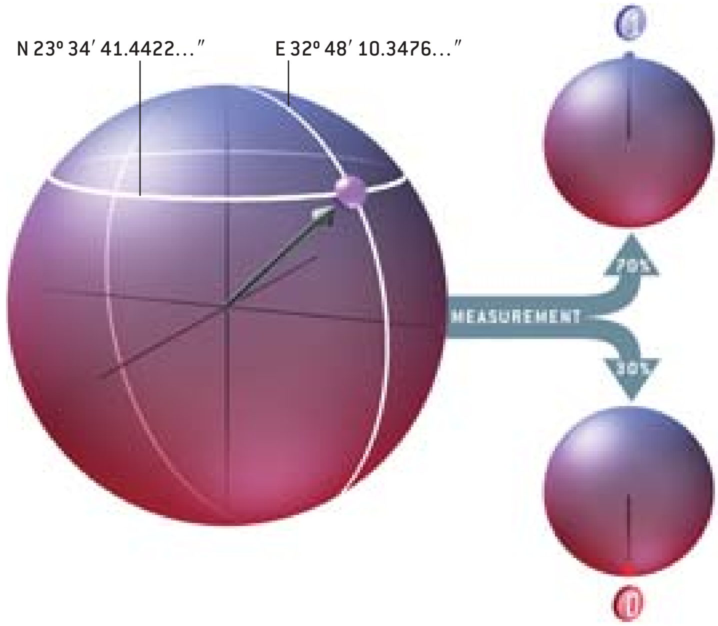
QUBITS EXPLAINED

A BIT can have one of two states: 0 or 1. A bit can be represented by a transistor switch set to "off" or "on" or abstractly by an arrow pointing up or down.



A QUBIT, the quantum version of a bit, has many more possible states. The states can be represented by an arrow pointing to a location on a sphere. The north pole is equivalent to 1, the south pole to 0. The other locations are quantum superpositions of 0 and 1.





A QUBIT MIGHT SEEM TO CONTAIN an infinite amount of information because its coordinates can encode an infinite sequence of digits. But the information in a qubit must be extracted by a measurement. When the qubit is measured, quantum mechanics requires that the result is always an ordinary bit—a 0 or a 1. The probability of each outcome depends on the qubit's "latitude."

output from the decompression stage perfectly matches the input to the compression stage.

The fundamental question of information science is then "What is the minimal quantity of the physical resource (1) we need to perform the information-processing task (2) in compliance with the success criterion (3)?" Although this question does not quite capture all of information science, it provides a powerful lens through which to view much research in the field [*see box on preceding page*].

The data-compression example corresponds to a basic question of classical information science—namely, what is the minimum number of bits needed to store the information produced by some source? This problem was solved by Claude E. Shannon in his famous 1948 papers founding information theory. In so doing, Shannon quantified the information content produced by an information source, defining it to be the minimum number of bits needed to reliably store the output of the source. His mathematical expression for the information content is now known as the Shannon entropy.

Shannon's entropy arises as the answer to a simple, fundamental question about classical information processing. It is perhaps not surprising, then, that studying the properties of the Shannon entropy has proved fruitful in analyzing processes far more complex than data compression. For example, it plays a central role in calculating how much information can be transmitted reliably through a noisy communications channel and even in understanding phenomena such as gambling and the behavior of the stock market. A general theme in information science is that questions about elementary processes lead to unifying concepts that stimulate insight into more complex processes.

In quantum information science, all three elements of Schumacher's list take on new richness. What novel physical resources are available in quantum mechanics? What information-processing tasks can we hope to perform? What are appropriate criteria for success? The resources now include superposition states, like the idealized alive and dead cat of Schrödinger. The processes can involve manipulations of entanglement (mysterious quantum correlations) between widely separated objects. The criteria of success become more subtle than in the classical case, because to extract the result of a quantum information–processing task we must observe, or measure, the system—which almost inevitably changes it, destroying the special superposition states that are unique to quantum physics.

Qubits

QUANTUM INFORMATION science begins by generalizing the fundamental resource of classical information—bits—to quantum bits, or qubits. Just as bits are ideal objects abstracted from the principles of classical physics, qubits are ideal quantum objects abstracted from the principles of quantum mechanics. Bits can be represented by magnetic regions on disks, voltages in circuitry, or graphite marks made by a pencil on paper. The functioning of these classical physical states as bits does not depend on the de-

BRYAN CHRISTIE DESIGN

tails of how they are realized. Similarly, the properties of a qubit are independent of its specific physical representation as the spin of an atomic nucleus, say, or the polarization of a photon of light.

A bit is described by its state, 0 or 1. Likewise, a qubit is described by its quantum state. Two possible quantum states for a qubit correspond to the 0 and 1 of a classical bit. In quantum mechanics, however, *any* object that has two different states necessarily has a range of other possible states, called superpositions, which entail both states to varying degrees. The allowed states of a qubit are precisely all those states that must be available, in principle, to a classical bit that is transplanted into a quantum world. Qubit states correspond to points on the surface of a sphere, with the 0 and 1 being the south and north poles [*see box on opposite page*]. The continuum of states between 0 and 1 fosters many of the extraordinary properties of quantum information.

How much classical information can we store in a qubit? One line of reasoning suggests the amount is infinite: To specify a quantum state we need to specify the latitude and longitude of the corresponding point on the sphere, and in principle each may be given to arbitrary precision. These numbers can encode a long string of bits. For example, 011101101... could be encoded as a state with latitude 01 degrees, 11 minutes and 01.101... seconds.

This reasoning, though plausible, is incorrect. One can encode an infinite amount of classical information in a single qubit, but one can never retrieve that information from the qubit. The simplest attempt to read the qubit's state, a standard direct measurement of it, will give a result of either 0 or 1, south pole or north pole, with the probability of each outcome determined by the latitude of the original state. You could have chosen a different measurement, perhaps using the "Melbourne–Azores Islands" axis instead of north-south, but again only one bit of information would have been extracted, albeit one governed by probabilities with a different dependence on the state's latitude and longitude. Whichever measurement you choose erases all the information in the qubit except for the single bit that the measurement uncovers.

The principles of quantum mechanics prevent us from ever extracting more than a single bit of information, no matter how cleverly we encode the qubit or how ingeniously we measure it afterward. This surprising result was proved in 1973 by Alexander S. Holevo of the Steklov Mathematical Institute in Moscow, following a 1964 conjecture by J. P. Gordon of AT&T Bell Laboratories. It is as though the qubit contains hidden information that we can manipulate but not access directly. A better viewpoint, however, is to regard this hidden information as being a unit of quantum information rather than an infinite number of inaccessible classical bits.

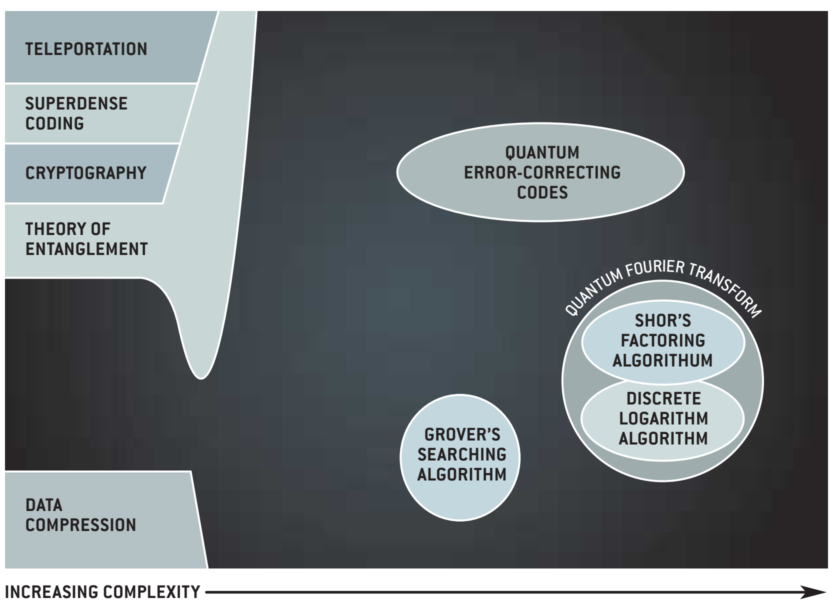
Notice how this example follows Schumacher's paradigm for information science. Gordon and Holevo asked how many qubits (the physical resource) are required to store a given amount of classical information (the task) in such a way that the information can be reliably recovered (the criterion for success). Furthermore, to answer this question, they introduced a mathematical concept, now known as the Holevo chi (represented by the Greek letter chi), that has since been used to simplify the analysis of more complex phenomena, similar to the simplifications enabled by Shannon's entropy. For example, Michal Horodecki of the University of Gdansk in Poland has shown that the Holevo chi can be used to analyze the problem of compressing quantum states produced by a quantum information source, which is analogous to the classical data compression considered by Shannon.

Entangled States

SINGLE QUBITS are interesting, but more fascinating behavior arises when several qubits are brought together. A key feature of quantum information science is the understanding that groups of two or

HERE THERE BE QUANTUM TYGERS

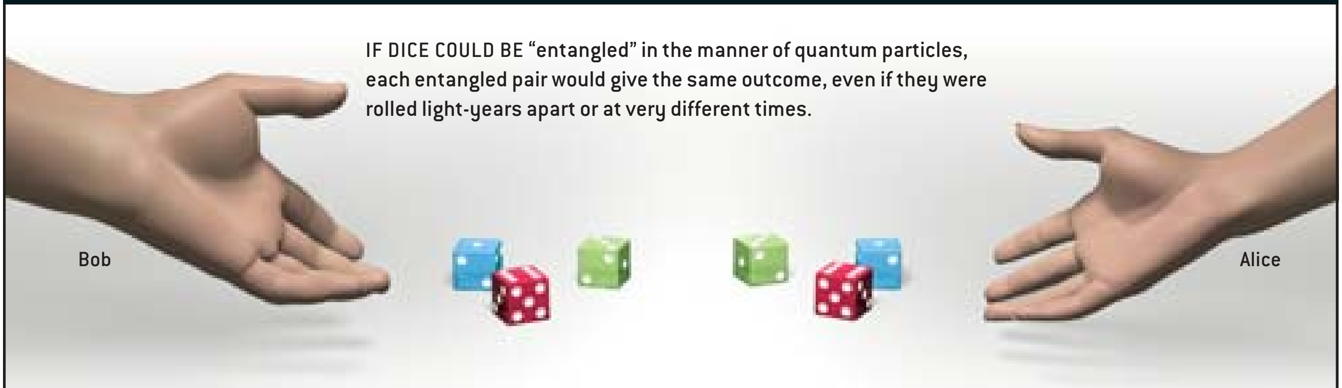
QUANTUM INFORMATION SCIENTISTS are still mapping out the broad topography of their nascent field. Some simpler processes, such as teleportation and quantum cryptography, are well understood. In contrast, complex phenomena such as quantum error correction and Peter W. Shor's factorization algorithm are surrounded by large tracts of terra incognita. One effort to bridge the gaps between the simple and the complex is work on a comprehensive theory of entanglement, analogous to the theory of energy embodied in thermodynamics.



BRYAN CHRISTIE DESIGN

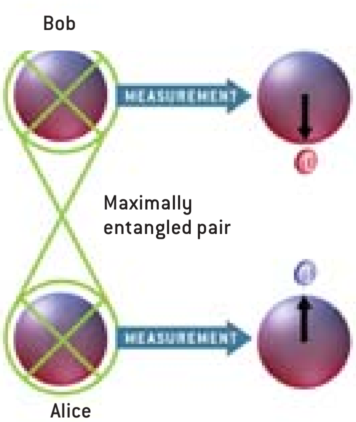
DISENTANGLING ENTANGLEMENT

IF DICE COULD BE "entangled" in the manner of quantum particles, each entangled pair would give the same outcome, even if they were rolled light-years apart or at very different times.



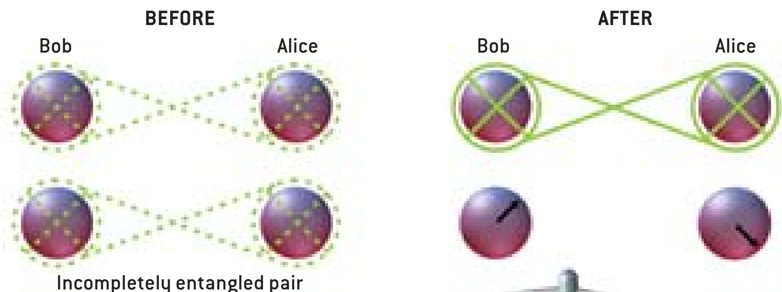
The Standard E-Bit

WHEN TWO QUBITS are entangled, they no longer have individual quantum states. Instead a relation between the qubits is defined. For example, in one type of maximally entangled pair, the qubits give opposite results when measured. If one gives 0, the other returns 1, and vice versa. A maximally entangled pair carries one "e-bit" of entanglement.



Weighing Entanglement

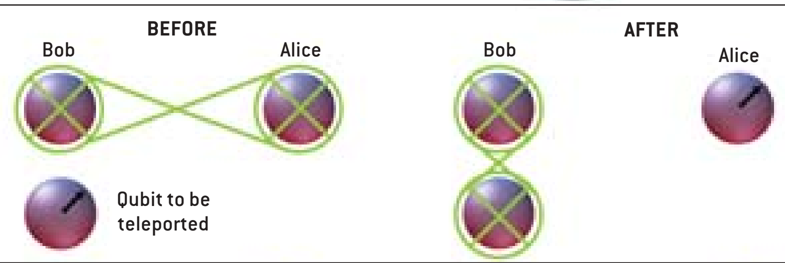
INCOMPLETELY ENTANGLED PAIRS carry less than one e-bit. If Alice and Bob share two partially entangled pairs, they can try to "distill" the entanglement onto a single pair. If distillation produces a maximally entangled pair, then Alice and Bob know their pairs originally carried a total of at least one e-bit of entanglement.



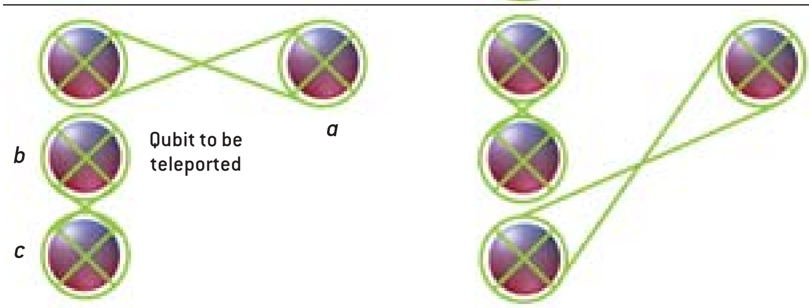
By using distillation (and the inverse process, entanglement dilution), one constructs a virtual set of scales for weighing the entanglement of various states against the standard e-bit.

Quantum Teleportation

IF ALICE AND BOB share one e-bit, they can teleport one qubit. The shared e-bit is "used up," in that they no longer share it after teleporting.



If Bob teleports a member (*b*) of an entangled pair to Alice, that particle's entanglement with its original partner (*c*) is transferred to Alice's particle (*a*). Alice and Bob cannot use teleportation, however, to increase their stock of shared e-bits.



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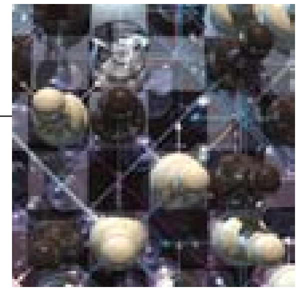


Entangled quantum systems behave in ways impossible in any classical world.

more quantum objects can have states that are entangled. These entangled states have properties fundamentally unlike anything in classical physics and are coming to be thought of as an essentially new type of physical resource that can be used to perform interesting tasks.

Schrödinger was so impressed by entanglement that in a seminal 1935 paper (the same year that he introduced his cat to the world) he called it "not *one* but rather *the* characteristic trait of quantum mechanics, the one that enforces its entire departure from classical lines of thought." The members of an entangled collection of objects do not have their own individual quantum states. Only the group as a whole has a well-defined state [*see box on opposite page*]. This phenomenon is much more peculiar than a superposition state of a single particle. Such a particle does have a well-defined quantum state even though that state may superpose different classical states.

Entangled objects behave as if they were connected with one another no matter how far apart they are—distance does not attenuate entanglement in the slightest. If something is entangled with other objects, a measurement of it simultaneously provides information about its partners. It is easy to be misled into thinking that one could use entanglement to send signals faster than the speed of light, in violation of Einstein's special relativity, but the probabilistic nature of quantum mechanics stymies such efforts.

Despite its strangeness, for a long time entanglement was regarded as a curiosity and was mostly ignored by physicists. This changed in the 1960s, when John S. Bell of CERN, the European laboratory for particle physics near Geneva, predicted that entangled quantum states allow crucial experimental tests that distinguish between quantum mechanics and classical physics. Bell predicted, and experimenters have confirmed, that entangled quantum systems exhibit behavior that is impossible in a classical world—impossible even if one could change the laws of physics to try to emulate the quantum predictions within a classical framework of any sort! Entanglement represents such an essentially novel feature of our world that even experts find it very difficult to think about. Although one can use the mathematics of quantum theory to reason about entanglement, as soon as one falls back on analogies, there is a great danger that the classical basis of our analogies will mislead us.

In the early 1990s the idea that entanglement falls wholly outside the scope of classical physics prompted researchers to ask whether entanglement might be useful as a resource for solving information-processing problems in new ways. The answer was yes. The flood of examples began in 1991, when Artur K. Ekert of the University of Cambridge showed how to use entanglement to distribute cryptographic keys impervious to eavesdropping. In 1992 Charles H. Bennett of IBM and Stephen Wiesner of Tel Aviv University showed that entanglement can assist the sending of classical information from one location to another (a process called superdense coding, in which two bits are transferred on a particle that seems to have room to carry only one). In 1993 an international team of six collaborators explained how to teleport a quantum state from one location to another using entanglement. An explosion of further applications followed.

Weighing Entanglement

AS WITH INDIVIDUAL qubits, which can be represented by many different physical objects, entanglement also has properties independent of its physical representation. For practical purposes, it may be more convenient to work with one system or another, but in principle it does not matter. For example, one could perform quantum cryptography with an entangled photon pair or an entangled pair of atomic nuclei or even a photon and a nucleus entangled together.

Representation independence suggests a thought-provoking analogy between entanglement and energy. Energy obeys the laws of thermodynamics regardless of whether it is chemical energy, nuclear energy or any other form. Could a general theory of entanglement be developed along similar lines to the laws of thermodynamics?

This hope was greatly bolstered in the second half of the 1990s, when researchers showed that different forms of entanglement are qualitatively equivalent—the entanglement of one state could be transferred to another, similar to energy flowing from, say, a battery charger to a battery. Building on these qualitative relations, researchers have begun introducing quantitative measures of entanglement. These developments are ongoing, and researchers have not yet agreed as to the best way of quantifying entanglement. The most successful scheme thus far is based on the notion of a standard unit of entanglement, akin to a standard unit of mass or energy [*see box on opposite page*].

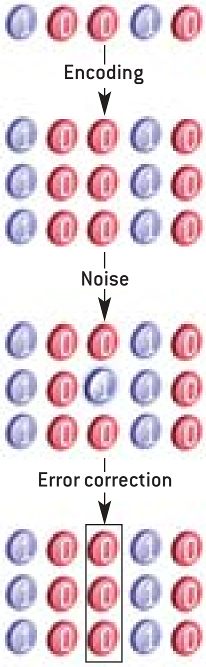
This approach works analogously to measuring masses by using a balance. The mass of an object is defined by how many copies of the standard mass are needed to balance it on a set of scales. Quantum information scientists have developed a theoretical "entanglement balance" to compare the entanglement in two different states. The amount of entanglement in a state is defined by seeing how many copies of some fixed standard unit of entanglement are needed to balance it. Notice that this method of quantifying entanglement is another example of the fundamental question of information science. We have identified a physical resource (copies of our entangled state) and a task with a criterion for success. We define our measure of entanglement by asking how much of our physical resource we need to do our task successfully.

The quantitative measures of entan-

DEALING WITH ERRORS

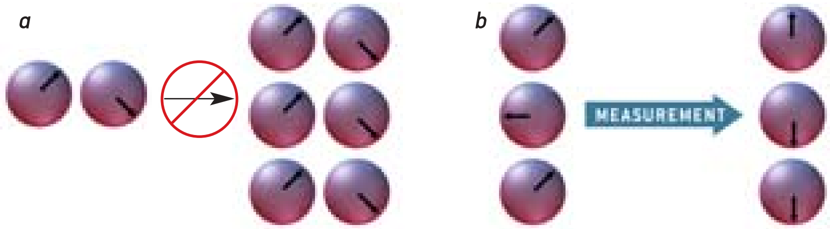
Classical Repetition Code

THIS SIMPLE CLASSICAL scheme for reducing errors encodes each bit as a triplet of identical bits. If noise flips one bit, the error can be corrected by fixing the minority bit of a triplet.

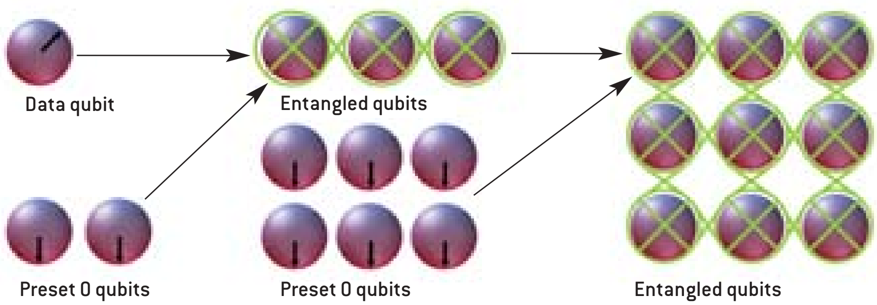


Error Correction for Qubits

THE REPETITION STRATEGY IS IMPOSSIBLE for qubits for two reasons. First, qubits in unknown states cannot be perfectly cloned (*a*). Even if duplicates are produced (for example, by running multiple copies of the computation), a simple measurement will not reveal errors (*b*).



ONE QUANTUM ERROR-CORRECTION CODE works by entangling each data qubit with two preset 0 qubits. These three qubits are in turn entangled with six others. Joint measurements on pairs of qubits will reveal whether one of these nine qubits suffers an error and, if so, how to correct it without disrupting the qubits' individual states.



glement developed by following this program are proving enormously useful as unifying concepts in the description of a wide range of phenomena. Entanglement measures improve how researchers can analyze tasks such as quantum teleportation and algorithms on quantum-mechanical computers. The analogy with energy helps again: to understand processes such as chemical reactions or the operation of an engine, we study the flow of energy between different parts of the system and determine how the energy must be constrained at various locations and times. In a similar way, we can analyze the flow of entanglement from one subsystem to another required to perform a quantum information-processing task and so obtain constraints on the resources needed to perform the task.

The development of the theory of entanglement is an example of a bottom-up approach—starting from simple questions about balancing entanglement, we gradually gain insight into more complex phenomena. In contrast, in a few cases, people have divined extremely complex phenomena through a great leap of insight, allowing quantum information science to proceed from the top down. The most celebrated example is an algorithm for quickly finding the prime factors of a composite integer on a quantum computer, formulated in 1994 by Peter W. Shor of AT&T Bell Labs. On a classical computer, the best algorithms known take exponentially more resources to factor larger numbers. A 500-digit number needs 100 million times as many computational steps as a 250-digit number. The cost of Shor's algorithm rises only polynomially—a 500-digit number takes only eight times as many steps as a 250-digit number.

Shor's algorithm is a further example of the basic paradigm (how much computational time is needed to find the factors of an *n*-bit integer?), but the algorithm appears isolated from most other results of quantum information science [*see box on page 71*]. At first glance, it looks like merely a clever programming trick with little fundamental significance. That appearance is deceptive; researchers have shown that Shor's algorithm can be interpreted as an instance of a procedure for determining the energy levels of a quantum system, a process that is more obviously fundamental. As time goes on and we fill in more of the map, it should become easier to grasp the principles underlying Shor's and other quantum algorithms and, one hopes, to develop new algorithms.

THE AUTHOR

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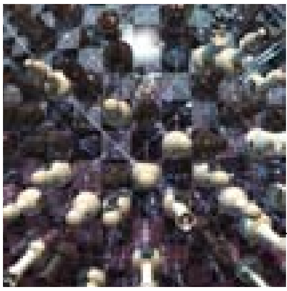
BRYAN CHRISTIE DESIGN



Quantum error correction might improve the precision of the world's best clocks.

One final application, quantum error correction, provides the best evidence to date that quantum information science is a useful framework for studying the world. Quantum states are delicate, easily destroyed by stray interactions, or noise, so schemes to counteract these disturbances are essential.

Classical computation and communications have a well-developed assortment of error-correcting codes to protect information against the depredations of noise. A simple example is the repetition code [*see box on opposite page*]. This scheme represents the bit 0 as a string of three bits, 000, and the bit 1 as a string of three bits, 111. If the noise is relatively weak, it may sometimes flip one of the bits in a triplet, changing, for instance, 000 to 010, but it will flip two bits in a triplet far less often. Whenever we encounter 010 (or 100 or 001), we can be almost certain the correct value is 000, or 0. More complex generalizations of this idea provide very good error-correcting codes to protect classical information.

Quantum Error Correction

INITIALLY IT APPEARED to be impossible to develop codes for quantum error correction because quantum mechanics forbids us from learning with certainty the unknown state of a quantum object—the obstacle, again, of trying to extract more than one bit from a qubit. The simple classical triplet code therefore fails because one cannot examine each copy of a qubit and see that one copy must be discarded without ruining each and every copy in the process. Worse still, making the copies in the first place is nontrivial: quantum mechanics forbids taking an unknown qubit and reliably making a duplicate, a result known as the no-cloning theorem.

The situation looked bleak in the mid-1990s, when prominent physicists such as the late Rolf Landauer of IBM wrote skeptical articles pointing out that quantum error correction would be necessary for quantum computation but that the standard classical techniques could not be used in the quantum world. The field owes a great debt to Landauer's skepticism for pointing out problems of this type that had to be overcome [see "Riding the Back of Electrons," by Gary Stix; Profile, Scientific American, September 1998].

Happily, clever ideas developed independently by Shor and Andrew M. Steane of the University of Oxford in 1995 showed how to do quantum error correction without ever learning the states of the qubits or needing to clone them. As with the triplet code, each value is represented by a set of qubits. These qubits are passed through a circuit (the quantum analogue of logic gates) that will successfully fix an error in any one of the qubits without actually "reading" what all the individual states are. It is as if one ran the triplet 010 through a circuit that could spot that the middle bit was different and flip it, all without determining the identity of any of the three bits.

Quantum error-correcting codes are a triumph of science. Something that brilliant people thought could not be done—protecting quantum states against the effects of noise—was accomplished using a combination of concepts from information science and basic quantum mechanics. These techniques have now received preliminary confirmation in experiments conducted at Los Alamos National Laboratory, IBM and the Massachusetts Institute of Technology, and more extensive experiments are planned.

Quantum error correction has also stimulated many exciting new ideas. For example, the world's best clocks are currently limited by quantum-mechanical noise; researchers are asking whether the precision of those clocks can be improved by using quantum error correction. Another idea, proposed by Alexei Kitaev of the California Institute of Technology, is that some physical systems might possess a type of natural noise tolerance. Those systems would in effect use quantum error correction without human intervention and might show extraordinary inherent resilience against decoherence.

We have explored how quantum information science progresses from fundamental questions to build up an understanding of more complex systems. What does the future hold? By following Schumacher's program, we will surely obtain novel insights into the information-processing capabilities of the universe. Perhaps the methods of quantum information science will even yield insights into systems not traditionally thought of as information-processing systems. For instance, condensed matter exhibits complex phenomena such as high-temperature superconductivity and the fractional quantum Hall effect. Quantum properties such as entanglement are involved, but their role is currently unclear. By applying what we have learned from quantum information science, we may greatly enhance our skills in the ongoing chess match with the complex quantum universe. SA

MORE TO EXPLORE

Quantum Theory and Measurement. Edited by John A. Wheeler and Wojciech H. Zurek. Contains reprints of landmark papers, including a translation of Erwin Schrödinger's 1935 "cat paradox" paper. Princeton University Press, 1983.

The Fabric of Reality. David Deutsch. Penguin Books, 1998.

The Bit and the Pendulum. Tom Siegfried. John Wiley & Sons, 2000.

Quantum Computation and Quantum Information. Michael A. Nielsen and Isaac L. Chuang. Cambridge University Press, 2000.

The Center for Quantum Computation's Web site: **www.qubit.org**

John Preskill's lecture notes are available at **www.theory.caltech.edu/people/preskill/ph229/**

See **www.sciam.com** for *Scientific American* articles related to quantum information science.

Although the explosion and subsequent high-rise blaze are nasty, most building residents are away at work, so nobody is seriously hurt. A parade of police cars, ambulances and fire trucks pulls up to the curb, lights flaring and sirens blaring. Emergency crews dodge bits of smoking debris and prepare to enter the stricken structure.

Suddenly a sensor panel on a fire truck flashes a warning. "The radiation detectors have gone off!" a stunned fire chief roars. "It looks like a dirty bomb!" *Activity stops abruptly as alarm sweeps through the assembled crews. What appeared to be a standard fire emergency is actually a terrorist attack with a radiological weapon.*

Alerted by radio, disaster-control agencies dispatch specially trained radiation-mitigation teams to the site. Rescue workers slip into brightly colored hazmat suits. Police officers in gas masks start to evacuate bystanders, but most of the frightened onlookers are already running away in panic, handkerchiefs over their mouths.

The explosive device, spiked with radioactive cesium, has released a cloud of toxic dust. When it drifts downwind, fallout settles over nearly 60 city blocks. Buildings, sidewalks, streets and cars are quickly coated with radioactive debris. As the ventilation systems of buildings in the neighborhood suck in the dust, people inhale small amounts of carcinogenic particles.

After sitting abandoned and quarantined for a short period, the environs are swept by teams of workers who decontaminate surfaces with vacuums, water jets and other apparatus as part of a prolonged cleanup effort. In retrospect, the incident has caused relatively few injuries, most of which were the result of traffic accidents during the frenzied exodus. Still, fearful residents refuse to return. Business revenues and real-estate values plummet, and several buildings near ground zero have to be demolished. The final costs reach the tens of billions of dollars.

Weapons of Mass Disruption

Radiological terror weapons could blow radioactive dust through cities, causing panic, boosting cancer rates and forcing costly cleanups

BY MICHAEL A. LEVI AND HENRY C. KELLY

DREAD WIND: The greatest danger of a dirty bomb is not the explosive blast but the radioactive particles it projects into the air.

This kind of scenario could become a reality in the not too distant future.

Defending ourselves from the threat of radiological weapons has become a grim necessity. The components and know-how needed to build a dirty bomb are available, and there are fanatics out there who just might do the deed. The arrest earlier this year of Al Qaeda sympathizer José Padilla (Abdullah al Muhajir) on suspicion of plotting to construct and set off a dirty bomb gives an indication of the interest in building such a device.

A radiological weapon, or dirty bomb, is typically a crude device comprising conventional explosives, such as TNT or a fuel oil/fertilizer mixture, laced with highly radioactive materials. The explosives generate a pulse of heat that vaporizes or aerosolizes radioactive material and propels it across a wide area.

Weapons experts consider radiological bombs a messy but potentially effective technology that could cause tremendous psychological damage, exploiting the public's fears of invisible radiation. Not weapons of mass destruction but weapons of mass disruption, these devices could wreak economic havoc by making target areas off-limits for an extended period. Radiological bombs have never been used, mainly because they have long been considered inappropriate for military purposes: their effect is too delayed and unpredictable to sway a battle.

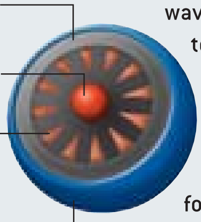
Although they are relatively simple in principle, constructing and deploying one of these mechanisms is difficult to do. It is more complicated than wrapping stolen materials around a stick of dynamite. Such a clumsy weapon might only scatter large chunks of material, limiting the area affected and making cleanup easy. An effective dirty bomb is, however, much easier to assemble than a nuclear weapon, although it would still require considerable skill. A major problem is that the builder could be fatally exposed to hot isotopes. But a deadly dose of radiation can take weeks to have an effect and so might not deter suicidal terrorists.

DIRTY VERSUS NUCLEAR BOMBS

People sometimes confuse radiological with nuclear weapons

A DIRTY BOMB is likely to be a primitive device in which TNT or fuel oil and fertilizer explosives are combined with highly radioactive materials. The detonated bomb vaporizes or aerosolizes the toxic isotopes, propelling them into the air.

A FISSION BOMB is a more sophisticated mechanism that relies on creating a runaway nuclear chain reaction in uranium 235 or plutonium 239. One type features tall, inward-pointing pyramids of plutonium surrounded by a shell of high explosives. When the bomb goes off, the explosives produce an imploding shock wave that drives the plutonium pieces together into a sphere containing a pellet of beryllium/polonium at the center, creating a critical mass. The resulting fission reaction causes the bomb to explode with tremendous force, sending high-energy electromagnetic waves and fallout into the air.



Radioactive Rebar

MATERIALS THAT ARE HIGHLY radioactive are employed in hundreds of medical, industrial and academic applications. There are about two million individual sources of ionizing radiation in the U.S. alone, thousands of which are of significant size. Their uses include destroying bacteria on food, sterilizing pharmaceutical products, killing cancer cells, inspecting welds, exploring for oil, and doing research in nuclear physics and engineering. The U.S. federal government encouraged the distribution of plutonium isotopes for research during the 1960s and 1970s, and much of the material is still out there because the government has not been willing to pay for its recovery.

Ionizing radiation sources, such as cobalt 60, cesium 137 and iridium 192, emit gamma rays; others, such as americium 241 and plutonium 238, produce alpha particles. These materials are often expensive, and authorities always assumed that there would be a clear economic incentive to protect them from thieves. Policymakers also expected that heavy protection of these substances would be unnecessary because no one would risk exposure to the life-threatening levels of radiation they produce.

Despite these assurances, significant quantities of materials suitable for dirty-bomb making have been found abandoned in scrap yards, vehicles and houses around the U.S. and Europe. A recent U.S. Nuclear Regulatory Commission (NRC) study reported that American business and research facilities had lost track of nearly 1,500 pieces of equipment with radioactive parts since 1996, scores of which would be big enough for a dirty bomb. Half were never recovered. Earlier this year a steel-recycling plant found a hot source mixed in with scrap metal. Several years ago radioactive cesium passed undetected through a recovery facility and was subsequently melted down and cast in steel reinforcing bars for concrete.

The International Atomic Energy Agency stated in late June that almost every nation in the world has the radioactive materials needed to build a dirty bomb. More than 100 countries lack adequate controls to prevent the theft of these materials. Late in 2001, for instance, two woodsmen in the former Soviet republic of Georgia were dosed after they found a portable radiothermal generator—a large radioactive strontium 90 source—abandoned in the woods. They used the generator as a heating device. Chechen rebels created a scare in 1995 when they placed a shielded container holding cesium 137 (taken from cancer-treatment equipment) in a Moscow park and then tipped off Russian news reporters to its location. Eight years previously, scrap scavengers broke into an abandoned cancer clinic in Goiânia, Brazil, and stole a medical device containing radioactive cesium. About 250 people were exposed to the source; eight de-

CATHERINE McINTYRE (*preceding pages*); SARA CHEN (*this page*) veloped radiation sickness, and four died. The incident produced 3,500 cubic meters of radioactive waste—enough to cover a football field to hip level—and left the local economy devastated.

Radiation Effects

IN ADDITION TO ACUTE HEALTH problems such as radiation sickness, radioactive materials can cause cancer. Quantifying dangerous radioactive dose levels is difficult, however, because specific health effects are uncertain.

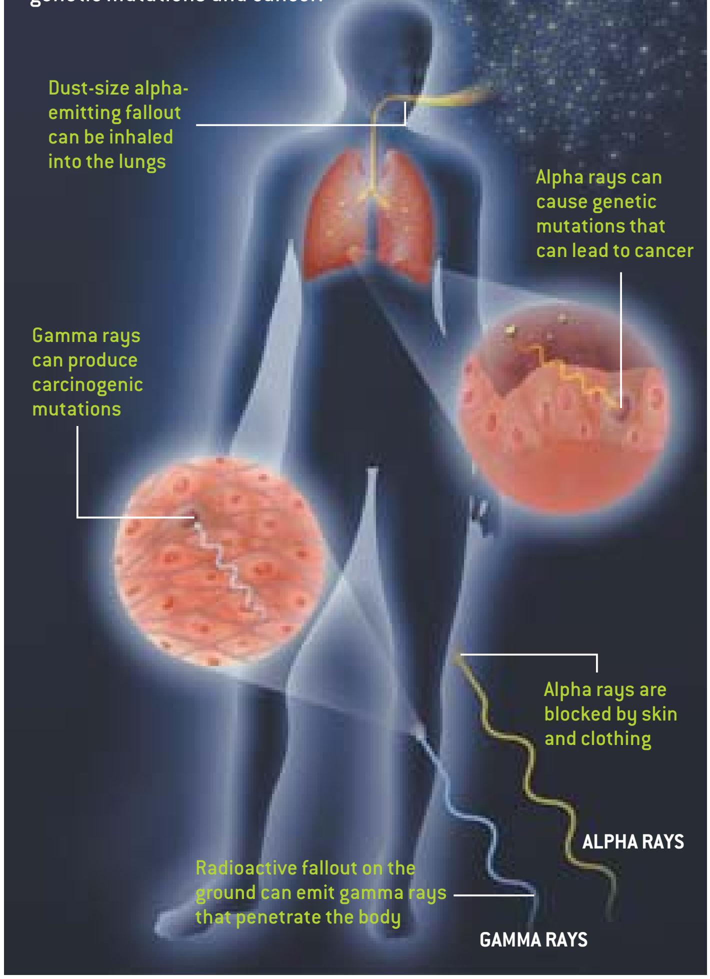
Radiation doses are often measured in rems. Everyone receives about a quarter of a rem every year from exposure to natural sources, including cosmic rays and the uranium in granite bedrock. In general, people subjected to 100 rems or more develop radiation sickness and require immediate medical attention. Half the people exposed to 450 rems will die within 60 days. Even small doses can increase the risk of getting cancer. On average, if 2,500 people are exposed to a single rem of radiation, one will die of an induced cancer.

Scientists and regulators have long debated what level of radiation exposure is tolerable. Federal regulations prohibit radiation workers from receiving more than five rems annually. The U.S. Environmental Protection Agency recommends that a contaminated area be abandoned if decontamination efforts cannot reduce the extra risk of cancer death to about one in 10,000. This additional risk is equivalent to having 25 chest x-rays over one's lifetime or being exposed to cosmic radiation in Denver (as opposed to sea level) for three years. The NRC typically sets a looser threshold, equivalent to a one-in-500 increased cancer death risk over 50 years. But these assessments are controversial because there are no good statistics showing how much cancer increases as a result of low levels of radiation. Currently experts estimate the hazards of exposure by assuming that the chance of developing cancer decreases in proportion to the amount of radiation received. They also presuppose that there is no minimum level of exposure that is harmless.

RADIATION EFFECTS ON THE BODY

ALPHA RAYS can produce genetic mutations, causing cells to divide rapidly and become cancerous. Suspended alpha-emitting particles can lodge in the lungs, where they can damage internal tissues and form tumors.

Gamma rays, which can penetrate the body, can also cause genetic mutations and cancer.



SARA CHEN

Hot Cloud in the City

TO UNDERSTAND THE POTENTIAL impact of a dirty bomb, we examined a range of plausible attacks. We studied hypothetical dispersal scenarios and estimated the sizes of the areas that would be contaminated above various dose thresholds. To do this, we used the HOTSPOT computer code, developed at Lawrence Livermore National Laboratory, which simulates the movement of radioactive particles. The model's results were then combined with experimental and theoretical data on the effects of radiation to produce estimates of health risks and contamination.

A simulated dispersal depends on a range of inputs, including time of day, weather, wind speed, and scattering methods. Higher winds, for example, spread materials over a greater area, reducing the amount of contamination in any one place. To ensure that our outputs were not simply the result of specific initial conditions, we ran more than 100 dispersal scenarios. For a given radioactive source, variations in ambient conditions produced changes in our estimates by at most a factor of 10. Such an error range does not affect our basic conclusions, if only because the various factors tend to offset one another. For every factor with the potential to make a bomb's impact half as bad, there is another to make it two times worse.

If people in the vicinity of an explosion are unable to leave the area before the dust cloud arrives, they will inhale small par-

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The authors would like to thank Jaime Yassif of the FAS for her research assistance.

NOXIOUS PLUME of hot fallout spreads over New York City's Manhattan Island after the simulated detonation of a radioactive cesium-based dirty bomb (assuming a wind from the southwest). The highlighted zones would be expected to have radiation levels comparable to those that caused the closing of contaminated regions around the damaged Chernobyl nuclear power plant.

ticles. From past incidents, we know that if the material is an alpha emitter, such as plutonium or americium, it could become lodged in victims' lungs for years and lead to long-term radiation exposure. But if evacuees are decontaminated quickly, thoroughly washing their skin and disposing of contaminated clothing, the total exposure will be minimal.

Dust from a radiological weapon would remain trapped for extended periods in cracks and crevices on the surfaces of buildings, sidewalks and streets, and some would have been swept into the interiors of buildings. Certain materials that could be used in a radiological attack, such as cesium 137, chemically bind to glass, concrete and asphalt. More than 15 years after the 1986 Chernobyl disaster, in which a Soviet nuclear power plant underwent a meltdown, cesium is still affixed to the sidewalks of many Scandinavian cities that were downwind of the disaster. Fortunately, the radiation exposure from underfoot is fairly low, increasing the cancer death risk by less than one in 10,000.

If the material contains alpha emitters, the long-term health risk comes from breathing radioactive dust suspended in the air by wind, the action of tires or pedestrian traffic. In Kiev, more than 100 kilometers from Chernobyl, dust in the streets still contains low levels of plutonium. Should the material remaining in the area contain cesium 137 or other gamma emitters, anyone entering a contaminated area would be exposed to low-level radiation because, unlike alpha rays, gamma rays penetrate clothing and skin.

Consider the dispersal of 3,500 curies of cesium 137 by an explosion at the lower tip of Manhattan Island. Sources capable of delivering this much radiation have been "orphaned" in the former Soviet Union; the U.S. recently committed $25 million, in partnership with Russia, to track these materials down. Such a source, if acquired by terrorists, would be difficult to handle, requiring some shielding to prevent a builder from receiving an incapacitating radiation dose. But the cesium would already be in powder form, making dispersion relatively easy.

If this source were prepared and then exploded, about 800 square kilometers would be contaminated above the strict EPA decontamination guidelines. The disaster would not be of Chernobyl's magnitude; it would release less radiation overall, and none in the form of potent short-lived isotopes such as iodine 131. But its strategic placement would wreak havoc. Over an area of about 20 city blocks, there would be a one-in-10 increased risk of death from cancer for residents living in the area (without decontamination) for 30 years, a 50 percent increase over the background rate. A broader area of 15 square kilometers—varying from four to 20 square kilometers, depending on the weather—would be contaminated above the relocation threshold recommended by the International Commission on Radiological Protection and accepted by the NRC. If these standards were relaxed and the relocation threshold were the same as that used around Chernobyl, the area affected would still be roughly 100 city blocks. The property value of this area is estimated in the hundreds of billions of dollars.

Decontamination Procedures

REMOVAL OF URBAN RADIOACTIVE contamination has never been performed on a large scale because no one has ever had to deal with the consequences of a radiological attack. Our current knowledge of how to cleanse an urban area is based on experience from smaller-scale industrial operations and from cold war–era studies on the aftermath of nuclear war.

The cleanup effort would initially involve removing loose contamination—radioactive dust particles settled on surfaces or lodged in interstices. Relatively low cost mechanical techniques such as vacuuming or pressure washing should be effective. More invasive, higher-cost surface-removal techniques, such as sandblasting, would be necessary where hot dust has penetrated deep into more porous materials. In some cases, sidewalks and asphalt may have to be removed. The top layer

COSTLY CLEANUP EFFORTS will follow any use of a dirty bomb. Hazmat-suited workers will have to scrub fallout from surfaces with water jets, vacuums and sandblasters, as well as remove contaminated plants and soil.

SARA CHEN (*top*); YUN JAI-HYOUNG *AP Photo* (*bottom*) of soil might have to be carted off-site and disposed of. Much vegetation might have to be cut down. Chemical agents such as acids might have to be used to dissolve rust and mineral deposits in which contaminants are trapped.

To make the process manageable, we may need to reevaluate contamination guidelines. The strict EPA regulations are appropriate for peacetime purposes—they were developed (with public consultation) to force limits on corporate polluters. Faced with the alternative of abandoning swaths of a city, we might have to accept an increased risk. We might choose, for example, to adopt the NRC guidelines, which require cleanup of all areas where contamination would deliver a dose greater than five rems over 50 years, increasing the risk of cancer death by more than one in 500 (equivalent to a reduction of each person's life expectancy by roughly 15 days). An alternative would be to require cleanup of all areas where contamination would more than double the background radiation rate.

Protective Measures

MANY RELATIVELY LOW COST, practical steps can be taken to reduce the risks from radiological weapons and minimize the effects if an attack should occur. The first step is to ensure that the materials themselves are secure. The NRC and other federal agencies are tightening the licensing process governing access to radioactive materials and the security standards for all dangerous materials. Inspections must be frequent and thorough. Programs to collect and safeguard unused materials, building on efforts such as the successful Los Alamos Offsite Source Recovery Project, need to be expanded.

Research should also be funded to identify less dangerous technologies—ion beams, for example—that can provide the food sterilization, medical and other services now supplied by radioactive materials. Increased security will raise the cost of using radioactive materials and create economic incentives for nonradioactive alternatives.

The next step would be to improve our ability to detect materials in the event that they are stolen. The U.S. ought to install an extensive array of radiation-detection systems at key points such as airports, harbors, rail stations, tunnels, highways and borders. This effort has already begun: radiation detectors from the Department of Energy's Nuclear Emergency Search Teams are being installed along the Boston–New York–Washington corridor and on the perimeter of the nation's capital. Routine checks of scrap-metal yards and landfill sites would also protect against illegal or accidental disposal of dangerous materials. In applications such as these, highly sensitive detectors are unnecessary because materials could all be checked at the entrance to a facility and would be unlikely to be shielded. Simple, inexpensive Geiger counters would suffice.

We must also ensure that the government is prepared to mitigate the impact of any radiological weapon that is actually used. An effective response to an attack requires a system capable of quickly gauging the extent of the damage, identifying appropriate responders, developing a coherent response plan, and getting the necessary personnel and equipment to the site rapidly. To help assuage fear, federal authorities should designate a single scientifically credible official who could provide consistent information about the attack.

All of this requires extensive training. Emergency and hospital personnel need to understand how to protect themselves and affected citizens during a radiological attack and be able to determine rapidly if individuals have been exposed to radiation. Although generous funding has been made available for instruction, the program needs a clear management strategy.

Finally, we need to learn how to decontaminate large urban areas and determine the steps necessary to minimize contamination. This could mean the difference between abandoning or demolishing a city and getting it back in operation after a few months of cleanup.

Although the effects of a radiological attack are minor compared with those of even a small nuclear weapon, a dirty bomb could have drastic economic and psychological consequences. Fortunately, studying the nature of the risk gives us the chance to take actions that could reduce the likelihood of an event and minimize the damage. We should begin immediately. SA

What to Do if Attacked

In the event of a radiological weapons incident, take these basic steps:

If you're inside, close your windows and turn off any external ventilation. This will stop radioactive particles from getting inside. Although filter masks are useful outside, they do not offer any added protection indoors.

If you're outside, get inside, wash up and discard your clothes. This will remove any radioactive particles. You might track in some radioactive fallout, but this danger is offset by the benefits of being indoors. You should stay inside until you're told to do otherwise by law-enforcement officials or emergency personnel. If people start fleeing the scene, it will be harder to contain contamination and to move emergency workers and equipment efficiently.

In all cases, listen for instructions from the authorities. The nature of the required response will depend on the size and type of the dirty bomb.

Iodine tablets are ineffective, because dirty bombs (unlike reactor meltdowns) would be unlikely to release radioactive iodine.

MORE TO EXPLORE

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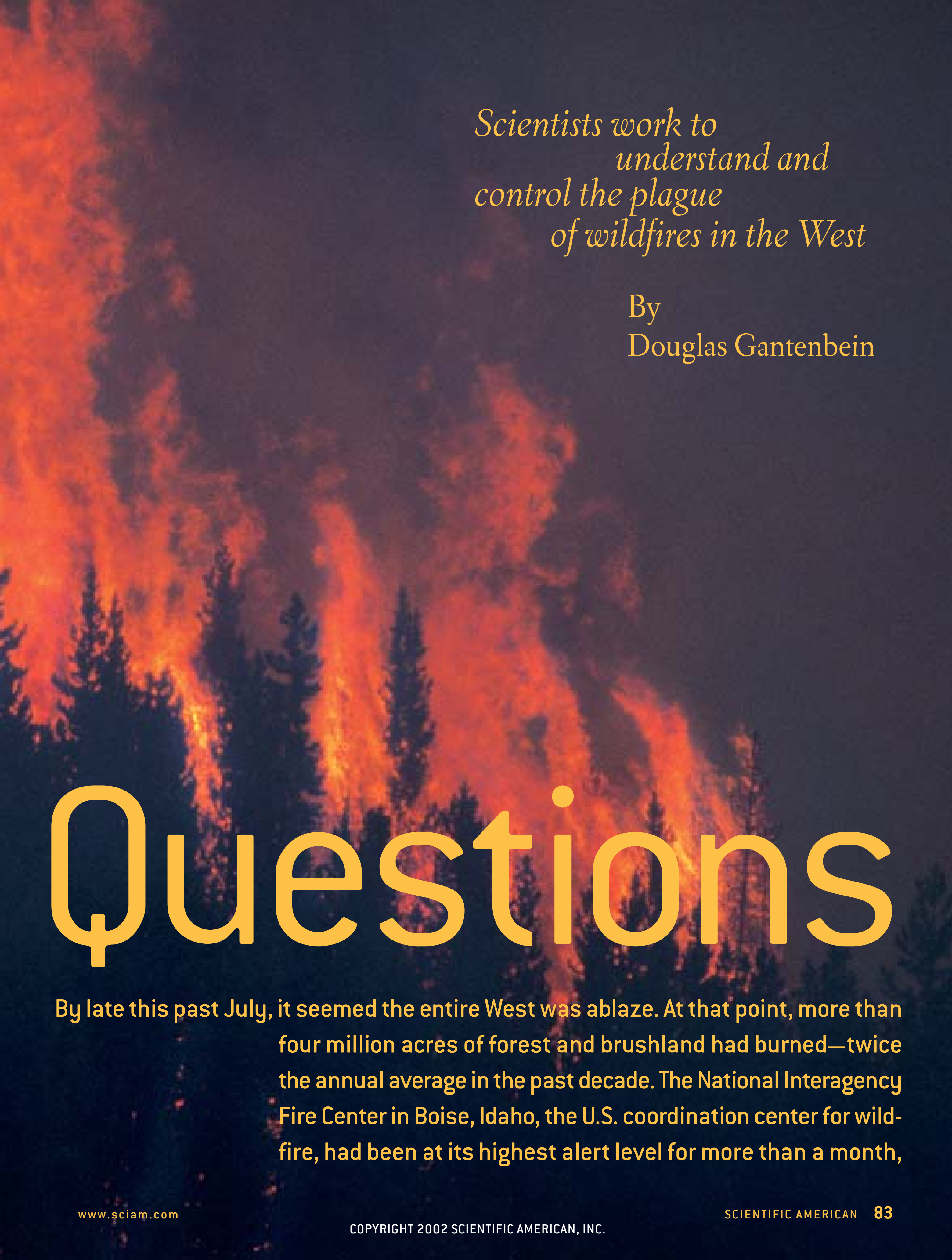
Senate Committee on Foreign Relations Hearing Testimony on "Dirty Bombs and Basement Nukes." Summary available at **www.ransac.org/new-web-site/related/congress/hearings/sfrc_notes.html**

Council on Foreign Relations Q&A on Dirty Bombs: **www.terrorismanswers.com/weapons/dirtybomb.html**

Burning



Scientists work to understand and control the plague of wildfires in the West

By Douglas Gantenbein

Questions

By late this past July, it seemed the entire West was ablaze. At that point, more than four million acres of forest and brushland had burned—twice the annual average in the past decade. The National Interagency Fire Center in Boise, Idaho, the U.S. coordination center for wildfire, had been at its highest alert level for more than a month,

a stage it didn't hit until August the previous year. The U.S. Forest Service was already predicting it would easily bust its annual $1-billion firefighting budget, and with other land-use agencies also facing big fire bills, it seemed 2002 might be the most expensive fire year ever. Worst of all, 15 people had been killed in fire-related mishaps, including five who died in horrifying airplane crashes when the wings of two aerial-retardant tankers peeled off in midair.

Fire Factors

FIRE HAS BECOME the defining characteristic of the West. From May until September, from New Mexico and Arizona to Washington, Idaho and Montana, plumes of smoke as high as 40,000 feet punctuate the horizon as tens of thousands of acres below them burn. This year some of those plumes have marked giant fires of 100,000 acres or more. In Colorado, for instance, the devastating Hayman fire scorched more than 100,000 acres and cost some $40 million to fight. In Arizona, the Rodeo fire joined with the Chediski fire to burn more than 300,000 acres. And in Oregon, the Biscuit fire consumed an astonishing 500,000 acres of forest, an area larger than all five boroughs of New York City, and forced nearly 17,000 to flee. The Biscuit fire ultimately cost $113 million to combat, making it the most expensive fire-suppression effort in wildland fire history.

The reasons behind these appalling seasons of fire are many: forest management that attempted to control fires but instead made them worse, severe drought, even arson. Since the early 1960s fires have become consistently hotter and bigger. In 1961, for instance, the Sleeping Child fire in Montana burned about 28,000 acres and amazed firefighters with its ferocity. Now such a fire hardly merits special notice.

The big fire season of 2000, which saw more than eight million acres burn, prodded the federal government to do more than merely write checks in October to cover the previous summer's firefighting bill. The Clinton administration committed $1.8 billion a year to a project called the National Fire Plan. While pouring millions more into firefighting equipment and hiring new firefighters, the plan also earmarked substantial sums for fire research, which will greatly help the efforts of fire scientists.

Kevin C. Ryan is a specialist on the effects of fire on a forest—how it hurts forests, how it enhances them—at the forest service's Fire Sciences Laboratory in Missoula, Mont. In particular, he focuses on methods for determining whether a fire-damaged tree has a chance of survival, something that cannot be resolved simply by looking at whether its needles are charred. "Until now, most attention to fires has been hero worship," Ryan says, referring to the tendency to rush TV crews and reporters to the scene. "But now there's a real interest in trying to understand the scientific underpinnings of what's going on." Scientists are learning how big fires burn, how to better comprehend their impact, perhaps even how to predict what a fire will do before it does it.

One area of interest is the way in which these conflagrations burn and grow. The fires that raged in Oregon, Colorado, Arizona and other states in 2002 all were crown fires, the most devastating type. In these blazes the flames literally leap from treetop to treetop. They are impossible to fight. Not only can crown fires easily cross a five-foot firebreak scratched out by crews using Pulaskis, the combination ax/pick that after nearly 70 years remains the staple tool of firefighters, they have been known to hurdle rivers hundreds of feet wide.

Fires of this kind were once rare; during the 1910s and 1920s, firefighters deployed by the nascent forest service often

Overview/*After the Fire*

- The summer of 1910, when the entire American West seemed to be aflame, was pivotal in U.S. fire history. Afterward, foresters adopted a policy of snuffing out all blazes. That approach is now discredited.
- Solving the problem isn't as simple as letting fires burn unchecked again. Forest detritus buildup, combined with recent droughts, has left large tracts at risk for catastrophic fire. These ecosystem-destroying conflagrations threaten the rising numbers of homes in "urban-wildland interfaces."
- With renewed federal support for fire research, scientists are exploring new ways to understand the behavior of wildfires and mitigate their destructive potential.

DOUGLAS GANTENBEIN (*preceding pages*); MARTOS A. HOFFMAN (*above*)

SMOKEY WAS HERE: After decades of fire suppression, a forest (*above*) is littered with brush and crammed with spindly "doghair" trees. Where naturally sparked fires have been permitted (*right*), well-spaced Ponderosa pines form stately columns.

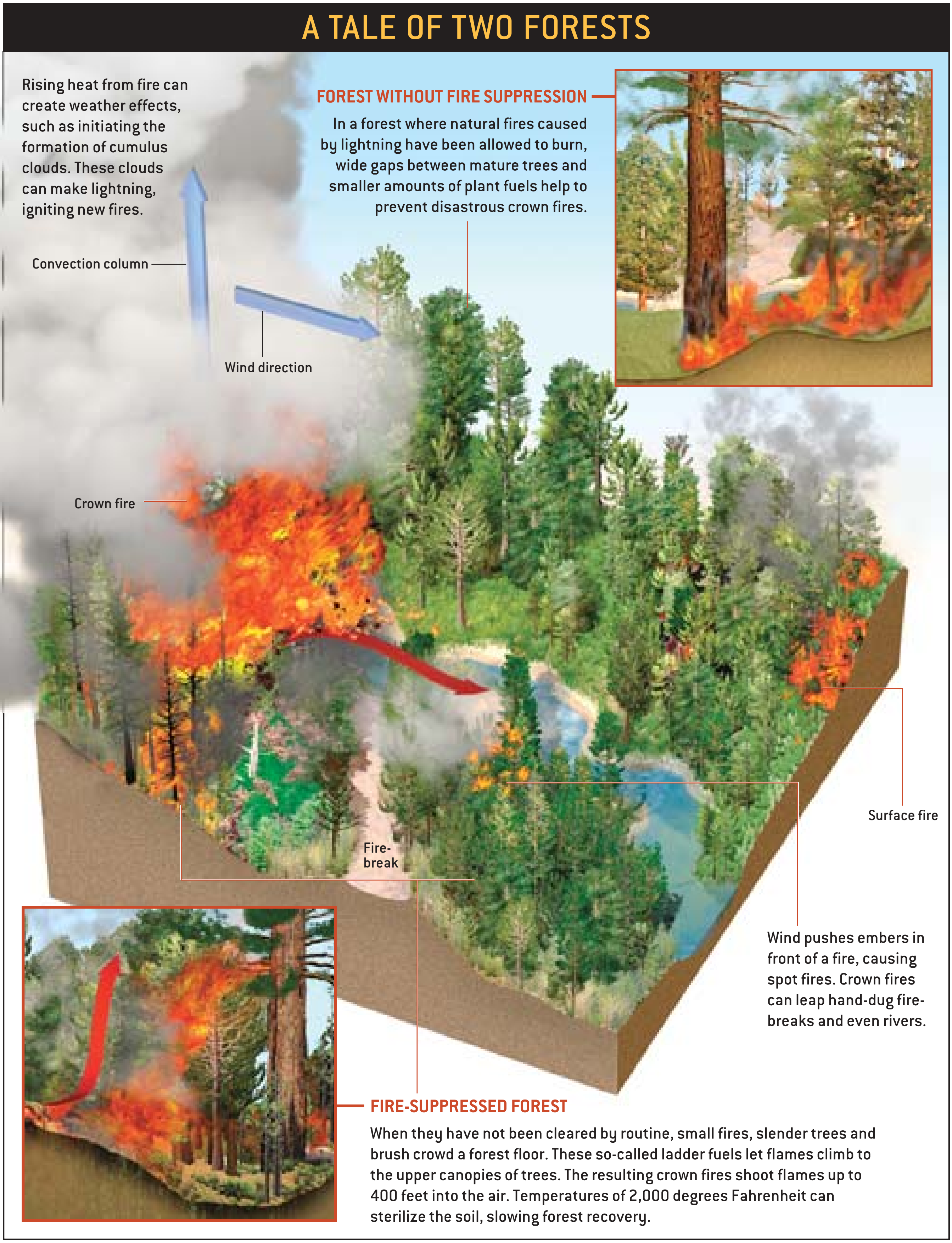
MARTOS A. HOFFMAN

could walk right up to a fire and beat it out with a blanket. Today fires commonly shoot flames 400 feet into the air, can generate temperatures of 2,000 degrees Fahrenheit and devour perhaps 35 tons of fuel an acre in just an hour. The winds they create may reach 100 miles an hour. Worse, these fires can utterly destroy forests of Ponderosa pine, the dominant tree species in the West. A big, beautiful tree that creates majestic, open forests that offer shade and sun in equal measure and provide habitat for dozens of birds, mammals and insects, the Ponderosa is supremely adapted to coexist with fire. But only frequent, small fires, not infrequent, huge ones.

"When a crown fire happens, this [Ponderosa pine] forest can't go home again," Ryan says. "What comes in next won't be a natural regime; it'll be dominated by exotic weeds and trees that couldn't exist when fire used to come through frequently." In Arizona, for instance, a 1977 crown fire near Mount Elden burned so hot that the thin volcanic soil was sterilized, and even now few Ponderosa pines, which once blanketed the site, have reemerged.

But the conditions that create such devastating fires also make them hazardous to study. "You're in harm's way if you try to plant something in front of a fire," says Don J. Latham, a fire-behavior scientist at the Fire Sciences Laboratory. "So almost all the data gathering has to be done remotely, either with aircraft or satellites." And those tools, Latham points out, can be fairly crude—good at determining the location of a fire but poor at gathering the details of what takes place inside it. Scientists are refining this information in a variety of ways.

Since the early 1960s, for example, much has been learned about the behavior of forest fires in the burn chamber of the Missoula lab. The 88-foot-tall chamber structure consists of a large central burn room and two smaller wind tunnels. During the 1960s and 1970s, fire researcher Richard Rothermel developed accurate computer models for explaining how fires spread as wind and topography change. That work came to prominence in Norman Maclean's 1992 book *Young Men and Fire,* an exploration of the 1949 Mann Gulch tragedy, in which 13 firefighters were overrun by a Montana blaze. For years, observers had wondered how young, fit smoke jumpers could be overtaken. Rothermel, who before joining the



DAVID FIERSTEIN

fire lab had worked on nuclear propulsion for aircraft, showed that the firefighters could not possibly have outrun a fire that moved uphill at close to seven miles per hour, faster than the tiring men could travel over the steep, rough terrain.

The Missoula burn chambers remain in regular use for, among other things, testing batches of fire retardant. Studies conducted in conjunction with Underwriters Laboratories have also helped refine a new class of water-based gels that thicken water and help it stick to the roof or the wall of a house threatened by an approaching fire.

But both the chamber and the computer models are limited. The burn chamber, where test samples such as pine needles or excelsior (fine, shredded wood often used as packing material) are ignited, creates fires that are too small to demonstrate the internal dynamics of a conflagration. Current computer models, meanwhile, allow a researcher to change wind conditions—but only those that would exist if no fire were burning. The models cannot, in other words, account for the hellacious winds created by the fire itself. But better models require better data, and forest fires are not willing research subjects.

The Flamethrower Test

THE OBVIOUS SOLUTION: set a fire in a place where fuel loads, topography and weather would just about guarantee that one would break out anyway. In 1997 Latham and his fellow researchers had an opportunity to light their own crown fire in a remote part of Canada's Northwest Territories, near the town of Fort Providence. There, in the International Crown Fire Modeling Experiment, Canadian and U.S. researchers set up nine five-acre plots of black spruce and jack pine, tree species not too dissimilar from lodgepole pine, a tree that fuels severe fires in the U.S. Canadian fire scientists came in before the Montana crews, carefully measuring and weighing the fuels to determine exactly how much combustible material was there—"getting down on their hands and knees to put a ruler into the duff," as Latham put it. The scientists wired the sites with heat sensors, high-speed movie cameras, video cameras, infrared imagers, and smoke-sampling devices.

And then it was show time. The researchers drove around the sites with a flamethrower mounted on the back of a pickup truck. The results were unbelievable. One tract was immolated in minutes. Video images taken from inside the burns show an eerie glow as the fire grows in intensity. Then what look like gleaming grasshoppers bound across the screen, a wave of hot embers thrown off by the flaming trees. These in turn set new, small fires, from which the smoke is at first blown away, then sucked backed into, the approaching fire front. For one burn, firefighters' protective Nomex clothing and silvery fire shelters were placed in the flames' path. They were vaporized.

Latham and his co-workers returned to the Northwest Territories in 1998 and 1999 and are continuing to digest the wealth of data taken from the tests, facts that will aid fire managers in better understanding the intensity inside a big fire and its potential to spread. For instance, the results will improve existing computer models such as Farsite (fire area simulator), a program created by Fire Sciences Lab computer expert Mark A. Finney

THE "NATURAL" SOLUTION

TO HELP FORESTALL today's catastrophic wildfires, some forest experts recommend that we return forests to yesterday's conditions. William Wallace Covington, a forest restoration expert at Northern Arizona University, suggests thinning Western forests from their current density of 200 trees per acre or more to a pre-1880 level of about 30 or 40 trees per acre—the level determined by how many old trees or pre-1880 tree stumps are counted on a given acre. With that goal accomplished, prescribed—or planned—fire or even natural fire could be reintroduced to forests without the risk of a huge blaze. To Covington, the stakes are enormous. "If we don't have this worked out by 2010 or 2015, we're not going to have any natural Ponderosa pine forests left," he says. "We'll have pines, but not 500-year-old ones. And people just won't know what a natural forest [in the West] looks like."

Solutions such as the one Covington proposes are gaining a sympathetic ear in U.S. Forest Service and government circles—in mid-July, Covington testified before a Senate committee on the growing problem of wildfire. But his ideas are not without controversy. Environmental groups are deeply suspicious of activities they view as illegal logging dressed up as "restoration" and suggest that Covington's prescriptions are overly aggressive and even damaging to already fragile forests. Then there is the sheer cost of such an endeavor, which may reach as much as $700 per acre, with perhaps 100 million acres requiring attention.

Although it is more costly per acre to battle a blaze, historically policy leaders have found it easier to do that than to set aside large sums for preventive measures. By late summer, enthusiasm for such fuel-reduction programs was nonetheless building, culminating in a call by President George W. Bush for Congress to relax logging laws in areas prone to devastating wildfires.

It's not completely clear, however, that treating forests in the manner advised by Covington and others will work. To learn more, researchers have set up 13 test sites in fire-prone states including Arizona, Montana and California. At these sites, various fuel-treatment regimes can be implemented—such as using mechanical thinning or controlled fire to remove underbrush—and the results will be measured for seven years or more. "This has just never been done before," says Bob Clark, a fire scientist in Boise, Idaho, who manages the nationwide Joint Fire Science Program that financed the fuel-test sites. "We'll be able to look at everything from how thinning affects arthropods to the plant community to fire." *—D.G.*

THE AUTHOR

DOUGLAS GANTENBEIN is the Seattle correspondent for the *Economist* and also contributes to *Air & Space Smithsonian, Travel and Leisure, Outside, This Old House* and other magazines. He is writing a book about forest fires in the American West.

that takes into account a site's topography, fuels and weather to show how a fire is apt to move across the countryside. The data will be useful to Latham and others in developing fire-specific models that demonstrate more precisely how small changes in a fire might affect its overall behavior, which can guide fire managers as they plot tactics.

The test burns in Canada will also help reduce the risk of fighting fires. Bret Butler, a mechanical engineer at the Fire Sciences Lab, is using the data to delve into the requirements for a "safety zone," where firefighters go if a fire threatens to overrun them. At present, a safety zone's parameters are subjective. Basically, firefighters search for as large an area as possible where rocky, moist or burned-over ground will hold back the fire. But Butler has found that even a slight change in the distance between a firefighter and a fire can greatly influence the chance of survival. A firefighter 1,100 feet from a tall fire front may live, whereas one only 100 feet closer might die. "It's a very nonlinear process," Butler says. "A small change in the distance can change the radiant energy transfer by four or five times."

MARTOS A. HOFFMAN

But increasingly, it is electronic technology that is giving scientists new insight into forest fires. On a hazy day this past May, Fire Sciences Lab researcher Colin C. Hardy and University of Montana forestry professor Lloyd P. Queen were working outside the lab, around what looked like one of the large, flat griddles popular in Korean-style restaurants. Next to it was a wading pool. Both devices—the griddle heated to about 400 degrees F and the pool cooled to about 70 degrees F—were wired to record their precise temperatures. A Cessna, outfitted with infrared sensors, circled overhead, so researchers could compare the temperature picked up from the air with the actual temperature of the pool and griddle.

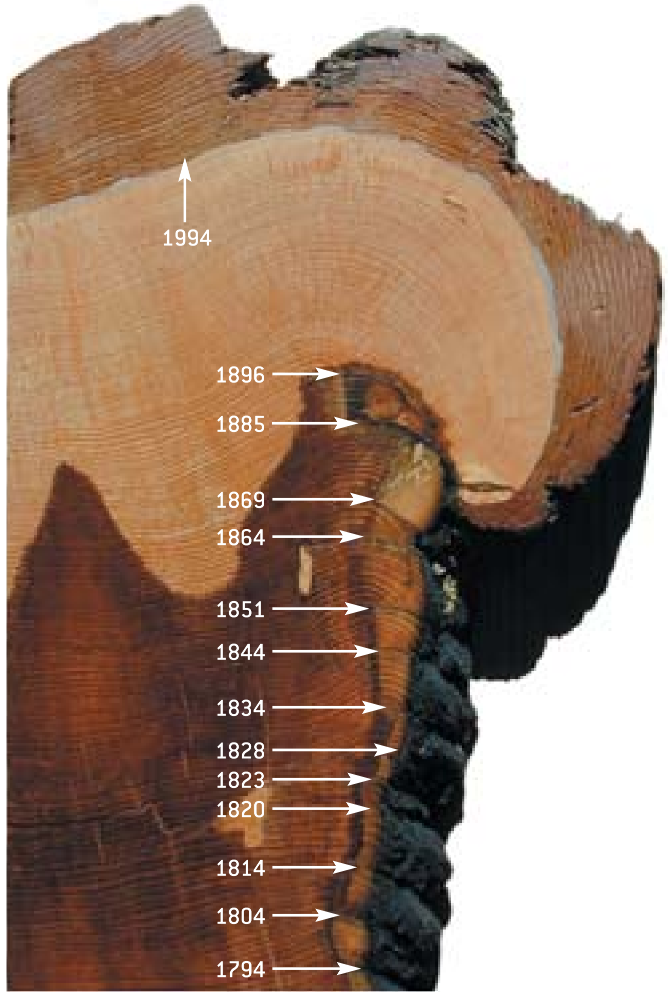
Queen and Hardy would use the airborne infrared sensors over the summer to build an accurate thermal image of fires—how hot they burned and for how long—and compare that with other data about the fuels and forest conditions known to exist at the fire's site. Hardy, a fire-effects specialist, also hoped to use data gathered from the air to determine whether a given fire is hot enough to kill trees or merely scorch their needles, information that forest managers may use to decide whether to salvage damaged trees or allow them to recover.

Predicting the Flames

REMOTE SENSING—the use of infrared scanners or devices such as lidar (light detection and ranging) to study a fire's intensity and emissions from a distance—is fast coming into its own. Such applications are not new; for several years, infrared images have helped fire managers peer through the smoke and haze of a big fire to pinpoint its location and size. Satellite imagery has also helped determine these factors. "But," Queen notes, "those methods basically give us pictures, not real data. What we're trying to do is say more than 'Here is a fire.' We want to understand its thermal characteristics—therefore, 'This is the effect it might have.'"

That will be important in taking a step toward what fire scientists view as their current holy grail: knowing what a fire will burn before the fire burns it. Atop the fire lab sits a white dome, installed early this year. Inside, a satellite dish tracks NASA's Terra satellite, launched in December 1999 as part of a 15-year project to collect data about Earth [see "Monitoring Earth's Vital Signs," by Michael D. King and David D. Herring; SCIENTIFIC AMERICAN, April 2000].

Terra makes three orbits every day over North America. With each pass, its MODIS (moderate resolution imaging spectroradiometer) unit scans the planet's surface, gauging such features as snowfall or melt, cloud cover, and the spread of green grass each spring. With its fairly rough, 10-meter resolution, MODIS also picks up hot spots (fires) and relays that information to the dish atop the burn tower and next to an array of servers in a room on the fire lab's second floor. There, within minutes of the satellite's pass, researchers can spot a fire that has devel-



TWO-INCH-THICK BARK allows Ponderosa pines, a dominant Western species, to survive small or moderate-size fires (*left*). Growth rings in a stump (*above*) record the historical occurrence of such fires every decade or so.

CHRIS BAISAN *University of Arizona*

oped since the satellite was last overhead.

The MODIS findings may allow scientists to combine news that a fire exists with data about the fuels around the fire, the terrain across which it is burning and what the weather will do. With these facts, fire scientists could tell managers within hours of a blaze's start what it will do, how much damage it will cause if left to its own devices and where it might make the most sense to try to stop it. Or the scientists could determine that a fire may actually benefit an area that is in need of one yet is not so overgrown that a burn would become catastrophic. At least that is the tantalizing prospect. Whether fire managers and the politicians to whom they answer will ever feel completely comfortable allowing a computer model to make the call remains to be seen.

Uncertain as well is whether the West's fire problem can be solved with human intervention. To simply let fires burn is intolerable: the environmental havoc they cause is tremendous, endangering animals such as the Mexican spotted owl and bighorn sheep in addition to threatening the vast Ponderosa pine ecosystem. Then there is the human cost, as people's lives are disrupted and property destroyed or damaged. But no amount of dollars or firefighters can stop a big fire once it gets moving, making the summer's showy firefighting efforts increasingly fruitless. One solution offered is to turn back the clock on forests, re-creating woodlands that look like they did before European settlers brought sheep and the forest service brought firefighting hotshot crews [*see box on page 87*].

In any event, fires will threaten the West for years to come, with climate change perhaps influencing them in ways not yet foreseen. But science is working hard to understand the danger fires pose and to help mitigate their impact. SA

A broadcast version of this article will air October 22 on *National Geographic Today,* a program on the National Geographic Channel. Please check your local listings.

MORE TO EXPLORE

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Year of the Fires: The Story of the Great Fires of 1910. Stephen J. Pyne. Viking Press, 2001.

Flames in Our Forest: Disaster or Renewal? Stephen F. Arno and Steven Allison-Bunnell. Island Press, 2002.

National Interagency Fire Center: **www.nifc.gov/**

Joint Fire Science Program: **www.nifc.gov/joint_fire_sci/jointfiresci.html**

Fire Sciences Laboratory: **www.firelab.org**

WEATHER RADAR

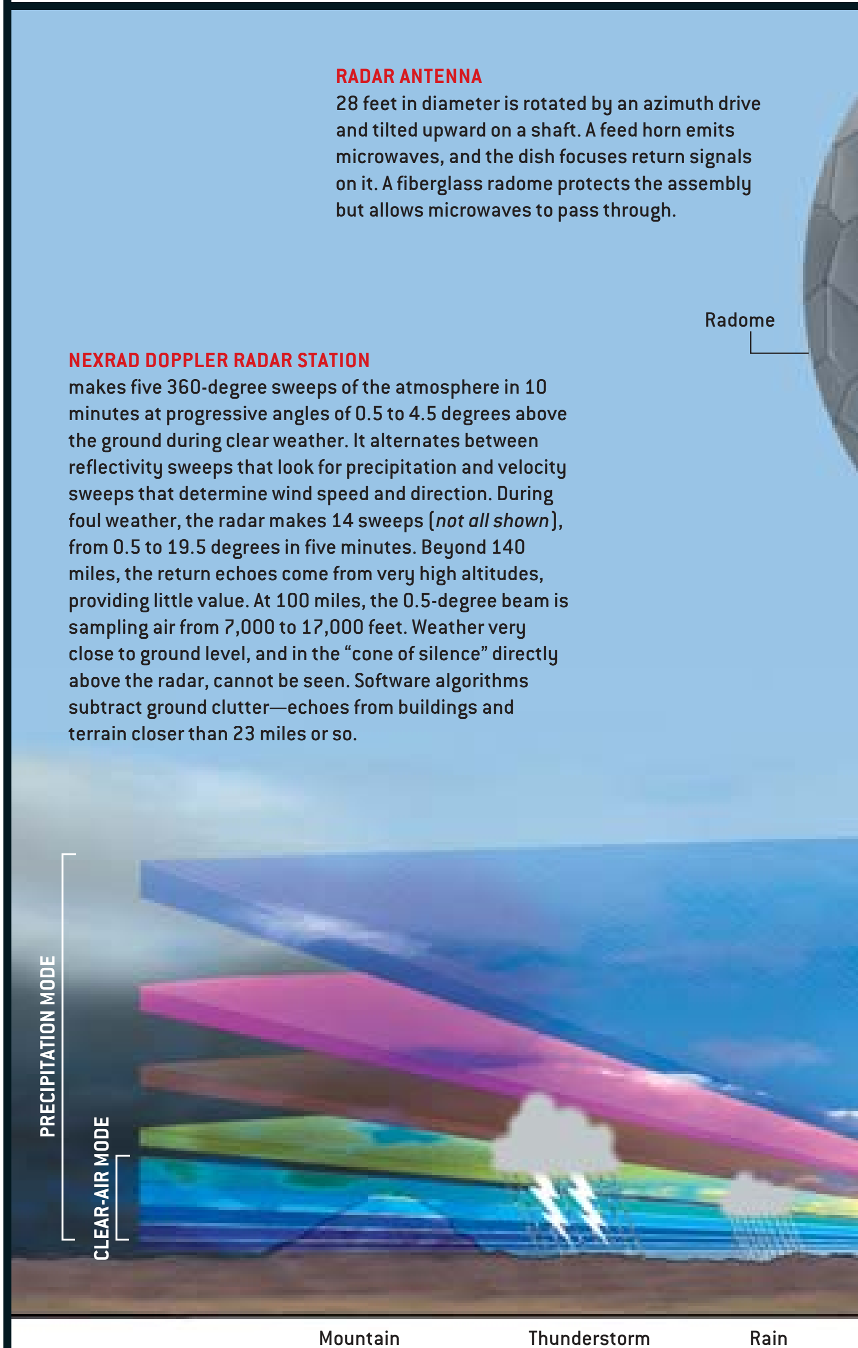
See the Wind

Watch your television news during stormy weather, and you'll most likely see maps pinpointing the heavy rain or snow neighborhood by neighborhood, as the meteorologist brags about his TV station's Doppler radar. The technology is indeed a leap ahead of conventional radar, and upgrades are soon to come.

Radars transmit microwaves that reflect off water, ice and other particles in the atmosphere. They can therefore indicate only the distance and size of particles such as raindrops. But Doppler radar can also measure the speed and direction in which the particles are moving, giving a picture of wind flow at various elevations. Today a national network of 158 Doppler radars known as Nexrad, erected in the 1990s by the National Oceanic and Atmospheric Administration, enables NOAA's National Weather Service meteorologists to issue hazardous weather warnings with far greater accuracy than before. Most local meteorologists subscribe to commercial services that interpret Nexrad's free data, allowing them to see the movement of thunderstorms and tornadoes almost in real time, previously impossible.

Doppler weather radars do have limitations. Because the beams are aimed slightly upward to scan the surrounding troposphere, they miss precipitation and wind very close to the ground. Also, the beams can determine only the horizontal width of particles they intercept because they transmit only horizontally polarized waves (the electric field lies in the horizontal plane). Engineers at the National Severe Storms Laboratory in Norman, Okla., are developing polarimetric radars that send vertically polarized waves as well, to gauge the vertical dimension of particles. The dual measurements will provide superior information on the size, shape and density of precipitation, ice particles and clouds, thereby allowing forecasters to better determine rain and snow rates. NOAA plans to install the technology in five to 10 years.

The storm lab is also experimenting with the U.S. Navy's phased array radar, the most advanced way for ships to detect enemy vessels. With multiple beams and frequencies, the radar could reduce a Nexrad station's scan time of storms from five minutes to one minute. *—Mark Fischetti*



RADAR ANTENNA
28 feet in diameter is rotated by an azimuth drive and tilted upward on a shaft. A feed horn emits microwaves, and the dish focuses return signals on it. A fiberglass radome protects the assembly but allows microwaves to pass through.

NEXRAD DOPPLER RADAR STATION
makes five 360-degree sweeps of the atmosphere in 10 minutes at progressive angles of 0.5 to 4.5 degrees above the ground during clear weather. It alternates between reflectivity sweeps that look for precipitation and velocity sweeps that determine wind speed and direction. During foul weather, the radar makes 14 sweeps (*not all shown*), from 0.5 to 19.5 degrees in five minutes. Beyond 140 miles, the return echoes come from very high altitudes, providing little value. At 100 miles, the 0.5-degree beam is sampling air from 7,000 to 17,000 feet. Weather very close to ground level, and in the "cone of silence" directly above the radar, cannot be seen. Software algorithms subtract ground clutter—echoes from buildings and terrain closer than 23 miles or so.

DANIELS & DANIELS

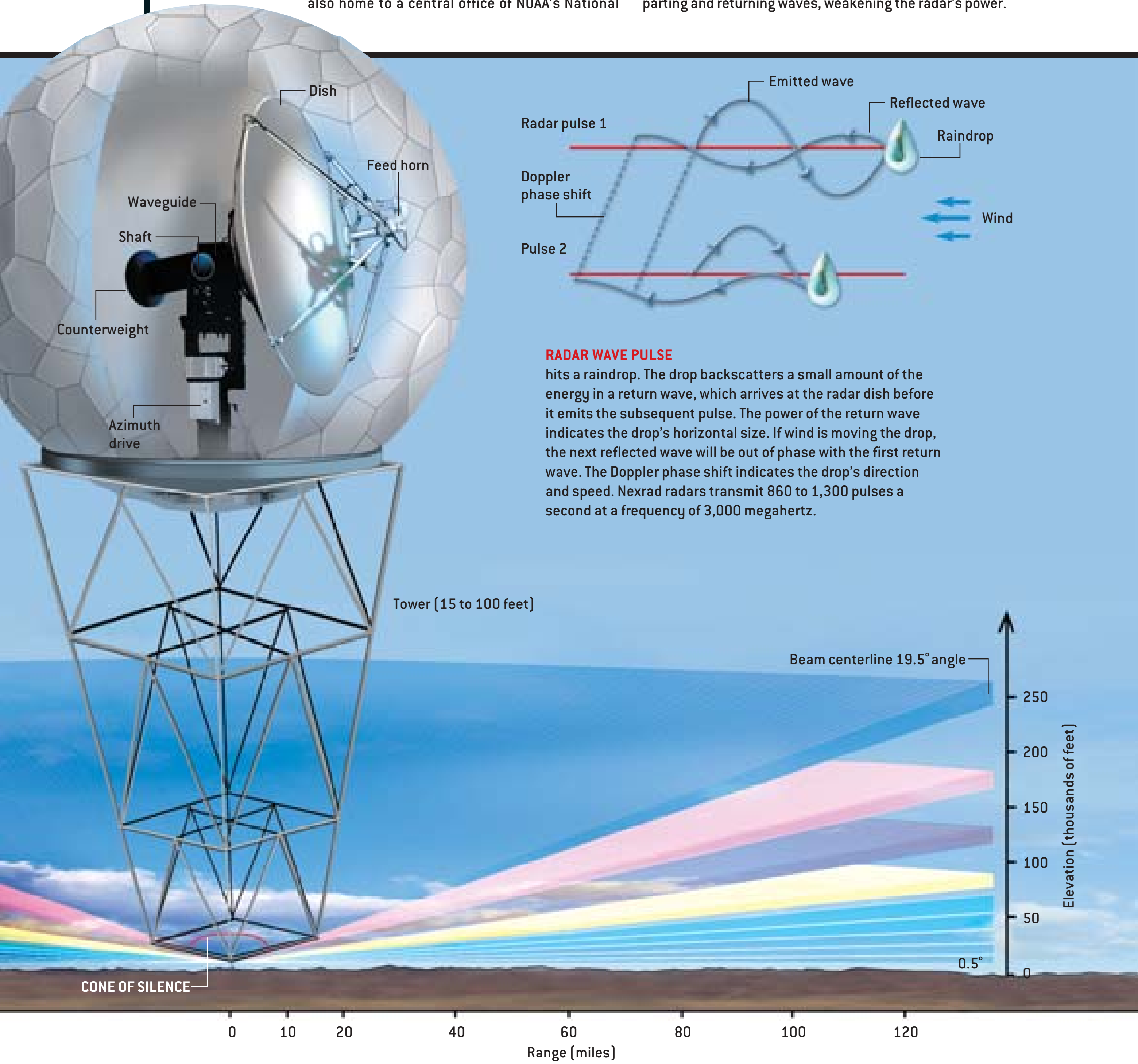
This month's topic was suggested by reader Ronald Gripshover.

DID YOU KNOW . . .

➤ THE BIRDS AND THE BEES: Nexrad Doppler radars are sensitive enough to distinguish a single bee as far as 18 miles downrange, according to National Weather Service radar trainer Jami Boettcher. In summer, large concentrations of bugs can collect along an advancing cold front and produce readings that mimic precipitation. In April and September, echoes from migrating birds following prevailing winds are so strong and sustained that they falsely add to the perceived wind speed. Forecasters are taught to compensate for such anomalies.

➤ STORMIN' NORMAN: Doppler radar was developed at NOAA's National Severe Storms Laboratory in Norman, Okla. The prairie town is also home to a central office of NOAA's National Weather Service, the primary source of weather data, forecasts and warnings in the U.S.; the service's Warning Decision Training Branch, which trains weather service forecasters; and NOAA's Radar Operations Center, which provides centralized meteorological, software and engineering support for all Nexrad radars.

➤ RADOME: Look carefully, and you'll notice that the geodesic radome that surrounds a Doppler radar dish is anything but regular. The fiberglass panels are irregularly shaped, and each one has a slightly different curvature. If the panels were all similar and abutted smoothly, as on a soccer ball, they would cause coherent scattering of the departing and returning waves, weakening the radar's power.



RADAR WAVE PULSE hits a raindrop. The drop backscatters a small amount of the energy in a return wave, which arrives at the radar dish before it emits the subsequent pulse. The power of the return wave indicates the drop's horizontal size. If wind is moving the drop, the next reflected wave will be out of phase with the first return wave. The Doppler phase shift indicates the drop's direction and speed. Nexrad radars transmit 860 to 1,300 pulses a second at a frequency of 3,000 megahertz.

Have an idea for a future column? Send it to workingknowledge@sciam.com

A Search for All Species

TRACKING DOWN EVERY FORM OF LIFE IN THE GREAT SMOKY MOUNTAINS BY W. WAYT GIBBS

Sweat trickles down my back as I traipse through a meadow of tall grass, ironweed, asters—and lots of poison ivy. I'm beginning to wish that I had joined the llama expedition up to one of the cool, bald peaks in the Great Smoky Mountains National Park rather than helping scientist David L. Wagner hunt for moths down here in the valley. Then I notice a little flutter of light.

I swing an open fist, clench, and feel the tickle of confirmation in my palm—my first catch. Like a spaniel, I trot proudly over to Wagner, who is whipping a fine white net through the ironweed. As I slowly uncurl my fingers, he bends to look at the pea-size moth paralyzed with fear in the center of my hand.

MOTH MORGUE was staffed with some of the top lepidopterists in the U.S. The experts and volunteers sorted through thousands of moths and butterflies to search for new and rare species.

Is it a new species for the park? Perhaps even one unknown to science? Wagner, an entomologist from the University of Connecticut and self-described "mother superior" on the park's 24-hour Lepidoptera Quest in June, gently opens the insect's translucent yellow wings. "Ah, that's a violet-feeder, *Eubaphe mendica,*" he says. It's not an unexpected sight, but it is the first of its kind seen today.

And the hunt has just begun. I am but one of two dozen volunteers and Wagner one of 30 scientists who are collecting and identifying as many species of moth and butterfly as we can find in the park by three o'clock tomorrow afternoon.

This event, too, is only one of an ongoing series of "bio-quests" that aim to assemble a complete and scientifically rigorous database of the species living in the largest national park in the eastern U.S. Discover Life in America, a nonprofit organization that is coordinating the All Taxa Biodiversity Inventory (ATBI), has already conducted a "beetle blitz," a "fern foray" and a "snail search," among others. It may take more than a decade to finish the survey, the most ambitious ever undertaken. But two years into the project, scientists and volunteers have tallied 2,163 species not previously known to live in the Smokies. Some 292 of those species are new to science altogether.

This morning Wagner organized the novice recruits with dispatch. To a father and son he handed sticks and canvas sheets for collecting caterpillars. "Find a good tree or shrub and beat the limbs for half an hour," Wagner said. "Currant, witch hazel, hackberry: those are all good. And oak—that's type O blood for caterpillars," he added. "In the summer an oak here can support 400 species."

Photographer Kevin FitzPatrick, artist Nancy Lowe and I followed Wagner to the meadow at Cades Cove. We are squinting in the sunshine to find "microleps," some of the most primitive and tiny species of moths, when a man in a "Lepidoptera 2001" T-shirt emerges from the forest and joins us in the meadow. It is biologist Brian G. Scholtens of the College of Charleston.

"We already got at least two new species for the park," Scholtens says. "I got a fresh diana, just immaculate."

"No way!" Wagner responds, his eyes widening. *Speyeria diana* is a beautiful, rare and threatened butterfly. The wings of female dianas are deep blue or black with spots the color of the moon and the sky.

PHOTOGRAPHS BY REBECCA P. SCHIFLETT

That evening, well after dark, I drive over to the visitors center. An eerie pale glow emanates from the edge of the woods. Michael W. Nelson, a graduate student of Wagner's, is standing next to a sheet that hangs down from a clothesline in front of a brilliant mercury vapor lamp. So many hundreds of moths and other bugs cling to the white sheet that it looks gray. I admire a luna moth as big as my hand. Nelson flips it over to reveal an abdomen swollen with eggs. "She'd probably be out laying her eggs right now if she weren't staring at this lamp," he says.

Quest participants have set 40 light traps tonight in meadows and woods throughout the park. Most of the devices are simple—such as a blacklight and funnel above a bucket of cyanide gas—but effective. "That kind of trap typically catches a few hundred moths in a night," Nelson says. "So we could easily have tens of thousands of specimens to sort through tomorrow."

As I ponder that image, we are startled by a thumping patter behind us. We spin around to see a coyote in hot pursuit of a panicked rabbit. The rabbit zips by, but the coyote balks at the sight of us and skulks off, deprived of his dinner.

We didn't mean to interrupt this natural drama, but human presence has unintended consequences. With more than nine million vehicle-propelled visitors to the park every year, ozone here often rises to dangerous levels for people and vegetation alike. Acid rain has lowered the pH of high-elevation streams, pushing trout out of their habitat. Chronic haze has made the Smoky Mountains smokier.

Once biologists have a baseline inventory of the park's biodiversity, it will be much easier to figure out how pollution, climate change and other human influences are affecting the Smokies. And because the park encloses five distinct kinds of forest, many of the lessons learned here can be applied to the entire eastern U.S. north of Florida.

In the morning the sorting room buzzes with activity. Pairs of scientists sit at long tables. Some peer through microscopes at microleps; others hold up colorful specimens with forceps to debate just what they are. As Nelson predicted, moths are piled up by the thousands. Volunteers dump out bucket traps and sift the lepidopterans from the many other kinds of bugs. A young woman takes especially well preserved specimens that have been identified and pins them in trays with labels noting the date and location of their capture. A young man next to her enters the information into a computer database.

Nelson leans bleary-eyed over a paper plate piled high with moth bodies.

"I was up until four last night with the traps," he says. "I'm working on about one hour's sleep." Wagner stayed up all night hunting leafminers with flashlights, but he bounces around the room taking $5 bets on the number of species the quest collected altogether.

"I'm running on adrenaline," Wagner says excitedly. "This is the greatest number of moths any of us has ever seen." One live moth, having miraculously escaped from a gas chamber, flits about in confusion for several minutes until someone captures it, opens a door and lets it go.

WHAT IS IT? The bio-quests uncover forms of life—such as the luna, carpenterworm and tuliptree moths above—that we rarely see.

Shortly after three o'clock, Wagner rises from his chair. "Okay, let's tally it all up," he announces. As the lead specialist for each family of Lepidoptera calls out the results of their survey, Wagner writes the figures on a whiteboard. Tineoids: 13 species, at least five never seen before and 10 new to the U.S. Noctuoidea: 232 species, including nine new records for the park. And on down the list, to a grand total of 793 species.

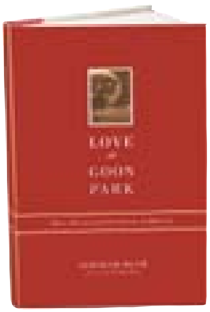
Weeks later, after the 24-hour haul has been completely sorted and examined, the final total is put at 860 species of moth and butterfly, including 133 park records and 51 newly discovered species. Considering how little money and time were spent on the quest and how much fun the participants had, it is a remarkable achievement. Officials at other national parks are already talking about copying the ATBI program.

Discover Life in America organizes about half a dozen ATBI bio-quests every year from March through October, most of them in June and July. Volunteers and school groups are welcome to participate and are encouraged to attend one of the training sessions, held every spring in Tennessee and North Carolina. More information is posted online at www.discoverlife.org; to get involved, contact Jeanie Hilten, the ATBI volunteer coordinator, at 865-430-4752. SA

PHOTOGRAPHS BY REBECCA P. SCHIFLETT

The Loveless Man . . .

. . . WHO INVENTED THE SCIENCE OF LOVE **BY ROBERT SAPOLSKY**



COURTESY OF PERSEUS PUBLISHING

LOVE AT GOON PARK: HARRY HARLOW AND THE SCIENCE OF AFFECTION
by Deborah Blum
Perseus Publishing, 2002 ($26)

It's one of the iconic images in psychology. Two "surrogate" primate mothers sit side by side. One is made of chicken wire with a milk bottle sticking out of the torso. The other, milkless, is swathed in terry cloth. And there is the infant rhesus monkey, clinging like mad, squeezing every bit of comfort and attachment it can out of the cloth mother.

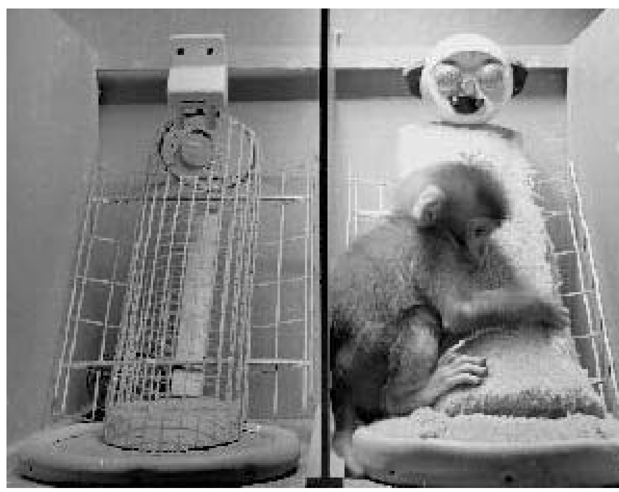
The work was revolutionary: it overturned remarkably damaging dogma about love and attachment in the 1940s and 1950s, and it was carried out by a contrarian psychologist with a troubled personal life, one in ironic contrast to what his science was demonstrating. In her 1994 book, *The Monkey Wars,* Pulitzer Prize–winning journalist Deborah Blum superbly balanced opposing views of the incendiary issue of primate vivisection. In *Love at Goon Park,* Blum does an equally skillful job balancing the pictures of that psychologist, Harry Harlow, as troubled soul and brutal abuser of his experimental subjects versus helper of humankind through brilliant science.

Harlow's career, mostly at the University of Wisconsin, had a unifying theme—tilting against the then dominant paradigm in psychology, the ideology of mindless behaviorism. In the first of three phases of his work, he demolished the behaviorist view that animal learning is rudimentary and solely motivated by reward. Instead Harlow showed animals strategizing, learning to learn, demonstrating curiosity and mastering tasks for their own sake, rather than for food reward.

Nice, and preparatory for the brilliant second phase of his work. Why do infants become attached to their mothers? Savants agreed: because Mom supplies food. For behaviorists, this was obvious: attachment was thought to arise solely from the positive reinforcement of food. For Freudians, it was also obvious: infants were thought to lack the "ego development" to form a relationship with anything or anyone other than Mom's breast. For physicians, it was obvious and convenient: no need for mothers to visit hospitalized infants; anyone with a bottle would supply attachment needs. No need to worry about preemies kept antiseptically isolated in incubators: regular feeding suffices for human contact. No need for children in orphanages to be touched, held, noted as individuals. What's love got to do with healthy development?

Everything, and when some scientists suggested this in the 1940s and 1950s, Harlow's study of surrogates was the irrefutable, scientific battering ram that they cited. Infant monkeys chose the cloth mothers. Attachment had nothing to do with having your caloric needs met.

Blum does the excellent, requisite historian's job, illuminating a period whose zeitgeist differs from ours. Once, all experts really believed that affection not only wasn't needed for development but was a squishy, messy thing that kept kids from becoming upright, independent citizens. This view dominated despite the evidence of its being wrong, even fatally so. And that we now regard that view as ludicrous reflects the impact of those surrogate mothers.



WIRE AND CLOTH surrogate mothers for infant rhesus monkey in Harry Harlow's famous experiments on attachment and love.

But there is more to mothering than being warm terry cloth: the cloth mother–reared monkeys matured into social cripples. This prompted the dark, last phase of Harlow's work. What is missing in a monkey raised with a cloth mother? In one raised with a living mother but no peers? In complete isolation? Can "therapists" (younger, unthreatening and highly socialized monkeys) repair the broken animal produced by isolation? What kind of mothers do isolated monkeys become (are they often violently abusive)? This period produced a horrific finding: if an infant is punished for hugging a surrogate mother (with, for example, a jet of air shot from the surrogate's torso), the infant hugs more, not less. This violated every tenet of behaviorist reinforcement theory but is obvious to anyone who loves the wrong person.

These were brutal studies, animals shattered by isolation. They made Harlow a pariah in many circles. Useful science was produced (though not nearly enough to justify the extent of what was done, in my opinion). Animals suffered unspeakably. And Blum documents Harlow's personal demons during this period: alcoholism, estrangement from his children, depression requiring hospitalization and electroconvulsive therapy.

It's an irresistible story told exceedingly well. I do have a few obligatory minor complaints. Good-guy scientists are always "passionate," which, though probably true, gets thin; individuals, along with their academic pedigrees and current positions, are introduced repeatedly. And one wishes for more insight into Harlow's childhood, beyond his mother's being the cold, chicken-wire type.

Blum makes two important points. First, that part of the problem with Harlow is that he did ethically troubling work without seeming ethically troubled. He responded to feminist and animal-rights critiques with caustic hostility, dinosaurish misogyny and flaunted indifference to his animals. His writing was savage and crude: I recall being moved to tears and outrage by those papers as a student. (An example: females who were socially isolated as infants were inept at mating. How to get them pregnant, to study their subsequent maternal behavior? Harlow wrote, proudly, of his "rape rack.")

Blum's other point is deep and eloquent: Harlow's pioneering work was required to demonstrate the unethical nature of that work. But wasn't it obvious before? If you prick us, do we not bleed? If you socially isolate us as infants, do we not suffer? Few in the know thought so. The main point of Harlow's work was not teaching what we might now assume incorrectly to have been obvious then—that if you isolate an infant monkey, she saddens and suffers for long after. It was the utterly novel fact that if you do the same to a human infant, the same occurs. SA

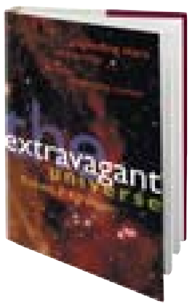
Robert Sapolsky, author of Why Zebras Don't Get Ulcers *and* A Primate's Memoir, *is professor of biology at Stanford University.*

THE EDITORS **RECOMMEND**

THE EXTRAVAGANT UNIVERSE: EXPLODING STARS, DARK ENERGY, AND THE ACCELERATING COSMOS

by Robert P. Kirshner. Princeton University Press, Princeton, N.J., 2002 ($29.95)

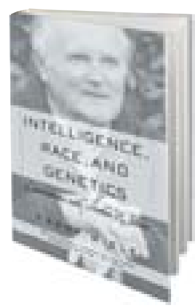
Astronomer Kirshner, the Clowes Professor of Science at Harvard University and head of the optical and infrared division at the Harvard-Smithsonian Center for Astrophysics, is part of a team studying supernovae that, by their apparent brightness, make it possible to measure distances in the universe. "The observations of distant supernovae show that we live in a universe that is not static as Einstein thought, and not just expanding as Hubble showed, but accelerating! We attribute this increase in expansion over time to a dark energy with an outward-pushing pressure.... Dark energy makes up the missing component of mass-energy that theorists have sought, reconciles the ages of objects with the present expansion rate of the universe, and complements new measurements of the lingering glow of the Big Bang itself to make a neat and surprising picture for the contents of the universe." It is an extravagant universe: "It has neutrinos as hot dark matter; something unknown as cold dark matter; inflation in the first 10^{-35} second after the Big Bang; and acceleration by dark energy now." Kirshner makes the story sing and the concepts of astronomy vivid.



INTELLIGENCE, RACE, AND GENETICS: CONVERSATIONS WITH ARTHUR R. JENSEN

by Frank Miele. Westview Press, Boulder, Colo., 2002 ($26)

Arthur R. Jensen is the psychologist who set off an enduring controversy with his 1969 article in the *Harvard Educational Review* holding that an individual's IQ is largely attributed to heredity, including racial heritage, and that efforts to boost IQ educationally do not achieve much. Miele, senior editor of *Skeptic* magazine, set out to "skeptically cross-examine" Jensen on his views. The questions and answers traveled by e-mail, but they read like a conversation. Jensen, now professor emeritus of educational psychology at the University of California at Berkeley, holds that the scientific evidence is stronger now than it was in 1969 that IQ is highly genetic, that race is a biological reality rather than a social construct, and that the cause of the 15-point average IQ difference between blacks and whites in the U.S. is partly genetic. Miele hopes the exchange will enable the reader "to decide for yourself whether Jensenism represents one man's search for provisional, not metaphysical, truth through the continuous and vigorous application of the methods of science ... or a dangerous diversion back down a blind alley of old and disproven ideas, deceptively dressed up in modern scientific jargon."



All the books reviewed are available for purchase through www.sciam.com

Perfect Billiards

BY DENNIS E. SHASHA

Imagine that you are playing pocket billiards on a pool table that is three meters long and one meter wide. The table has been engineered to perfection: when a ball banks against a cushion, the angle of incidence is exactly equal to the angle of reflection. Furthermore, the table is oriented so that its short sides run north-south and its long sides east-west. The position of each ball is denoted as (x, y), where x is the distance east from the table's southwest corner and y is the distance north from the same corner. The table has a pocket in each corner but no side pockets.

Suppose you want to hit a ball at position (2, 0) into the southwest pocket—that is, position (0, 0)—but another ball is blocking a direct shot. The simplest alternative would be to bank once against the opposite side cushion, as shown in illustration *a*. Just hit the ball northwest (a slope of –1), and it will ricochet off position (1, 1) and glide into the pocket. It's also easy to see how to make the shot with three reflections against the cushions. Hit the ball north by northwest (a slope of –2), as shown in illustration *b*. The ball will bounce off positions ($1\frac{1}{2}$, 1), (1, 0) and ($\frac{1}{2}$, 1) before dropping into the hole.

But what about making the shot by banking the ball exactly twice against the cushions? Suppose that someone is willing to wager a sizable sum that you can't pull off this trick. At what slope should you hit the ball? SA

Dennis E. Shasha is professor of computer science at the Courant Institute of New York University. His latest puzzle book is Dr. Ecco's Cyberpuzzles *(W. W. Norton, 2002).*

Answer to Last Month's Puzzle

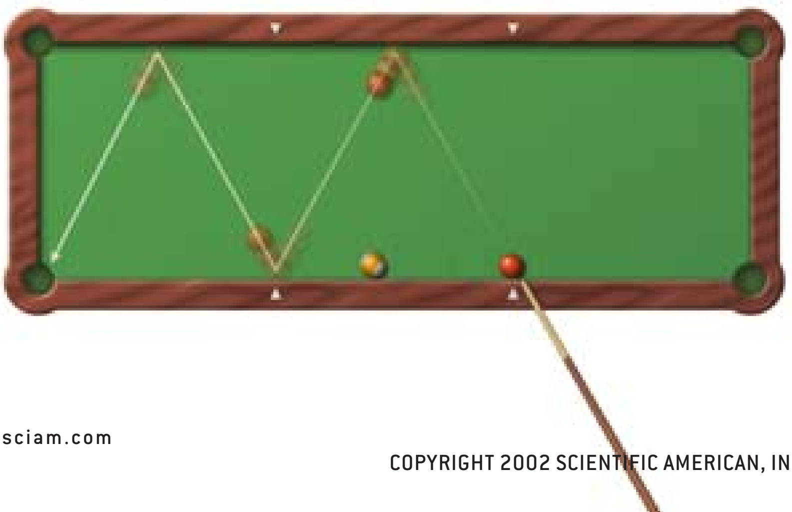
The spy generates two large, random prime numbers and gives the border guards the product of the two numbers. On his return, the spy gives a guard the two prime numbers; the guard multiplies them and sees that the product matches the product he was given earlier. Note that even if the guard reveals the product, it would be impractical for an adversary to discover the two primes—if factoring is truly hard. For a full explanation, visit www.sciam.com

Web Solution

For a peek at the answer to this month's problem, visit www.sciam.com

a

b



SARA CHEN

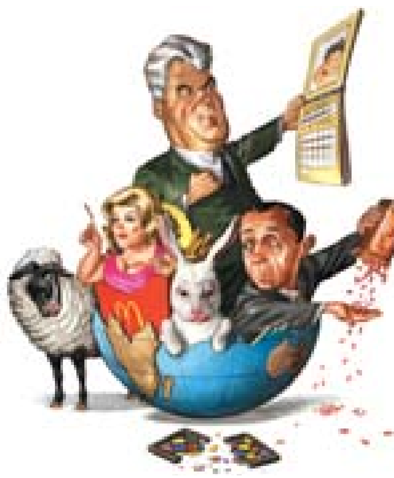
Aye (Caramba) on the News

FROM AROUND THE WORLD, ALL THE STUFF THAT'S FIT TO PRINT, ON THIS PAGE, ANYWAY **BY STEVE MIRSKY**

I have been scratching my head a lot lately, and no, I haven't gotten any splinters. The scratching was a natural reaction to various items that found their way to my desk. Join me for a brief tour of these highlights, or possibly lowlights, or maybe just lights, from the world of recent science and medical news.

■ **Stages of Man Revised.** The Associated Press reported in August that Saparmurat Niyazov, the president of Turkmenistan, issued a decree that officially makes adolescence last until age 25 and postpones old age until 85. (In the U.S., of course, adolescence lasts indefinitely, and old age is simply no longer done.) What's particularly interesting about Niyazov's gerontological edict, however, is that the World Health Organization lists the average life expectancy as 60 for Turkmen men and 65 for Turkmen women (or Turkwomen, or possibly Turkpersons). The new decree means that, tragically, they all die young. By the way, earlier in August, Niyazov renamed January in honor of himself. He also renamed April "Mother," which some commentators said was to honor his own mother. Others said it had something to do with T. S. Eliot's notion about April being the cruelest month.

■ **Hospitals Harmful to Your Health.** The *Archives of Internal Medicine* published a study in September that tracked drug administration in 36 hospitals and nursing homes in Colorado and Georgia. The report showed that in your average 300-patient institution, some kind of error was involved in one out of every five instances that a patient was given a drug. The most frequent errors were giving the drug at the wrong time (43 percent), not giving it at all (30 percent), improper dosage (17 percent) and unauthorized dispensation (4 percent). "Seven percent of the errors were judged potential adverse drug events," according to the study, which translates to "seven percent of the time, the errors were really, really bad."



That figure further translates to more than 40 really, really bad errors every day at that average 300-bed facility. When I shared this statistic with a friend who works at a medical school, she said, "Forty? That's it?" After all, previous studies have shown that fully 50 percent of all physicians graduate in the bottom half of their medical school classes. And that's at the *good* schools. As for the two states in the *Archives* research, Colorado had higher error rates than Georgia. This surprised me, as I had recently seen graphic footage of a leg amputation that was performed with no anesthesia whatsoever in an Atlanta hospital. Admittedly, I was watching *Gone with the Wind.*

■ **Breakthrough Bunny Burrowing.** Reuters reported in August that a major archaeological find was made in central England by "an intrepid bunch of rabbits." The bunnies, while "burrowing into an unremarkable grassy hump," unearthed valuable pieces of a window that once hung in a 14th-century manor house. According to the article, the house was known to have been torn down in the 15th century when the owners built a larger home and the old one blocked their view, perhaps of a really terrific grassy hump. Strangely, I found this story in the politics section of a Miami Web site. Maybe this placement was a knee-jerk response, with the Florida editors assuming that anything involving buried stuff getting dug up has to be politics.

■ **Bottoms Up!** A September press release from Duke University revealed that "scientists have discovered an elusive, mutated gene, named for the Greek goddess Aphrodite Kallipygos, that causes certain sheep to have unusually big and muscular bottoms." Although the sheep might have preferred to be big*horn,* the finding could shed light on fat metabolism, muscle development and Anna Nicole Smith.

■ **Oil Change.** McDonald's announced in September that it would change its frying oil, cutting the amount of trans-fatty acids in its french fries almost in half. The move could have a significant impact on fat metabolism, muscle development and Anna Nicole Smith, who might be interested in meeting a wealthy, older Turkmen man. SA

ILLUSTRATION BY MATT COLLINS; PHOTOGRAPH BY FRANK VERONSKY

ASK THE EXPERTS

Why do we yawn when we are tired? And why does it seem to be contagious?

—A. Wong, Berkeley, Calif.

Mark A. W. Andrews, associate professor of physiology and director of the independent study program at the Lake Erie College of Osteopathic Medicine, provides an explanation:

Yawning appears to be not only a sign of tiredness but also a much more general sign of changing conditions within the body. Studies have shown that we yawn when we are fatigued, as well as when we are awakening and during other times when our state of alertness is changing.

Yawning is characterized by a single deep inhalation (with the mouth open) and stretching of the muscles of the jaw and trunk. It occurs in many animals and involves interactions between the unconscious brain and the body.

For years it was thought that yawns served to bring in more air when low oxygen levels were sensed in the lungs by nearby tissue. We now know, however, that the lungs do not necessarily detect an oxygen deficit. Moreover, fetuses yawn in utero, even though their lungs are not yet ventilated. In addition, different regions of the brain control yawning and breathing. Low oxygen levels in the paraventricular nucleus (PVN) of the hypothalamus of the brain can induce yawning. Another hypothesis is that we yawn because we are tired or bored. But this, too, is probably not the case—the PVN also plays a role in penile erection, an event not typically associated with boredom.

SARA CHEN

It does appear that the PVN of the hypothalamus is, among other things, the "yawning center" of the brain. It contains a number of chemical messengers that can induce yawns, including dopamine, glycine, oxytocin and adrenocorticotropic hormone (ACTH). ACTH, for one, surges at night and prior to awakening and elicits yawning and stretching in humans. Yawning also seems to require production of nitric oxide by specific neurons in the PVN. Once stimulated, the cells of the PVN activate cells of the brain stem and/or hippocampus, causing yawning. Yawning likewise appears to have a feedback component: if you stifle or prevent a yawn, the process is somewhat unsatisfying.

You are correct that yawns are contagious. Seeing, hearing or thinking about yawning can trigger the event, but there is little understanding of why. Many theories have been presented over the years. Some evidence suggests that yawning is a means of communicating changing environmental or internal body conditions to others, possibly as a way to synchronize behavior. If this is the case, yawning in humans is most likely a vestigial mechanism that has lost its significance.

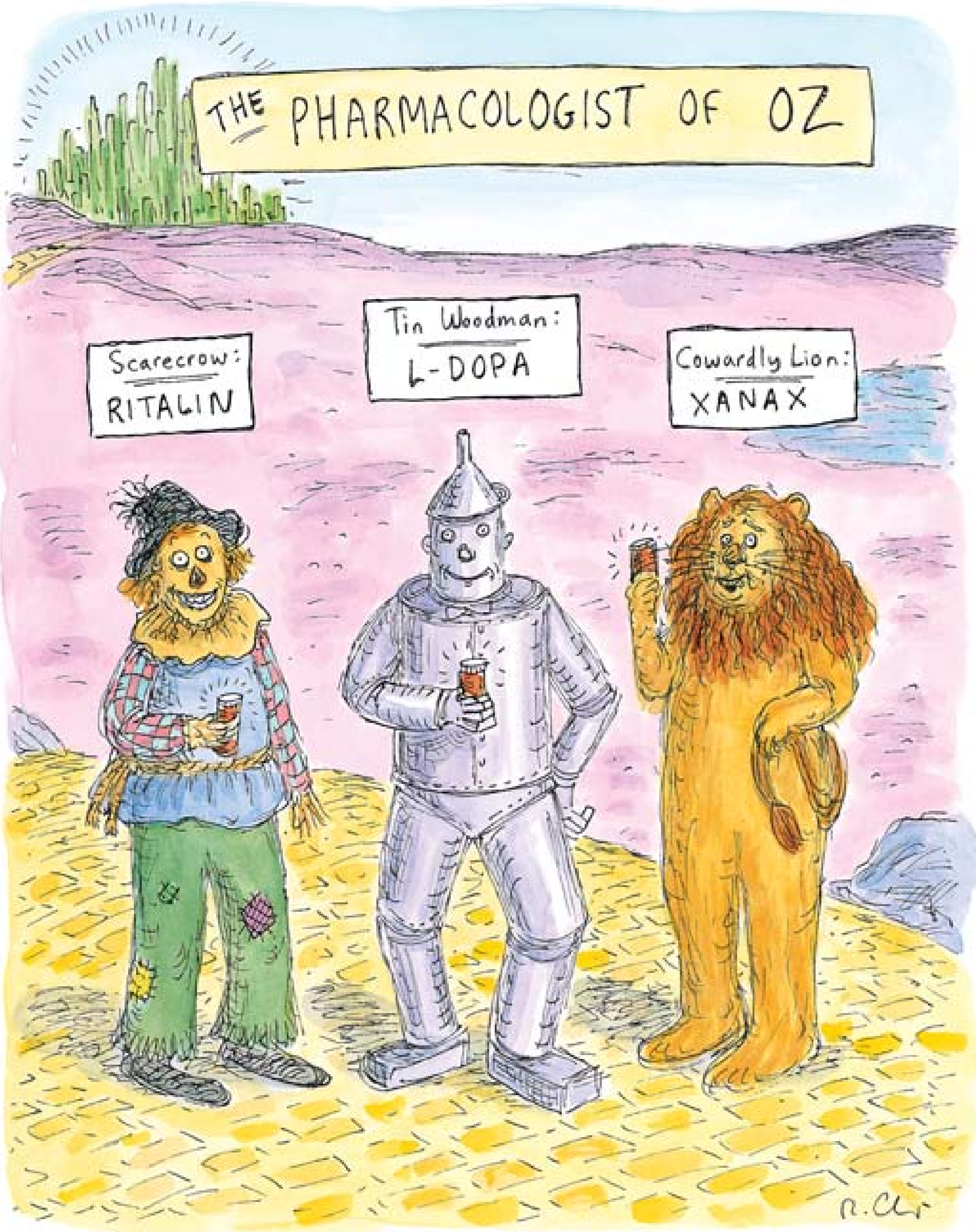
Why do stars twinkle?

John A. Graham, an astronomer at the Carnegie Institution in Washington, D.C., offers an answer:

Have you ever noticed how a coin at the bottom of a swimming pool seems to wobble? This occurs because the water in the pool bends the path of light reflected from the coin. Similarly, stars twinkle because their light has to pass through several miles of Earth's atmosphere before it reaches the eye of an observer. It is as if we are looking at the universe from the bottom of a swimming pool.

Our atmosphere is turbulent, with streams and eddies forming, churning and dispersing all the time. These disturbances act like lenses and prisms that shift a star's light from side to side by minute amounts several times a second. For large objects such as the moon, these deviations average out. (Through a telescope with high magnification, however, the objects appear to shimmer.) Stars, in contrast, are so far away that they effectively act as point sources, and the light we see flickers in intensity as the incoming beams bend rapidly from side to side. Planets such as Mars, Venus and Jupiter, which appear to us as bright stars, are much closer to Earth and look like measurable disks through a telescope. Again, the twinkling from adjacent areas of the disk averages out, and we see little variation in the total light emanating from the planet. SA

For a complete text of these and other answers from scientists in diverse fields, visit Ask the Experts (www.sciam.com/askexpert_directory.cfm).



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