TAMING LUPUS • LAST OF THE WILD EQUIDS • THE GENIUS OF NIKOLA TESLA

SCIENTIFIC AMERICAN

BIG BANG BUNGLED: 6 Common Errors about the Expanding Universe

MARCH 2005
WWW.SCIAM.COM

DID HUMANS STOP AN ICE AGE?

8,000 YEARS OF GLOBAL WARMING

Fuel-Cell Cars: The Future May Be Stuck in Neutral

Virtual Smallpox in a Real City

march 2005

contents

SCIENTIFIC AMERICAN Volume 292 Number 3

features

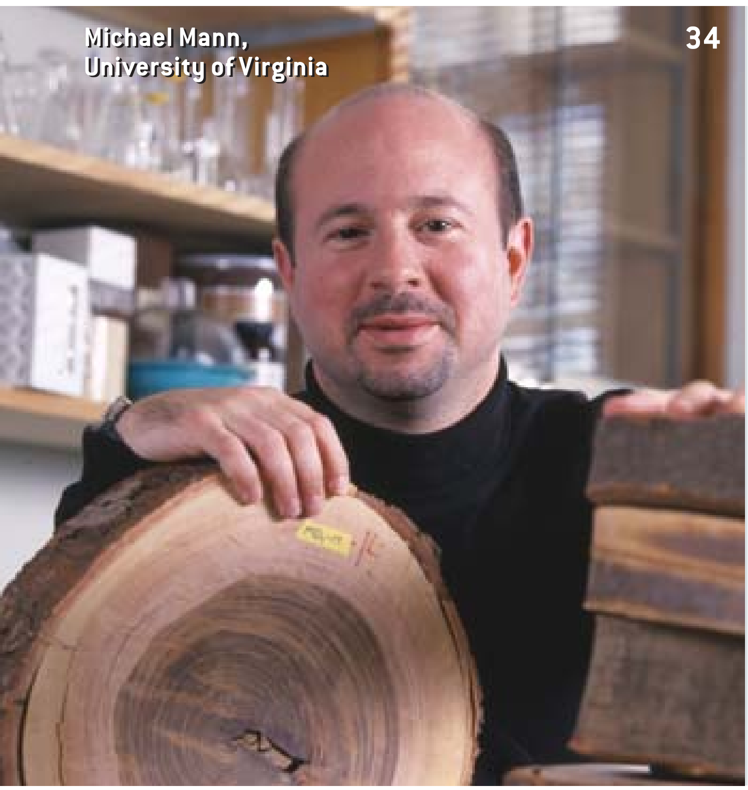
46 Postponing an ice age

SCIENTIFIC AMERICAN Volume 292 Number 3

departments

30

104



Michael Mann, University of Virginia

34

columns

Cover image by Kenn Brown; page 3: image by Jean-Francois Podevin; photograph at left: Jon Golden

Scientific American (ISSN 0036-8733), published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017-1111. Copyright © 2005 by Scientific American, Inc. All rights reserved. No part of this issue may be reproduced by any mechanical, photographic or electronic process, or in the form of a phonographic recording, nor may it be stored in a retrieval system, transmitted or otherwise copied for public or private use without written permission of the publisher. Periodicals postage paid at New York, N.Y., and at additional mailing offices. Canada Post International Publications Mail (Canadian Distribution) Sales Agreement No. 40012504. Canadian BN No. 127387652RT; QST No. Q1015332537. Publication Mail Agreement #40012504. Return undeliverable mail to Scientific American, P.O. Box 819, Stn Main, Markham, ON L3P 8A2. Subscription rates: one year $34.97, Canada $49 USD, International $55 USD. Postmaster: Send address changes to Scientific American, Box 3187, Harlan, Iowa 51537. **Reprints available:** write Reprint Department, Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017-1111; (212) 451-8877; fax: (212) 355-0408 or send e-mail to sacust@sciam.com **Subscription inquiries: U.S. and Canada (800) 333-1199; other (515) 247-7631.** Printed in U.S.A.

Relief Is Not Enough

In the Andaman Islands, a helicopter delivering food and water to survivors of December's tsunami briefly found itself under assault from the arrows of xenophobic Sentinelese tribesmen. Outsiders feared the flooding might finish the already endangered societies native to the islands. But the Sentinelese attack was welcome proof that at least some of them were still alive.

In these first weeks after the tsunami, with the death toll still climbing past 225,000, good news has been redefined as the absence of bad. Reports exult over selected survivors—a baby floating on a mattress, an injured model, a pregnant woman rescued from the open sea—and many of us are grateful for word of friends and family who are safe. But for every one of them, thousands of others unknown to us were lost. Meanwhile the ranks of the injured and homeless stretch from Indonesia to Africa, and the questions and concerns that their plight raises are not confined to that side of the planet.

WATERLOGGED WRECKAGE left by the tsunami in Banda Aceh in Indonesia is patrolled by Malaysian police officers.

The outpouring of emergency aid will be a great help to the ravaged countries, but disaster relief is an inadequate, expensive substitute for more timely improvements to their infrastructures. The most obvious example was that Indian Ocean nations lacked a tsunami-warning system like the one in the Pacific, but that omission may be forgivable. Tsunamis are rare in the Indian Ocean. Undersea sensors can cost a quarter of a million dollars apiece and have steep maintenance costs. India, Sri Lanka and the other wave-torn nations had far more urgent spending priorities. (In January a chastened India announced belatedly that it would invest $29 million on tsunami detectors after all.)

The real humanitarian fiasco is not the inadequate preparation of these nations, and many others, for freakish catastrophes. It is their inadequate preparation for the day-to-day horrors that routinely slaughter their populations. Millions of people die annually from malaria and AIDS—more than the equivalent of a tsunami a month. Lack of clean water in parts of Africa promotes disease and fuels civil conflicts. Poor countries face chronic crises so dire that the world's sensibilities have been numbed to them.

The U.S. and other industrial nations need to be more forthcoming with aid outside of calamitous times. In 2000, as part of the Millennium Development Goals program, the United Nations General Assembly embraced the target that rich states would pledge 0.7 percent of their national incomes to development assistance. Few countries (and the U.S. is not among them) are living up to that promise. Making matters worse, countries sending tsunami aid now will probably subtract those donations from their development aid budgets. In mid-January the Millennium program issued a new recommendation that countries donate just 0.5 percent, a retrenchment from the old goal but still twice the average now in practice. Even that figure has been criticized as unrealistic.

Sound public health policy needs more than fitful, reactive generosity. When the media focus our attention on the aftermath of tsunamis and other disasters, it is easy to empty our wallets for the agonized sufferers. But we need to do more on the fairest days for the billions out of sight and out of mind, whose survival depends on more days without bad news.

THE EDITORS editors@sciam.com

How to Contact Us

EDITORIAL

For Letters to the Editors:
Letters to the Editors
Scientific American
415 Madison Ave.
New York, NY 10017-1111
or
editors@sciam.com
Please include your name and mailing address, and cite the article and the issue in which it appeared. Letters may be edited for length and clarity. We regret that we cannot answer all correspondence.

For general inquiries:
Scientific American
415 Madison Ave.
New York, NY 10017-1111
212-754-0550
fax: 212-755-1976
or
editors@sciam.com

SUBSCRIPTIONS

For new subscriptions, renewals, gifts, payments, and changes of address:
U.S. and Canada
800-333-1199
Outside North America
515-247-7631
or
www.sciam.com
or
Scientific American
Box 3187
Harlan, IA 51537

REPRINTS

To order reprints of articles:
Reprint Department
Scientific American
415 Madison Ave.
New York, NY 10017-1111
212-451-8877
fax: 212-355-0408
reprints@sciam.com

PERMISSIONS

For permission to copy or reuse material from *SA*:
www.sciam.com/permissions
or
212-451-8546 for procedures
or
Permissions Department
Scientific American
415 Madison Ave.
New York, NY 10017-1111
Please allow three to six weeks for processing.

ADVERTISING

www.sciam.com has electronic contact information for sales representatives of Scientific American in all regions of the U.S. and in other countries.

New York
Scientific American
415 Madison Ave.
New York, NY 10017-1111
212-451-8893
fax: 212-754-1138

Los Angeles
310-234-2699
fax: 310-234-2670

San Francisco
415-403-9030
fax: 415-403-9033

Detroit
Karen Teegarden & Associates
248-642-1773
fax: 248-642-6138

Midwest
Derr Media Group
847-615-1921
fax: 847-735-1457

Southeast
Publicitas North America, Inc.
404-262-9218
fax: 404-262-3746

Southwest
Publicitas North America, Inc.
972-386-6186
fax: 972-233-9819

Direct Response
Special Aditions
914-461-3269
fax: 914-461-3433

Belgium
Publicitas Media S.A.
+32-(0)2-639-8420
fax: +32-(0)2-639-8430

Canada
Derr Media Group
847-615-1921
fax: 847-735-1457

France and Switzerland
PEM-PEMA
+33-1-46-37-2117
fax: +33-1-47-38-6329

Germany
Publicitas Germany GmbH
+49-211-862-092-0
fax: +49-211-862-092-21

Hong Kong
Hutton Media Limited
+852-2528-9135
fax: +852-2528-9281

India
Convergence Media
+91-22-2414-4808
fax: +91-22-2414-5594

Japan
Pacific Business, Inc.
+813-3661-6138
fax: +813-3661-6139

Korea
Biscom, Inc.
+822-739-7840
fax: +822-732-3662

Middle East
Peter Smith Media & Marketing
+44-140-484-1321
fax: +44-140-484-1320

Scandinavia and Finland
Publicitas Nordic AB
+46-8-442-7050
fax: +46-8-442-7059

U.K.
The Powers Turner Group
+44-207-592-8331
fax: +44-207-630-9922

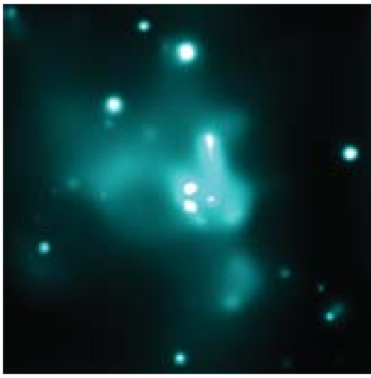
On the Web

WWW.SCIAM.COM

UPDATED EVERY WEEKDAY

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

Evidence for Milky Way's Long-Theorized Stellar Graveyard Found



Astronomers have known for several years that a supermassive black hole called Sagittarius A* resides at the center of the Milky Way galaxy. New data indicate that a swarm of smaller black holes that have accumulated over billions of years may surround it. The findings suggest that the smaller black holes will eventually fall into Sagittarius A*, elucidating how such behemoths grow.

How Geckos Keep Their Sticky Feet Clean

Gecko lizards can cling easily to nearly any surface, thanks to their extraordinarily adhesive feet. In fact, a single toe can support the animal's entire body weight. Now researchers have figured out just how the gecko's feet stay clean.

ASK THE EXPERTS

Are one's fingerprints similar to those of his or her parents in any discernible way?
Glenn Langenburg of the Bureau of Criminal Apprehension in St. Paul, Minn., explains.

New at Scientific American.com

Recreations
Puzzles, illusions and interactive games

Gallery
Science in pictures

E-mail Newsletters & Alerts

Stay informed with Scientific American.com's Weekly Review, delivering the latest science and technology news every Tuesday.

Sign up today

Visit www.sciam.com/newsletter

NASA/CXC/U.C.L.A./M. MUNO ET AL. (*Sagittarius A* region*); COURTESY OF *PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES USA* (*gecko foot*)

Letters

EDITORS@SCIAM.COM

THE NOVEMBER 2004 ISSUE included "Holes in the Missile Shield," by Richard L. Garwin, a topic that attracted volleys of letters from all sides. David Caccia of Honokaa, Hawaii, found an additional hole in the shield: "If an enemy nation could produce only a few nuclear weapons, would it risk sending them on rockets, which have a considerable chance of malfunctioning? And even if the launch was successful, the country could expect retaliation. Wouldn't it rather transport a weapon to one of our cities in a shipping container, which would have a much better chance of reaching its target and also leave no trace of its sender after detonation?" But Taras Wolansky of Kerhonkson, N.Y., saw a hole in one of the arguments against a defense system: "The Soviets went to great lengths to prevent the [Reagan administration's] Strategic Defense Initiative. Perhaps they understood that to make use of those 'easy' countermeasures, they would have to rebuild their entire ICBM arsenal every time the Americans tweaked their detectors." Other stimulating queries and observations on more topics follow.

BLACK HOLE DATA CRUNCH

I enjoyed "Black Hole Computers," by Seth Lloyd and Y. Jack Ng, but have two questions: When the radius of the space being measured in the sidebar "Computing Spacetime" doubles, wouldn't the maximum number of satellites allowed in it increase eightfold rather than double, allowing the same spacing of satellites without exceeding the critical density?

Also, what would be the effect of relativistic time dilation on a particle (and its encoded information) from the perspective of a frame of reference outside a black hole? Would relativistic time dilation cause the particle and its information to appear to "freeze" on the surface of the event horizon from the perspective of an outside observer, thereby conserving the amount of information available to the universe outside the black hole?

Michael Sklar
Huntington Woods, Mich.

LLOYD AND NG REPLY: To answer Sklar's first question, recall that we are talking about a system (of measuring apparatus consisting of the GPS satellites) on the verge of becoming a black hole. Thus, the maximum total energy is proportional to the radius of the region being mapped, not the volume of the region.

As for the second, this is an excellent point. In fact, from the perspective of an observer outside the black hole, a clock falling into the hole slows down and effectively stops just before it falls through the event horizon. So according to an outside observer, nothing ever falls into the black hole. The problem arises when one considers the perspective of a person falling into the black hole. From his vantage point, he falls through the horizon and hits the singularity in finite time.

Lloyd and Ng evidently are not mathematicians, for they imply that computation is mostly a physical process. For instance, they assert that a group of particles swapping their spin axes forms a fundamental "computer." Computation is a mathematical concept, however, not a mere physical one.

An electron spinning on its axis is not "information" any more than a rock falling and splintering into flint edges exhibits "knowledge" of toolmaking. An event's significance is purely subjective.

The article suggests that the whole universe, though observably finite, qualifies as the most prolific computer, if not the best ever. But this view quickly deteriorates into two self-referential paradoxes: First, if the entire universe is a computer, who (or what) is left to watch it run? It isn't enough to simply mandate quantum-mechanical event measurements in the absence of interpretation. Second, assuming the universe is computing its own evolution, as the authors contend, does it have a finite lifetime or not? If it is infinite, then its self-computation won't get done; it never produces an answer (not even *The Hitchhiker's Guide to the Galaxy*'s "42"). Hence, it does not qualify as a computation.

Richard Borbely
Simi Valley, Calif.

PHYLO FACTS

"What's in a Name?" by Christine Soares [Insights] contains a number of factual errors that must be corrected if your readership is ever to come to grips with the Linnaeus-PhyloCode debate. The International Code of Zoological Nomenclature was first published in 1960, not 250 years ago as the article states. This distinction is extremely important since the latter date suggests that the present Code (fourth edition, 1999) is considerably more antiquated than is the case.

Furthermore, proponents of the Linnaean system these days are mostly full-fledged phylogenetic systematists. The crux of the issue here is the distinction between phylogenetic systematics ("Hennigian cladistics") and biological nomenclature—the naming of living organisms. The former is a specialized discipline, whereas the latter is firmly in the public domain, reaching into every area of biology, including biodiversity, conservation, agriculture, medicine and veterinary studies. All serious taxonomists adopt the phylogenetic framework for constructing classifications. The naming of animals, however, requires pragmatism if it is to be at all useful.

The idea proposed by Kevin de Queiroz that the PhyloCode can somehow coexist with the official ICZN Code is analogous to enforcing two sets of traffic laws simultaneously, one stating that we drive on the right, the other, on the left (the disastrous consequences of which are obvious). At the same time, we have long been aware that the current Code is in need of modification and have not hesitated to say so in public and in print. The Code is now available on the Web (www.iczn.org). The next stage is to make it user-friendly and to provide a system to facilitate the official naming of living organisms. Our position is that the present challenge is to describe the world's vanishing biodiversity with the tools we already have; the PhyloCode is a regrettable distraction.

Andrew Polaszek
Executive Secretary, International Commission on Zoological Nomenclature
James Carpenter
American Museum of Natural History
Quentin D. Wheeler
Natural History Museum, London

GALACTIC WINTER

I wonder if anyone has considered the possibility that drastic climatic changes on Earth ["Abrupt Climate Change," by Richard B. Alley] have been and will be influenced by something far beyond. Could it be that as our solar system orbits our galaxy's center, it, along with our planet, might travel through one of the many clouds of particles and debris, dimming the sun enough to cause a sudden ice age? Conversely, the climate would warm when we emerged from the cloud.

Robert F. Wilson
Kingman, Ariz.

BALANCING ACT: **A dramatic shift in Earth's climate may occur suddenly and unpredictably.**

ALLEY REPLIES: A big meteorite like the one that killed the dinosaurs would have a great effect for some years, and it remains possible that the extraterrestrial environment weakly affects climate over many timescales, but the weight of evidence points to most of our climate variability as homegrown.

Many scientists share Wilson's interest in possible extraterrestrial causes of climate changes. One approach looks at variations over time in the rate at which meteorites or other objects have reached Earth. Some suggest that data show time variations in extraterrestrial flux correlated with climate changes over tens of thousands to hundreds of millions of years, but I believe most researchers consider these results tenuous at best.

A weak role for the sun remains possible for some changes over thousands of years and shorter. A strong variation in Earth's magnetic field allowed more cosmic rays to reach its surface around 40,000 years ago, as documented by the odd isotopes they produced, but the climate was largely or entirely unaffected by the event, so cosmic rays do not seem especially important.

CEREBRAL HARMONY

Norman M. Weinberger's article, "Music and the Brain," brought to mind Pythagoras of Samos, who was the first to explore music mathematically and experimentally. Specifically, he discovered that the most harmonious musical intervals are created by the simple numerical ratios of the first four integers that derive, respectively, from the relations of string length: the eighth, the fifth, the fourth.

Constantine J. Vamvacas
Athens, Greece

ERRATA In "Music and the Brain," by Norman M. Weinberger, research showing that infants prefer consonance to dissonance should have been attributed to Laurel Trainor of McMaster University, instead of Sandra Trehub of the University of Toronto. Also, the ratio for a minor second (for instance, C-sharp to C), used in studies of dissonance, was incorrectly stated as 9:8, which refers to a major second (for example, D to C). Depending on the particular type of scale used, the ratio is closer to 19:18, for example, 17:16.

In "What's In a Name?" by Christine Soares [Insights], it was incorrectly stated that members of the Chordate phylum must have a backbone. Members must have a notochord at some time during their development.

In "Computing at the Speed of Light," by W. Wayt Gibbs, the element phosphorus was incorrectly identified as phosphate.

MATT COLLINS

Building Evolution ▪ Typewriter Perfection ▪ Military Stagnation

MARCH 1955

THE CURTAIN WALL—"The term 'curtain wall' is used nowadays to describe the sheath, or 'skin,' of a modern building. It looks quite different from its predecessor, the old load-bearing wall, and in fact it represents a big advance in architectural evolution. The structural specialization involved in separation of the skin and the skeleton in a building corresponds to the specialization of tissue in biological evolution. Yet no building skin today approaches the performance of the biological world. The curtain wall is passive, lacking the power to adjust to the fluctuating external environment. It should be able to intervene actively in the building's struggle to maintain its internal stability. —James Marston Fitch"

WEST NILE—"During an epidemiological survey of infantile paralysis in a village north of Cairo in 1950, three blood specimens from children turned out on laboratory analysis to contain active West Nile virus. The find was electrifying, for no one had seen a human case of this infection since the original one in 1937. Other Egyptian studies soon showed that Egypt was a hotbed of West Nile infection; close to 100 per cent of the adults tested were found to have antibodies. West Nile virus has been isolated not only from Egyptian children but also from mosquitoes (of the *Culex* genus) and from hooded crows and pigeons. This is a remarkable range of hosts."

MARCH 1905

WRITING MACHINE— "It is a far cry from the monkish calligrapher, working in his cell in silence, to the brisk 'click, click' of the modern writing machine, which in a quarter of a century has revolutionized and reformed business. Its introduction marks an era of progress not inferior to that brought about by the telegraph and telephone."

TOMBS AT MUKDEN—"These graves in Manchuria are in a plain, so that the entire grounds can be readily overlooked from a near-by hill. Formerly the Mantchoo-Tartar emperors even went so far as to offer sacrifices at the graves of their predecessors, but this practice has been discontinued long ago. The Holy Road is the most interesting feature of the burial grounds. It is lined on both sides with colossal monolithic statues, standing about 200 yards apart. There are in all thirty-six statues, of which twenty-four represent animals [*see illustration*] and twelve high dignitaries."

COLOSSAL STATUE in Mukden (from the early Qing dynasty in what is now Shenyang, China), 1905

MARCH 1855

MUDDLED—"Capt. Norton made a number of very useful inventions in shot and shells, and recommended them to the head men in the British army more than ten years ago, but they were passed over unheeded, and now when danger threatens them in the Crimea, they rub their eyes and inquire about their utility. In 1826 one of his rifle percussion shells for cannons was shown to Lord Fitzroy Somerset (now Lord Raglan). That personage replied, 'All inventions in the improvement of arms tend to place the weak on a level with the strong; we are the strong, and therefore do not encourage improvements.' No better evidence could be afforded of the incapacity of Lord Raglan, to conduct the war in the Crimea, than the above piece of mud-headed enterprise."

FLOATING ROCKS—"On Manhattan Island, we behold innumerable loose rocks, of every size, from the small cobble to the large block of many tuns weight. These rocks grew not where they are found, and no human hands carried them thither. Whence came they? The only plausible theory is, that those places where they are now found, were once the bed of the sea, over which icebergs floated from an arctic ocean, with these stones attached to them, and were dissolved by warm currents of water, and thus relieved of their stony cargoes. To conceive of a period when tall icebergs floated over the place where the city of New York now stands, seems to be a draft upon the imagination as heavy as to believe in Aladdin's 'Wonderful Lamp.'"

GEOPHYSICS

The Scarred Earth

TSUNAMI-SPAWNING QUAKE LEAVES GEOPHYSICAL CHANGES BY MADHUSREE MUKERJEE

SUBMERGED: Part of the Indonesian city of Banda Aceh, on the northern tip of the island of Sumatra, was wiped away, as seen in these satellite images before the tsunami (*top*) and after (*bottom*).

DIGITALGLOBE

A year of death and destruction wreaked mostly by humans ended with nature flexing her own muscles, to terrifying effect. A section of the earth's crust hundreds of kilometers long tore off its moorings, slamming into the seawater above. The resulting tsunami traveled at 700 kilometers per hour to rear up like a hydra onto shores, sweeping away some 225,000 lives and millions of livelihoods across 12 nations. Now, as broken-hearted survivors turn to piecing together the remnants, scientists are scrutinizing the oceanic and island terrain to determine how the crust has changed and to gauge what further horrors the earth may have in store.

The magnitude 9.0 earthquake was the largest ever recorded in the region and the world's biggest since a 1964 Alaskan quake. The underground tear started 100 kilometers off the coast of Sumatra, on the western edge of the Burma plate. This "sliver" plate, a long, thin section of crust that reaches southward from Myanmar (Burma), pushes over and against the India plate to its west at the rate of 14 millimeters a year; on December 26, 2004, the Burma plate jerked westward and upward along an incline by perhaps 15 meters.

According to an early reconstruction by seismologist Chen Ji of the California Institute of Technology, the earthquake initially displaced 400 kilometers of crust 20 kilometers below the seabed. The tear very likely continued farther north but too slowly to generate seismic waves. (Long ruptures produce very low frequency seismic waves that are difficult to measure and interpret.) "Our preliminary tsunami modeling indicates the length of the rupture was significantly larger than the estimates the seismologists are putting up," remarks Frank Gonzalez of the National Oceanic and Atmospheric Administration in Seattle. In any case, the earthquake shook the bottom of the sea along a ridge aligned north to south, sending upraised walls of water barreling mainly east and west.

On reaching gently sloping coastlines the tsunami slowed down, shoaled and rose many meters to descend on unsuspecting humans. It first bulldozed coastal towns in Sumatra and, farther north, washed clean over several of the Nicobar Islands, leaving in places only a handful of survivors clinging to treetops. Sloshing within the confines of the Andaman Sea to the east, it carried off vacationers in Thailand. The westward wave traveled across the Indian Ocean as swiftly as a jet plane, striking India and Sri Lanka. Six hours later it claimed lives on Africa's shores and kept on going until it had circled the globe and dissipated.

At the same time the tsunami scoured the planet, the earthquake permanently altered its shape. Because the plates pulled tight and snug over one another, the earth's crust became more compact. Calculations suggest that, like an ice skater drawing in her arms, the contraction made the planet rotate faster, by perhaps three microseconds. And because the ocean bottom near the epicenter thrust upward, the planet's water now has less room, causing the sea level to rise by about a millimeter.

More locally, the earthquake and its aftershocks changed the shape and orientation of virtually the entire Burma plate and the lands it supports—in particular, the Andaman and Nicobar islands. The two island groups are the peaks of an undersea mountain range, raised by the scraping up of soft sediments as the plate's leading edge pressed down and forward against the India plate. After the earthquake, some of the Nicobar Islands seem to have sunk, and one island, Trinkat, has split into three pieces, with fish now swimming around once idyllic, palm-fringed villages.

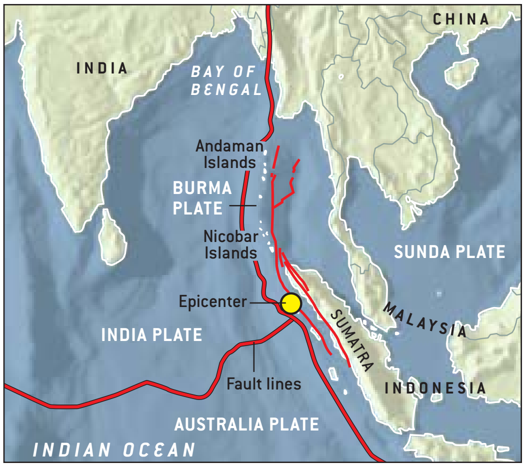
The western edge of the Burma plate has risen a few meters—exposing coral beds around the tiny island of North Sentinel—whereas the eastern edge has dropped. According to Survey of India, a government mapping department, the main town in the Andaman-Nicobar region, Port Blair, has shifted by a meter and sunk by 25 centimeters. Such tilting is to be expected, notes Joseph Curray of the Scripps Institution of Oceanography in La Jolla, Calif.: one undersea ridge south of the Nicobars was once, he suspects, a piece of Sumatra that sunk in the distant past. "Sooner or later Banda Aceh will subside" and disappear into the ocean, he concludes of the Sumatran city.

"Sooner" for a geologist usually means "later" for other humans: the earthquake and its aftershocks, Curray believes, eventually ruptured and released stress along the entire western edge of the Burma plate, making other massive jolts unlikely for a century. Large quakes could still be expected along the eastern edge, he warns: the Burma plate, drifting northward around 25 millimeters a year, tends to stick and unstick against the plate to its east in motions that produce "strike-slip" earthquakes. Such earthquakes probably would not result in tsunamis, because they would cause the water column above mainly to shear, not to lift.

But Kerry Sieh of Caltech suspects that an increased risk of a tsunami-spawning earthquake prevails south of the epicenter, where the rupture did not propagate. Sensitive measurements of the region's contours will be necessary to resolve this question.

Seismometers, tide gauges and other detection instruments now being deployed will make the next tsunami, if not the next earthquake, come as less of a surprise. Still, the coastal areas of Asia face future challenges: cyclones and their attendant surges will take an increasing toll as global warming disturbs weather systems. The devastated communities should ideally be rebuilt on high ground far from shore, where they would be protected by mangroves from the ever rising ocean. But for millions of the poor in crowded countries, such safety may never be possible.

Madhusree Mukerjee, reporting from Kolkata, India, is author of The Land of Naked People: Encounters with Stone Age Islanders, *a book about the Andamanese.*



COLLIDING PLATES: The Burma tectonic plate lurched west over the India plate, uplifting the seafloor and triggering the December 26, 2004, tsunami.

JEN CHRISTIANSEN

WHEN OLD WAYS TRUMP NEW WAYS

Days after the tsunami, an Indian coast guard helicopter flew 50 kilometers west of the town of Port Blair in the Andaman Islands. There, hovering over North Sentinel Island, it found itself targeted by two-meter-long arrows: evidently the inhabitants had survived. The Sentinelese are Paleolithic hunter-gatherers who choose to live in isolation. They are one of four groups of Andaman aboriginals, all 500 or so of whom appear to have run to high ground after they felt the earthquake.

"Our forefathers told us," explains one tribesman, "that when the earth shakes, the sea will rise up onto the land. They said we should run to the hills or get into a boat and go far out to sea." The Andamanese had a lead time of less than an hour. So while people in the information age groped through phone books to issue a tsunami warning that never arrived, those in the Stone Age had packed up their children, baskets, nets, bows, arrows and embers and run for the hills.

PHYSICS

Back to Square One

GOVERNMENT REVIEW REPEATS COLD FUSION CONCLUSIONS BY CHARLES Q. CHOI

After 15 years, cold fusion got a second chance at legitimacy from the U.S. Department of Energy, often seen by cold fusion advocates as their greatest enemy. This rematch, many hoped, would vindicate the field or kill it once and for all. Instead history repeated itself, with a verdict that evidence remained inconclusive.

Conventional physics holds that nuclear fusion ignites at multimillion-degree temperatures. In March 1989 controversy erupted when electrochemists Martin Fleischmann and Stanley Pons, then at the University of Utah, claimed room-temperature experiments with palladium electrodes in heavy water generated heat far in excess of any chemical reaction. The suggestion was that the deuterons—hydrogen nuclei bearing an extra neutron each—making up the heavy water were fusing.

COLD FUSION allegedly occurs in a jar of heavy water with electrodes.

Repeated experiments led to unpredictable results, and in November 1989 a special DOE panel found no convincing evidence for cold fusion. The panel remained open to further investigations through regular channels, but it recommended against research centers or special funding. In the aftermath, the scientific community for the most part decided cold fusion "was basically dead," says physicist Peter Hagelstein of the Massachusetts Institute of Technology.

Cold fusion investigations continued sporadically around the world in industry, university and government labs, including those at the Naval Research Laboratory in Washington, D.C., and, most recently, the Space and Naval Warfare Systems Command in San Diego. After the 10th International Conference on Cold Fusion, Hagelstein and fellow cold fusion proponents thought research had progressed far enough to request an update on the first review. "Recognizing a lot of work had been done in the last 15 years, I agreed," says James Decker, principal deputy director of science at the DOE.

Eighteen nuclear physicists, electrochemists and materials scientists reviewed research submitted by Hagelstein and his colleagues. In its December 2004 report, the DOE stated that when it came to whether the evidence for excess power was compelling or not, the panel split about evenly. When it came to whether nuclear reactions took place in the experiments, the report noted that two thirds of reviewers found the evidence unconvincing, one person found it compelling, and the remainder were somewhat convinced.

Experts cited many deficiencies in the interpretation of the data and the research methods, which used equipment far less than state of the art. But even some skeptical reviewers thought that experiments to look for the products of standard fusion reactions could be pursued to a clear conclusion. In the end, most reviewers suggested that funding agencies should entertain proposals of cold fusion studies via the conventional route of peer review. They concluded future research could investigate the properties of deuterium-loaded metals and look for fusion products with better tools and techniques.

Hagelstein thinks that the report downplays optimism among reviewers, and he contests the accuracy of its poll numbers. Still, he now feels that cold fusion proposals can gain positive recommendations. Of the DOE Decker says, "we've always been open to good proposals. We never said we would not fund proposals in cold fusion." But without dedicated programs, Hagelstein remarks, any cold fusion proposals will have to fight for money from programs that can disregard them as outside their area. When asked if this meant that nothing had changed since the last DOE review, Decker replies, "I think that may be a fair comment."

Charles Q. Choi is a frequent contributor.

GEORGE FREY *Time Life Pictures/Getty Images*

NUCLEAR DOUBTS

Some cold fusion experiments produced slight excess heat. But scientists reviewing the studies for the Department of Energy found several reasons to be skeptical that fusion occurred:

- Helium 4, a suggested cold fusion by-product, was detected at amounts close to background levels.
- Expected gamma rays were not produced; experts doubted the explanation that all energy was generated as heat instead.
- Not all chemical explanations for the excess heat were eliminated.
- Excess power was only a few percent more than the power applied, suggesting that measurement errors could account for the purported net energy.

METABONOMICS

The Diet That Fits

ANALYZING METABOLISM FOR PERSONALIZED NUTRITION **BY GUNJAN SINHA**

No single diet works for everyone. Some people can slurp cabbage soup for a week and lose only a few ounces, while others on the same spartan regimen lose 10 pounds. But what if you could measure your metabolism and get a prescription for a customized diet?

Metabonomics may do just that. It is one of the latest offshoots of the "-omics" revolution—after genomics (genes) and proteomics (proteins). With the understanding that some diseases such as obesity are metabolic syndromes in which multiple biochemical pathways interact to cause complex symptoms, metabolic testing offers a way to gauge health over a lifetime. What is more, metabonomic technology might identify disorders before they produce symptoms. Such testing could help people choose diet and exercise regimens that are tailored to their individual metabolic states.

COMFORT FOOD: In a new field called metabonomics, you eat (and drink) what you are.

CORBIS

Alan J. Higgins of Icoria, a company based in Research Triangle Park, N.C., that is applying its metabonomic technology to human health, explains that "metabonomics gives you the functional component" that is not always evident from a genetic or protein analysis. Changes in gene expression do not necessarily affect health, because the body's homeostatic mechanisms may compensate. Moreover, genes and proteins interact and only sometimes cause net changes in metabolic pathways. Metabonomics attempts to unify genomics and proteomics by examining an organism as a system. "We pick up those changes on the downstream end," Higgins adds.

At any given moment, the human body excretes thousands of metabolites that can be measured in urine, plasma and various body tissues. Conventional technology such as mass spectrometry and nuclear magnetic resonance can measure such components—that is how biochemists test the toxicity of drugs or environmental pollutants on human cells. The challenge, however, has been interpreting the reams of data generated. The bioinformatics boom has helped solve that problem. Scientists can now analyze metabolites in greater detail and also conduct more informative comparative studies. For example, three years ago London-based Metabometrix demonstrated that high-frequency radio waves bounced off a blood sample could identify atherosclerosis. The radio waves measure the sample's magnetic properties, and computer software generates a telltale pattern.

Profiling metabolic disease before symptoms appear may also be possible. Researchers at BG Medicine, based in Waltham, Mass., examined mice genetically engineered to develop atherosclerosis if placed on a high-fat diet. Scientists fed the mice a moderate-fat diet and after nine weeks measured lipid molecules in their livers and plasma. Compared with levels in a control group, certain lipid metabolites were elevated in the transgenic mice, even though they appeared perfectly healthy.

Of course, biochemical markers that flag disease, such as high cholesterol, already exist, but they are not sufficient. "A single biomarker gives information," says Jan van der Greef of BG Medicine, "but typically biomarker patterns are necessary to tell the complete story." Van der Greef suspects that many diseases have metabolic signatures that technology can detect even before a marker such as cholesterol would be elevated—the challenge is to identify the patterns. That is no small task: there is not yet a clear understanding of normal human metabolism, let alone abnormal metabolism.

Relatively speaking, "gene sequencing is

NEED TO KNOW: CUSTOM FOOD

The notion of preventing disease through diet has naturally caught the food industry's attention. In fact, food giant Nestlé has allocated about $50 million of its annual research budget to metabonomics and personalized nutrition and has directed 75 of its staff scientists to focus on the effort. Once researchers validate the concept, Nestlé would offer consumers customized foods. But these foods would not contain "one particular nutrient for each person," says José M. Ordovas of Tufts University. "That is not feasible. It would be rather like buying shoes. There will be lots of things to choose from, but you buy the shoe that fits."

so easy," says José M. Ordovas, director of the Nutrition and Genomics Laboratory at Tufts University. He notes that sequencers have to cope with only four components (A, C, T and G), whereas "in metabonomics you have different [technology] platforms that measure things in different ways. We are talking about thousands of components."

To move forward, scientists would like to see a human metabonome established—an equivalent of the human genome for metabolism. But the field lacks coordination and money, says Ordovas, who estimates that it might take analyses of half a million people or more to accomplish the task.

Ordovas is, however, inching his way ahead. In a joint project with Metabometrix, he is examining a few thousand subjects, some who have severe cases of metabolic diseases such as obesity and some who are healthy, to identify how extremes differ from the norm. He will also investigate whether diet and exercise tailored to a person's unique metabolic profile can bring weight down to normal and prevent a premature slide into bad health. In the future, instead of scanning food labels for calories, fats and carbs, we might be matching labels to our metabolic type.

Gunjan Sinha is a science writer based in Frankfurt, Germany.

EVOLUTION

Rooting the River Horse

A NEW ANALYSIS WEIGHS IN ON WHERE HIPPOS COME FROM **BY KATE WONG**

It might look docile lolling among the water lilies, but bad-tempered and surprisingly swift on terra firma, the hippopotamus has a deservedly fearsome public image in its African homeland. It also has a formidable reputation among evolutionary biologists: the beast has defied attempts to pinpoint its origin for nearly two centuries. To that end, recent findings may finally put the hippo in its place.

With its gaping maw, hairless body and eyes that sit high on its head, the semiaquatic hippo is one of the most distinctive members of Africa's mammalian menagerie. Two species exist today—the common *Hippopotamus amphibius* and the smaller Liberian hippo, *Choeropsis liberiensis*—and 40 more are known from the fossil record. Experts agree that hippos belong to the mammalian order Artiodactyla, a group of even-toed, hoofed creatures whose extant representatives include camels, pigs and ruminants such as cows. But exactly where hippos sit on the artiodactyl family tree has proved devilishly difficult to discern.

A PLACE FOR HIPPOS: Evolutionary biologists think they have finally figured out where the ill-tempered creature belongs on the mammalian family tree.

FRANS LANTING *Minden Pictures*

Two hypotheses lead the pack. The first posits that the piglike peccaries, or tayassuids, are the closest relatives of the hippo. The second proposes that extinct swamp-dwelling creatures called anthracotheres own that distinction. To evaluate the two scenarios, Jean-Renaud Boisserie, a postdoctoral researcher at the University of California at Berkeley, and his colleagues scrutinized all the characteristics ever used to support one or the other of these models, incorporating data from 32 artiodactyl species (including new fossil hippos from Chad and Ethiopia).

In presenting their work at a fall meeting and, more recently, in a paper published online January 24 by the *Proceedings of the National Academy of Sciences USA*, the investigators concluded that many of the putative resemblances between hippos and peccaries—the rounded shape of the muzzle in cross section, for example—are in fact primitive artiodactyl traits and therefore not indicative of a deeper relationship. Other similarities were also judged meaningless. The anthracothere hypothesis fared much better: the team's analysis supports a link between hippos and anthracotheres, pointing to an especially close relationship with a dentally advanced subset of anthracotheres known as the Bothriodontinae. Although hippo teeth look rather different, the two groups have in common a number of features in the skull, lower jaw and limbs.

The results stand to elucidate not only the ancestry of hippos but also that of whales. In 2001 key fossil whale discoveries revealed the ocean dwellers to be descended from artiodactyls [see "The Mammals That Conquered the Seas," by Kate Wong, Scientific American, May 2002]. And several DNA analyses have concluded that whales and hippos in particular share a common ancestor. But some paleontologists have been reluctant to embrace the molecular findings because whereas the oldest known whales date back to more than 53 million years ago, the earliest hippos yet found are only around 15 million years old. The fossil trail of anthracotheres, however, doesn't peter out until some 41 million years ago. An anthracothere origin of hippos could thus reduce the gap between them and whales to just 12 million years. "This is the best work so far to link anthracotheres to hippos," comments fossil-cetacean expert J.G.M. (Hans) Thewissen of the Northeastern Ohio Universities College of Medicine. The challenge now, he adds, will be to identify anthracothere ancestors from the right time and place to bridge the remaining break between hippos and whales.

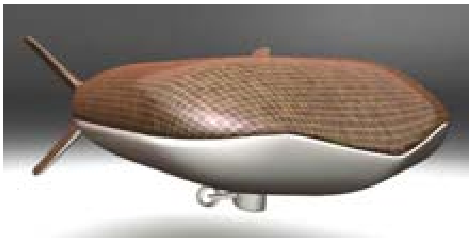
The hippo will no doubt remain a force to be reckoned with in the wilds of Africa. But paleontologists may have at last wrestled with the river horse and won.

TELECOM

Aerial Base Station

TRYING AGAIN: STRATOSPHERIC AIRSHIPS FOR COMMUNICATIONS BY STEVEN ASHLEY

The plan is familiar: park an antenna high in the stratosphere and then relay signals to and from devices below. Such an airborne transceiver could blanket urban areas with wireless coverage more cheaply than satellite-based alternatives while avoiding the need to build forests of mast-mounted base stations on the ground. In the past, various remote-controlled airplanes, balloons and blimps have been proposed to keep antennas aloft for months on end, but few have ever made it into the air, and none have operated commercially.



POOR MAN'S SATELLITE: High-tech airship could fly for months above a city to provide Wi-Fi coverage.

SANSWIRE NETWORKS STRATELLITE

Previous failures, however, do not daunt the latest contender for the prize. This spring engineers at Sanswire Networks, an Atlanta-based Wi-Fi provider, plan to test a prototype of a high-tech airship that they claim could supply mobile communications service to major metropolitan areas for as long as 18 months at a stretch. "It's like a big pontoon boat in the sky," says company chairman Michael K. Molen. If the concept proves successful, fleets of whale-shaped "Stratellites"—short for stratospheric satellites—will fly 20 kilometers up to where the air is so thin that solar-powered electric motors can keep the $10-million-plus ships in geostationary "orbits."

Beyond standard financial and political difficulties, these projects face formidable

CONTINUOUS COVERAGE

The Stratellite program began three and a half years ago, when Sanswire Networks began to consider airborne telecommunications. If the airships prove successful, then the hope is "to build three to five Stratellites in the first 18 months of operation," says company chairman Michael K. Molen. After a year and a half in service, the rechargeable batteries onboard will need changing. "When refitting becomes necessary, a replacement ship will take the three-hour trip up to the stratosphere, where it will change places with the original ship to maintain uninterrupted service." Each Stratellite would provide Wi-Fi-based voice, video and data services across a 240-kilometer-diameter area defined by a line-of-sight signal.

technical difficulties, observes aerospace engineer James D. DeLaurier of the University of Toronto. A veteran of a late-1980s effort to fly a microwave beam–powered drone, DeLaurier explains that the region above "20 kilometers is no atmospheric Shangri-la, as was once thought." Despite the rarefied air in the stratosphere, wind pressures are still significant, he notes, adding that the "area is full of ozone, ultraviolet radiation and even atomic oxygen, all of which degrade materials over time." Helium management is another issue: the enclosing envelope bag, which has to be thin to reduce weight, "looks like Highway 95" to helium molecules, which zip right through it, DeLaurier says. "So you have to have a way to replenish lost lifting gas."

To overcome such obstacles, Sanswire has hooked up with Vernon Koenig, an expert in lighter-than-air technology who designed an airship for an earlier, underfinanced effort. Called *Sanswire 1,* the one-third-scale prototype will rely on a lightweight skin of body-armor-grade polyethylene fibers and incorporate thousands of square meters of photovoltaic film on the upper exterior. Once builders install the engines, high-altitude propellers and a triple-redundant computer guidance system, flight-testing will be conducted above a California U.S. Air Force base.

A full-size Stratellite would be nearly as large as a football field. It would be able to loft a 1.5-ton payload using mostly helium and would employ nitrogen to maintain the shape of its outer skin as the craft rises and falls. Some 37,000 cubic meters of helium inside will expand nearly 17-fold by the time the ship reaches cruising altitude. The commercial airship will most likely include a technology to manufacture lifting gas, perhaps hydrogen, to replace lost helium.

Molen says the aerodynamic lifting body-type shape means the airship will be able to "fly" under power, maneuvering its way up rather than simply floating higher. Presumably this approach will enable the ship to navigate past the jet stream and maintain its position.

As with the earlier, similar efforts, it all sounds promising. But the question remains whether the idea will really fly.

HYGIENE

No Bath Time

IN SPACE, IT'S NOT EASY BEING CLEAN BY PHIL SCOTT

After a grimy day of tussling with yet another alien species, the crew of the average *Star Trek* franchise might shower off with sound waves and don fresh uniforms courtesy of the ship's replicator. "I wish we had those things," Stephanie Walker says of the replicators. As a systems manager for flight crew equipment at the NASA Johnson Space Center in Houston, Walker remains keenly aware of the limitations of life in space. We can send a human to the moon, but we cannot ensure that astronauts on the International Space Station (ISS) stay fresh for their six-month missions.

Of course, NASA ranks comfort well below safety and health. And the station has a ways to go before it resembles Mir, which "had its own odor, like 12 years in a sock closet," quips Marsha Ivins, a veteran of five shuttle flights who is currently assigned to the Johnson center. Future manned flights, however, will demand extended togetherness: a round-trip to Mars should last at least 18 months. That's a problem, because space alters an astronaut's sense of taste and smell. "Things that don't bother you normally may nauseate you over time," explains Jeff Jones, a Houston-based flight surgeon for the ISS.

Today's astronauts use various off-the-shelf waterless products, such as body wipes and no-rinse shampoos developed for hospitals. All conform to strict station parameters. "We send up

SILVER-LACED BEDSHEETS, T-shirts and other fabrics, which resist microbial growth, were tested in NASA's Aquarius habitat.

nothing with alcohol in it, because the environmental-control system can't get the alcohols out," Walker says. Propylene glycol, commonly used to keep cleansing ingredients in the proper physical state, also poses a problem in large quantities. Most space soaps are herbal instead.

As for astronauts and their laundry, "they can wash clothing with soap and rinse it out with a water-bag system and let it air-dry," Jones states. "Things dry pretty quickly" with good air movement, he adds, thanks to an onboard humidity that hovers around 30 to 40 percent—a relative Sahara compared with Mir's 80 to 90 percent. Clothes drying is especially popular in the station's Zvezda service module, where airflow is best.

Higher-tech hygiene might be possible. NASA astronauts have tried two T-shirts woven with silver thread. The metal inhibits bacterial growth. The results, though anecdotal, seem promising: the shirts "were encrusted with salt, but they did not smell," Ivins reports. Last year NASA began testing silver-laced bedsheets, blankets and other items in its Aquarius underwater habitat, off the Florida coast.

Ivins downplays the idea of silver-suited space travelers. But she notes that "we have now the opportunity to look at new materials and new technologies, and one of these may turn out to be the Velcro of the future." A springtime-fresh Velcro, perhaps.

Phil Scott showers daily in New York City.

NASA

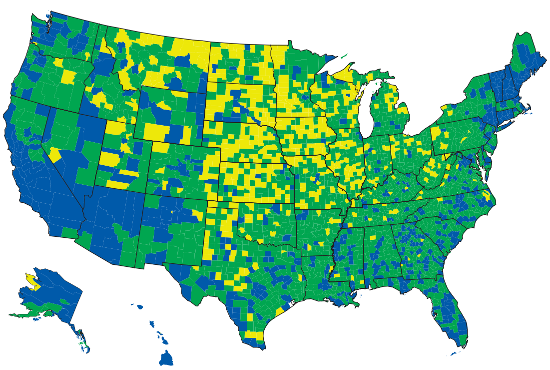
news SCAN

BY THE NUMBERS

Gay and Lesbian Census

A HARD-TO-MEASURE POPULATION STARTS COMING INTO FOCUS **BY RODGER DOYLE**

Tabulating the U.S. gay and lesbian populations has never been easy. Not only are many people reluctant to discuss intimate matters, but also their sense of identity evolves: today's gay man may have been straight yesterday. Like past efforts, the 2000 U.S. decennial census undoubtedly undercounted them, but it does provide substantial new information—specifically, on those gays and lesbians who live together as couples.



U.S. Counties Classified by Proportion of Gay or Lesbian Households

Lowest quintile Three middle quintiles Highest quintile

SOURCE: U.S. Decennial Census, 2000

The census form asked respondents to classify any unrelated people in their household as a housemate, boarder, foster child, unmarried partner or other nonrelative. If the unmarried partner is reported to be of the same sex, that partner and the respondent are very likely gay or lesbian. The census showed that 0.6 percent of men and 0.5 percent of women 18 years of age and older live together as same-sex unmarried partners. The data provide a good indication of geographic distribution. The map shows the proportion of households that are gay or lesbian, and because of the likelihood of undercounting, it categorizes the dispersion of this population by quintiles, rather than by absolute percentages. The map combines the three middle quintiles for simplicity.

As might be expected, San Francisco has the highest concentration of gays and lesbians; Washington, D.C., and New York City's borough of Manhattan are not far behind. Perhaps surprisingly, gays and lesbians appear in high concentrations in all regions except for the Midwest, particularly the west-central region. And gays and lesbians do not merely abound in the big metropolitan areas; they live in smaller ones as well, especially college towns such as Bloomington, Ind., Iowa City, Iowa, Corvallis, Ore., and Lawrence, Kans. Moreover, some nonmetropolitan counties such as Presidio, Texas, Lyon, Kentucky, and Shannon, South Dakota, are among the top 50 counties in terms of their proportion of gay and lesbian population.

The 2000 census found that at least a quarter of a million children live in households headed by same-sex couples and that nearly one in five people in same-sex couples is 55 and older. The number of unpartnered gay and lesbian individuals can be estimated from survey data showing that 24 percent of gay men and 43 percent of lesbians are coupled. By extrapolation, the proportion of gay men in the population is 2.5 percent and of lesbians 1.2 percent, consistent with earlier research.

The two-to-one disparity is curious in light of studies showing that the percentages of those claiming sexual desire for the same sex is virtually identical for both men and women (7.7 and 7.5 percent, respectively). No conclusive explanation exists for this anomaly. Gary Gates of the Urban Institute in Washington, D.C., who co-authored the recently published *Gay and Lesbian Atlas*, notes the evidence that women's conception of sexual orientation may be more fluid than that of men. He suggests that women, although they may be as prone to same-sex attraction, may be less willing to label that attraction with a specific sexual orientation such as gay or lesbian.

Rodger Doyle can be reached at rdoyle2@adelphia.net

RODGER DOYLE

SAME-SEX LOCATIONS

The 10 counties with the largest numbers of gays and lesbians:

1. Los Angeles
2. Cook, Illinois (Chicago)
3. New York (Manhattan)
4. San Francisco
5. Harris, Texas (Houston)
6. San Diego
7. Dallas
8. Maricopa, Arizona (Phoenix)
9. King, Washington (Seattle)
10. Broward, Florida (Ft. Lauderdale)

The 10 counties with the highest proportion of gays and lesbians:

1. San Francisco
2. District of Columbia
3. DeKalb, Georgia (Atlanta area)
4. New York
5. Suffolk, Massachusetts (Boston)
6. Denver
7. Multnomah, Oregon (Portland)
8. Alameda, California (Oakland)
9. King, Washington (Seattle)
10. Fulton, Georgia (Atlanta)

SOURCE: U.S. Decennial Census, 2000

FURTHER READING

Sex in America: A Definitive Survey. Robert T. Michael et al. Little, Brown, 1994.

The Social Organization of Sexuality: Sexual Practices in the United States. Edward O. Laumann, John H. Gagnon, Robert T. Michael and Stuart Michaels. University of Chicago Press, 2000.

The Gay and Lesbian Atlas. Gary J. Gates and Jason Ost. Urban Institute Press, 2004.

DATA POINTS: FEELING TERROR

Fear of terrorism has made many Americans willing to curtail rights and sacrifice basic freedoms, according to a national survey of 715 respondents prepared by Erik C. Nisbet and James Shanahan of Cornell University for a December 2004 report.

Percent of respondents who think the federal government should:

Have more power to monitor Internet activities: 47

Indefinitely detain suspected terrorists: 63

Outlaw some activities even if constitutionally protected: 36

Percent who say the media should not:

Cover protests: 33

Report criticisms of the government: 31

ATTITUDES TOWARD ISLAM:

“Islam promotes violence.”

Percent who agree: 47

Percent of highly religious Christians who agree: 65

“Muslim-Americans should be forced to register their whereabouts.”

Percent who agree: 27

Among highly religious Christians: 42

“Mosques should be closely monitored.”

Percent who agree: 26

Among highly religious Christians: 34

SOURCE: Media & Society Research Group, Cornell University. Analyses involving religion included data only from Christians, agnostics and atheists. Degree of religiosity was based on self-identification, church attendance, and beliefs about Israel and a literal interpretation of the Bible.

ROBOTICS

Remote-Controlled Hump

Camel racing, a favorite pastime in the Middle East, has taken flack from human-rights advocates for the young boys imported to jockey the humpbacked desert beasts. Accordingly, the government of Qatar announced right before year’s end that it was banning child jockeys. Their replacements? Why, robots, of course. Camel racers in Qatar have reportedly tested remote-controlled, titanium robot jockeys built by an unnamed Swiss company. Camel owners would jockey via joystick from the sidelines as the animals galumph around a kilometers-long track. The robots are apparently armed with whips, and future models may include cameras to give the controllers a jockey’s-eye view. But exactly how they work is being kept secret for now. “They won’t let me near the robot,” says Chuck Thorpe, a member of the Robotics Institute at Carnegie-Mellon University’s Qatar campus. He speculates that remote control might work well in camel races, which require little tight maneuvering compared with horse races. —*JR Minkel*

BUT CAN THEY SAY “GIDDYAP?”: Robot camel jockeys get tested in Qatar, which has banned child jockeys.

GENE THERAPY

Vector without Virus

To deliver genes into cells, scientists rely on engineered viruses, but these germs often provoke immune responses and make them potentially lethal. New silica nanoparticles with organic components may prove effective nonviral DNA carriers. Chemists at the University at Buffalo found that the electric charge on these nanoparticles held and compacted the DNA, protecting it from enzymatic digestion in cells. The organic components also render normally rigid silica nanoparticles more flexible and capable of releasing encapsulated biomolecules and might make the nanoparticles safely biodegradable as well. Nanoparticles with the gene for green fluorescent protein penetrated cultured monkey kidney cells, delivered the DNA once inside and successfully modified their genes. The investigators now are using the technique in mice to carry genes into nerve cells. Their report appeared in the January 11 issue of *Proceedings of the National Academy of Sciences USA.* —*Charles Q. Choi*

PHARMACEUTICALS

Off Target

The drug industry has heralded targeted cancer therapies, which attack a specific protein identified through molecular analysis, as the next wave in treatment. This strategy received a setback last December, when the European drugmaker AstraZeneca reported that its targeted therapy, Iressa (gefitinib), shrank tumors but was no more effective than a placebo at extending the lives of patients with lung cancer. In light of this study, which included 1,700 people, AstraZeneca withdrew its application for approval in Europe. The company’s hopes of ever achieving blockbuster status for Iressa have now all but faded. The drug’s future in the U.S., which approved it in 2003, is uncertain as the FDA deliberates whether to pull it off the market. Many patients have moved to Tarceva, a targeted treatment from Genentech and OSI Pharmaceuticals that has improved patient survival. AstraZeneca plans to continue studies of Iressa for other types of cancer. —*Gary Stix*

AP PHOTO; ILLUSTRATION BY MATT COLLINS

COMPUTING

Broadband to the People

The secret to universal broadband Internet access could be right above your head. Power lines can carry broadband in the form of high-frequency electrical signals, and some European and U.S. utilities are already testing such systems. The problem is that forks in the electrical grid reflect broadband signals and thereby degrade transmission. Pennsylvania State University researchers simulated what would happen if lines were synched up with transformers and other electrical loads to minimize reflection. They found that signals should flow fast enough to give homes data-transfer rates of hundreds of megabits per second, tens of times faster than DSL or cable, they told the IEEE Consumer Communications & Networking Conference on January 5. The cost-effectiveness of broadband power lines remains to be seen, says lead researcher Mohsen Kavehrad, as it would interfere with some radio signals. *—JR Minkel*

POWER LINES can in theory deliver faster Internet access than cable or DSL.

CLONING

KC & the Sunshine Cow

Breeding cows for beef is often slow because the qualities of a top-grade cut, marbling and tenderness, are unknown until after a cow is slaughtered. That may change soon thanks to a newborn calf born healthy to the first cow cloned from a beef carcass. The mother, KC, is named after the kidney cell from which she was cloned. Her calf, Sunshine, was born naturally in mid-December, lively and fit at 72 pounds. The technology used to generate KC could also clone an animal from a freshly processed cut of beef, says Steven Stice, an animal scientist at the University of Georgia. Although cloned animals cannot legally enter the food chain, their offspring might soon: later this year the Food and Drug Administration is expected to weigh in on the safety of eating such animals, which an earlier FDA draft deemed safe. *—Charles Q. Choi*

BIOLOGY

Whales on a Bender

A long-standing mystery in marine biology is whether whales suffer from decompression sickness, a.k.a. the bends, after rapidly rising from the ocean depths. Biologists worked on the assumption the creatures were immune, but recent reports of beaked whales suffering acute bendslike symptoms after military sonar exposure raised the question anew. Now researchers from the Woods Hole Oceanographic Institution have examined 16 sperm whale skeletons collected since 1870 and found pockmarks and erosion in the bones of adult whales. The damage worsened with age and is consistent with the kind of bone injury that deep-sea divers suffer. If the bends is the culprit, whales have likely evolved behaviors to avoid the malady, such as gradual surfacing, says study co-author Michael Moore, and stressors such as sonar could sicken whales if they disrupt those behaviors. The study surfaced in the December 24, 2004, *Science*. *—JR Minkel*

WHALES are not immune to decompression sickness.

TOM IVES *Corbis* (top); FLIP NICKLIN *Minden Pictures* (bottom)

BRIEF POINTS

- **Wet sand or soft clay is how the Huygens spacecraft portrayed Titan's surface when it successfully landed on the Saturnian moon on January 14.**

  Cassini-Huygens homepage: http://saturn.jpl.nasa.gov/home/index.cfm

- **Retinal recordings explain why swordfish have a heating organ in the muscle to keep their eyes 10 to 15 degrees warmer than ambient temperatures: the warmth enables the fish to process visual information 10 times faster, improving the ability to spot prey.**

  Current Biology, January 11

- **Regenerating hair cells of the inner ear, and thus restoring hearing, could be possible: hair cells proliferated in mice engineered to lack the *Rb1* gene, which helps to regulate cell division.**

  Science Express Online, January 14

- **Rats can distinguish spoken Dutch from Japanese. This ability, however, probably is a by-product of general perceptual facilities rather than an indication of linguistic capacity.**

  Journal of Experimental Psychology: Animal Behavior Processes, January

The Fossil Fallacy

Creationists' demand for fossils that represent "missing links" reveals a deep misunderstanding of science By MICHAEL SHERMER

Nineteenth-century English social scientist Herbert Spencer made this prescient observation: "Those who cavalierly reject the Theory of Evolution, as not adequately supported by facts, seem quite to forget that their own theory is supported by no facts at all." Well over a century later nothing has changed. When I debate creationists, they present not one fact in favor of creation and instead demand "just one transitional fossil" that proves evolution. When I do offer evidence (for example, *Ambulocetus natans,* a transitional fossil between ancient land mammals and modern whales), they respond that there are now *two gaps* in the fossil record.

This is a clever debate retort, but it reveals a profound error that I call the Fossil Fallacy: the belief that a "single fossil"—one bit of data—constitutes proof of a multifarious process or historical sequence. In fact, proof is derived through a convergence of evidence from numerous lines of inquiry—multiple, independent inductions, all of which point to an unmistakable conclusion.

We know evolution happened because of a convergence of evidence.

We know evolution happened not because of transitional fossils such as *A. natans* but because of the convergence of evidence from such diverse fields as geology, paleontology, biogeography, comparative anatomy and physiology, molecular biology, genetics, and many more. No single discovery from any of these fields denotes proof of evolution, but together they reveal that life evolved in a certain sequence by a particular process.

One of the finest compilations of evolutionary data and theory since Charles Darwin's *On the Origin of Species* is Richard Dawkins's magnum opus, *The Ancestor's Tale: A Pilgrimage to the Dawn of Evolution* (Houghton Mifflin, 2004)—688 pages of convergent science recounted with literary elegance. Dawkins traces numerous transitional fossils (what he calls "concestors," the last common ancestor shared by a set of species) from *Homo sapiens* back four billion years to the origin of heredity and the emergence of evolution. No single concestor proves that evolution happened, but together they reveal a majestic story of process over time.

Consider the tale of the dog. With so many breeds of dogs popular for so many thousands of years, one would think there would be an abundance of transitional fossils providing paleontologists with copious data from which to reconstruct their evolutionary ancestry. In fact, according to Jennifer A. Leonard, an evolutionary biologist then at the Smithsonian Institution's National Museum of Natural History, "the fossil record from wolves to dogs is pretty sparse." Then how do we know whence dogs evolved? In the November 22, 2002, *Science,* Leonard and her colleagues report that mitochondrial DNA (mtDNA) data from early dog remains "strongly support the hypothesis that ancient American and Eurasian domestic dogs share a common origin from Old World gray wolves."

In the same issue, molecular biologist Peter Savolainen of the Royal Institute of Technology in Stockholm and his colleagues note that even though the fossil record is problematic, their study of mtDNA sequence variation among 654 domestic dogs from around the world "points to an origin of the domestic dog in East Asia" about 15,000 years before the present from a single gene pool of wolves.

Finally, anthropologist Brian Hare of Harvard University and his colleagues describe in this same issue the results of a study showing that domestic dogs are more skillful than wolves at using human signals to indicate the location of hidden food. Yet "dogs and wolves do not perform differently in a nonsocial memory task, ruling out the possibility that dogs outperform wolves in all human-guided tasks," they write. Therefore, "dogs' social-communicative skills with humans were acquired during the process of domestication."

No single fossil proves that dogs came from wolves, but archaeological, morphological, genetic and behavioral "fossils" converge to reveal the concestor of all dogs to be the East Asian wolf. The tale of human evolution is divulged in a similar manner (although here we do have an abundance of fossils), as it is for all concestors in the history of life. We know evolution happened because innumerable bits of data from myriad fields of science conjoin to paint a rich portrait of life's pilgrimage. SA

Michael Shermer is publisher of Skeptic *(www.skeptic.com) and author of* The Science of Good and Evil.

BRAD HINES

Behind the Hockey Stick

Seven years ago Michael Mann introduced a graph that became an iconic symbol of humanity's contribution to global warming. He has been defending his science ever since By DAVID APPELL

Michael Mann knows his students and his subject. The topic of the graduate seminar: El Niño and radiative forcing. The beer he will be serving: Corona, "because I'm going to be talking about tropical climate." Not surprisingly, attendance is high.

Mann is most famously known for the "hockey stick," a plot of the past millennium's temperature that shows the drastic influence of humans in the 20th century. Specifically, temperature remains essentially flat until about 1900, then shoots up, like the upturned blade of a hockey stick. The work was also the first to add error bars to the historical temperatures and allow for regional reconstructions of temperature.

JON GOLDEN

MICHAEL MANN: DETECTING PAST CLIMATE

- Started out as a physicist in theoretical condensed matter but switched to climatology for the big picture.
- With nine other scientists, he blogs at www.realclimate.org
- On whether global warming is really a problem: "To some extent, that's a value judgment"—that is, whether society prefers economic growth or the environment.

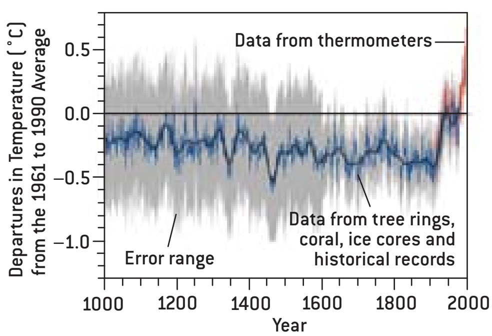
That stick has become a focal point in the controversy surrounding climate change and what to do about it. Proponents see it as a clear indicator that humans are warming the globe; skeptics argue that the climate is undergoing a natural fluctuation not unlike those in eras past. But Mann has not been deterred by the attacks. "If we allowed that sort of thing to stop us from progressing in science, that would be a very frightening world," says the 39-year-old climatologist in his University of Virginia office overlooking the hills of Monticello, the home of Thomas Jefferson.

To construct the hockey-stick plot, Mann, Raymond S. Bradley of the University of Massachusetts Amherst and Malcolm K. Hughes of the University of Arizona analyzed paleoclimatic data sets such as those from tree rings, ice cores and coral, joining historical data with thermometer readings from the recent past. In 1998 they obtained a "reconstruction" of Northern Hemisphere temperatures going back 600 years; by the next year they had extended their analysis to the past 1,000 years. In 2003 Mann and Philip D. Jones of the University of East Anglia in England used a different method to extend results back 2,000 years.

In each case, the outcome was clear: global mean temperature began to rise dramatically in the early 20th century. That rise coincided with the unprecedented release of carbon dioxide and other heat-trapping gases into the earth's atmosphere, leading to the conclusion that industrial activity was boosting the world's mean temperature. Other researchers subsequently confirmed the plot.

The work of Mann and his colleagues achieved special prominence in 2001. That is when the Intergovernmental Panel on Climate Change (IPCC), an international body of climate experts, placed the hockey-stick chart in the Summary for Policymakers section of the panel's Third Assessment Report. (Mann also co-authored one of the chapters in the report.) It thereby elevated the hockey stick to iconic status—as well as making it a bull's-eye. A community skeptical of human-induced warming argued that Mann's data points were too sparse to constitute a true picture, or that his raw data were numerically suspicious, or that they could not reproduce his results with the data he had used. Take down Mann, it seemed, and the rest of the IPCC's conclusions about anthropogenic climate change would follow.

That led to "unjustified attack after unjustified attack," complains climatologist Gavin A. Schmidt of the NASA Goddard Institute for Space Studies. Although questions in the field abound about how, for example, tree-ring data are compiled, many of those attacking Mann's work, Schmidt claims, have had a priori opinions that the work must be wrong. "Most scientists would have left the field long ago, but Mike is fighting back with a tenacity I find admirable," Schmidt says. One of Mann's more public punch backs took place in July 2003, when he defended his views before a congressional committee led by Senator James M. Inhofe of Oklahoma, who has called global warming a "hoax." "I left that meeting having demonstrated what the mainstream views on climate science are," Mann asserts.



"HOCKEY STICK" graph shows a 20th-century upturn in temperature in the Northern Hemisphere. The error range is greater in the past because the data are sparser.

SOURCE: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

More recently, Mann battled back in a 2004 corrigendum in the journal *Nature,* in which he clarified the presentation of his data. He has also shown how errors on the part of his attackers led to their specific results. For instance, skeptics often cite the Little Ice Age and Medieval Warming Period as pieces of evidence not reflected in the hockey stick, yet these extremes are examples of regional, not global, phenomena. "From an intellectual point of view, these contrarians are pathetic, because there's no scientific validity to their arguments whatsoever," Mann says. "But they're very skilled at deducing what sorts of disingenuous arguments and untruths are likely to be believable to the public that doesn't know better."

Mann thinks that the attacks will continue, because many skeptics, such as the Greening Earth Society and the Tech Central Station Web site, obtain funds from petroleum interests. "As long as they think it works and they've got unlimited money to perpetuate their disinformation campaign," Mann believes, "I imagine it will go on, just as it went on for years and years with tobacco until it was no longer tenable—in fact, it became perjurable to get up in a public forum and claim that there was no science" behind the health hazards of smoking.

As part of his hockey-stick defense, Mann co-founded with Schmidt a Weblog called RealClimate (www.realclimate.org). Started in December 2004, the site has nine active scientists, who have attracted the attention of the blog cognoscenti for their writings, including critiques of Michael Crichton's *State of Fear,* a novel that uses charts and references to argue against anthropogenic warming. The blog is not a bypass of the ordinary channels of scientific communication, Mann explains, but "a resource where the public can go to see what actual scientists working in the field have to say about the latest issues."

The most challenging aspect today, Mann thinks, is predicting regional disruptions, because people are unlikely to take climate change seriously until they see how it operates in their backyard. In that regard, he has turned his attention to El Niño, a warming of eastern tropical Pacific waters that affects global weather. In discussing the issue with his students over their Coronas, Mann notes that comparisons with the paleoclimatic record seem to confirm a mechanism proposed by other researchers. Specifically, radiative forcings—volcanic eruptions and solar changes, for instance—do in fact alter El Niño, turning it into more of a La Niña state, with colder sea-surface temperatures. Understanding how El Niño has changed with past radiative forcings is a first step to understanding how it will change in an increasingly greenhouse-gassed world.

Mann remains somewhat mum on whether the U.S. should join the Kyoto Treaty, an international agreement to limit fossil-fuel emissions: "It's hard enough predicting the climate. I don't pretend to be able to predict the behavior of politicians." He sees the Kyoto accord as an initial step that is unlikely to curtail emissions all that much, but it will at least set in motion a process that can be built on with other treaties.

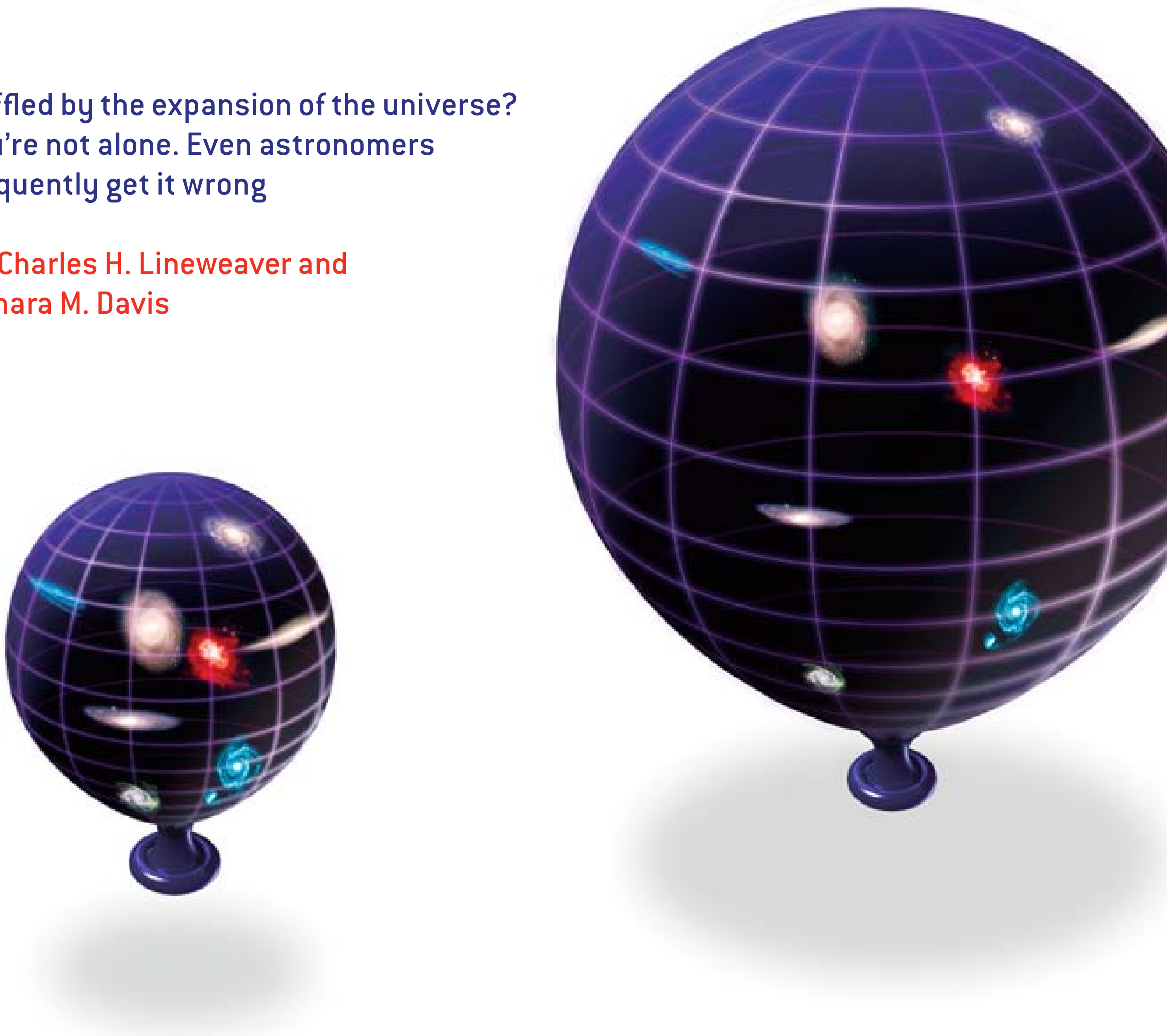
Such efforts are essential, because the blade of Mann's hockey stick will get longer. He notes that "we're already committed to 50 to 100 years of warming and several centuries of sea-level rise, simply from the amount of greenhouse gases we've already put in the atmosphere." The solution to global warming, he observes, "is going to be finding an appropriate set of constraints on fossil-fuel emissions that allow us to slow the rate of change down to a level we can adapt to." SA

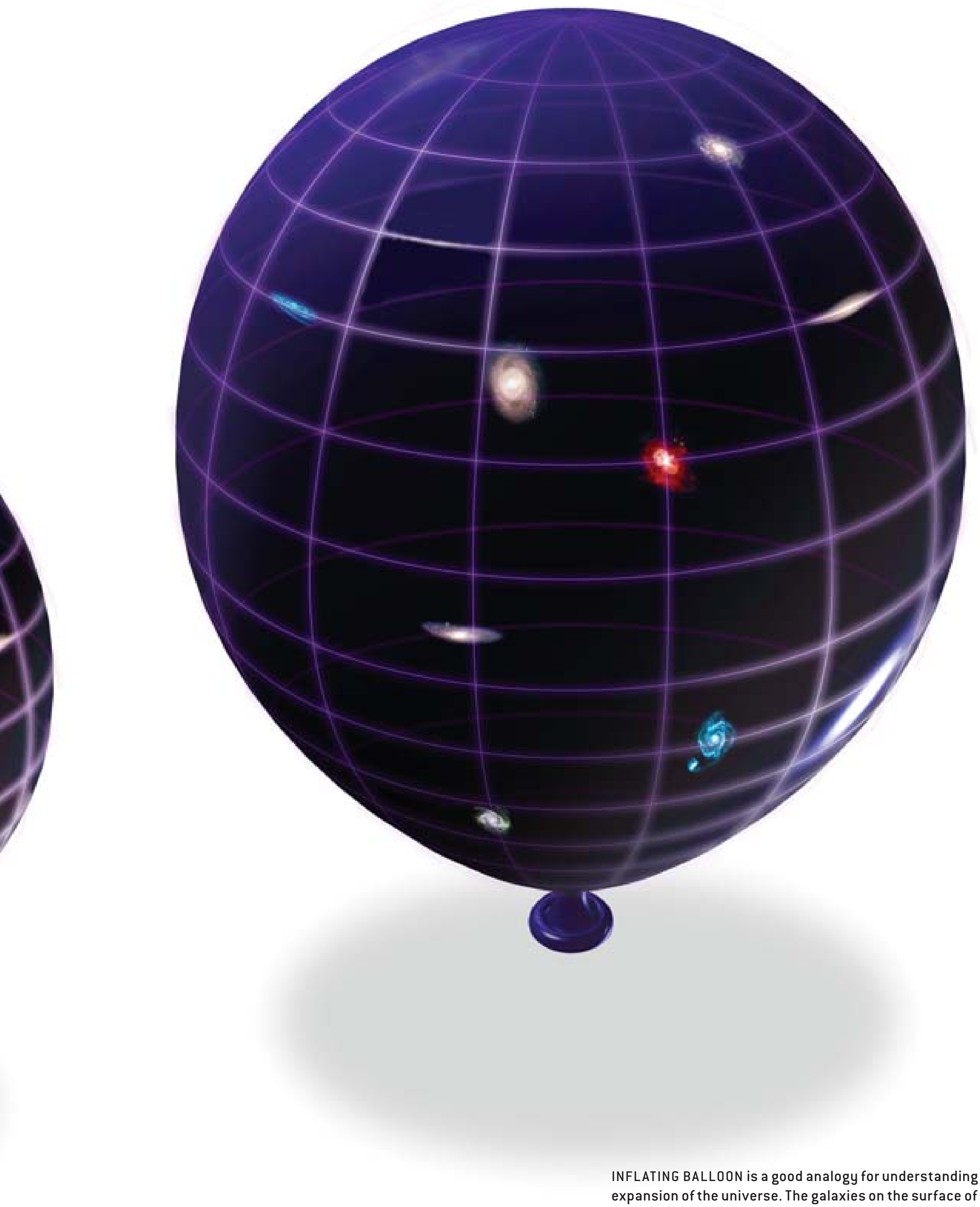
David Appell is based in Newmarket, N.H.

MISCONCEPTIONS ABOUT THE BIG BANG

Baffled by the expansion of the universe? You're not alone. Even astronomers frequently get it wrong

By Charles H. Lineweaver and Tamara M. Davis





INFLATING BALLOON is a good analogy for understanding the expansion of the universe. The galaxies on the surface of the balloon are effectively at rest, and yet as the universe expands, the distance between any two galaxies increases. The galaxies themselves do not increase in size.

The expansion of the universe may be the most important fact

we have ever discovered about our origins. You would not be reading this article if the universe had not expanded. Human beings would not exist. Cold molecular things such as lifeforms and terrestrial planets could not have come into existence unless the universe, starting from a hot big bang, had expanded and cooled. The formation of all the structures in the universe, from galaxies and stars to planets and *Scientific American* articles, has depended on the expansion.

Forty years ago this July, scientists announced the discovery of definitive evidence for the expansion of the universe from a hotter, denser, primordial state. They had found the cool afterglow of the big bang: the cosmic microwave background radiation. Since this discovery, the expansion and cooling of the universe has been the unifying theme of cosmology, much as Darwinian evolution is the unifying theme of biology. Like Darwinian evolution, cosmic expansion provides the context within which simple structures form and develop over time into complex structures. Without evolution and expansion, modern biology and cosmology make little sense.

The expansion of the universe is like Darwinian evolution in another curious way: most scientists think they understand it, but few agree on what it really means. A century and a half after *On the Origin of Species,* biologists still debate the mechanisms and implications (though not the reality) of Darwinism, while much of the public still flounders in pre-Darwinian cluelessness. Similarly, 75 years after its initial discovery, the expansion of the universe is still widely misunderstood. A prominent cosmologist involved in the interpretation of the cosmic microwave background, James Peebles of Princeton University, wrote in 1993: "The full extent and richness of this picture [the hot big bang model] is not as well understood as I think it ought to be … even among those making some of the most stimulating contributions to the flow of ideas."

Renowned physicists, authors of astronomy textbooks and prominent popularizers of science have made incorrect, misleading or easily misinterpreted statements about the expansion of the universe. Because expansion is the basis of the big bang model, these misunderstandings are fundamental. Expansion is a beguilingly simple idea, but what exactly does it mean to say the universe is expanding? What does it expand into? Is Earth expanding, too? To add to the befuddlement, the expansion of the universe now seems to be accelerating, a process with truly mind-stretching consequences.

Overview/*Cosmic Confusion*

- The expansion of the universe is one of the most fundamental concepts of modern science yet one of the most widely misunderstood.
- The key to avoiding the misunderstandings is not to take the term "big bang" too literally. The big bang was not a bomb that went off in the center of the universe and hurled matter outward into a preexisting void. Rather it was an explosion of space itself that happened everywhere, similar to the way the expansion of the surface of a balloon happens everywhere on the surface.
- This difference between the expansion *of* space and the expansion *in* space may seem subtle but has important consequences for the size of the universe, the rate at which galaxies move apart, the type of observations astronomers can make, and the nature of the accelerating expansion that the universe now seems to be undergoing.
- Strictly speaking, the big bang model has very little to say about the big bang itself. It describes what happened afterward.

What Is Expansion, Anyway?

WHEN SOME FAMILIAR OBJECT expands, such as a sprained ankle or the Roman Empire or a bomb, it gets bigger by expanding into the space around it. Ankles, empires and bombs have centers and edges. Outside the edges, there is room to expand into. The universe does not seem to have an edge or a center or an outside, so how can it expand?

A good analogy is to imagine that you are an ant living on the surface of an inflating balloon. Your world is two-dimensional; the only directions you know are left, right, forward and backward. You have no idea what "up" and "down" mean. One day you realize that your walk to milk your aphids is taking longer than it used to: five minutes one day, six minutes the next day, seven minutes the next. The time it takes to walk to other familiar places is also increasing. You are sure that you are not walking more slowly and that the aphids are milling around randomly in groups, not systematically crawling away from you.

This is the important point: the distances to the aphids are increasing even though the aphids are not walking away. They are just standing there, at rest with respect to the rubber of the balloon, yet the distances to them and between them are increasing. Noticing these facts, you conclude that the ground beneath your feet is expanding. That is very strange because you have walked around your world and found no edge or "outside" for it to expand into.

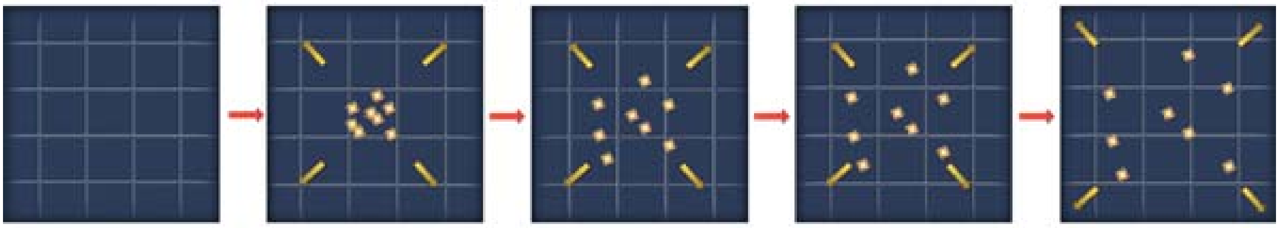
The expansion of our universe is much like the inflation of a balloon. The distances to remote galaxies are increasing. Astronomers casually say that distant galaxies are "receding" or "moving away" from us, but the galaxies are not traveling through space away from us. They are not fragments of a big bang bomb. Instead the space between the galaxies and us is expanding. Individual galaxies move around at random within clusters, but the clusters of galaxies are essentially at rest.

SLIM FILMS (*preceding pages*)

WHAT KIND OF EXPLOSION WAS THE BIG BANG?

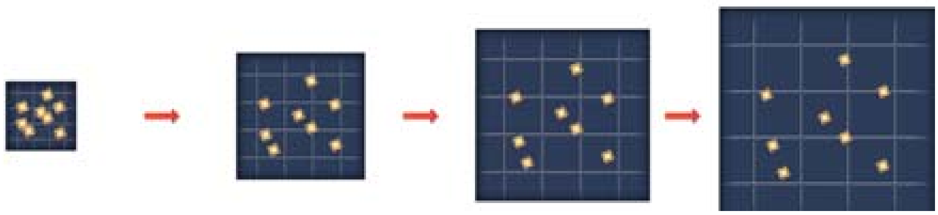
WRONG: **The big bang was like a bomb going off at a certain location in previously empty space.**

In this view, the universe came into existence when matter exploded out from some particular location. The pressure was highest at the center and lowest in the surrounding void; this pressure difference pushed material outward.



RIGHT: **It was an explosion of space itself.**

The space we inhabit is itself expanding. There was no center to this explosion; it happened everywhere. The density and pressure were the same everywhere, so there was no pressure difference to drive a conventional explosion.



The term "at rest" can be defined rigorously. The microwave background radiation fills the universe and defines a universal reference frame, analogous to the rubber of the balloon, with respect to which motion can be measured.

This balloon analogy should not be stretched too far. From our point of view outside the balloon, the expansion of the curved two-dimensional rubber is possible only because it is embedded in three-dimensional space. Within the third dimension, the balloon has a center, and its surface expands into the surrounding air as it inflates. One might conclude that the expansion of our three-dimensional space requires the presence of a fourth dimension. But in Einstein's general theory of relativity, the foundation of modern cosmology, space is dynamic. It can expand, shrink and curve without being embedded in a higher-dimensional space.

In this sense, the universe is self-contained. It needs neither a center to expand away from nor empty space on the outside (wherever that is) to expand into. When it expands, it does not claim previously unoccupied space from its surroundings. Some newer theories such as string theory do postulate extra dimensions, but as our three-dimensional universe expands, it does not need these extra dimensions to spread into.

ALFRED T. KAMAJIAN

Ubiquitous Cosmic Traffic Jam

IN OUR UNIVERSE, as on the surface of the balloon, everything recedes from everything else. Thus, the big bang was not an explosion *in* space; it was more like an explosion *of* space. It did not go off at a particular location and spread out from there into some imagined preexisting void. It occurred everywhere at once.

If one imagines running the clock backward in time, any given region of the universe shrinks and all galaxies in it get closer and closer until they smash together in a cosmic traffic jam—the big bang. This traffic-jam analogy might imply local congestion that you could avoid if you listened to the traffic report on the radio. But the big bang was an unavoidable traffic jam. It was like having the surface of Earth and all its highways shrink while cars remained the same size. Eventually the cars will be bumper to bumper on every road. No radio broad-

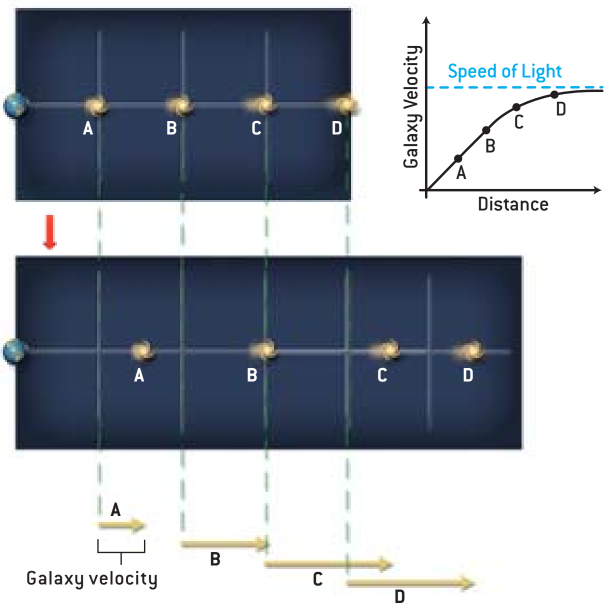
THE AUTHORS

CHARLES H. LINEWEAVER and TAMARA M. DAVIS are astronomers at Mount Stromlo Observatory near Canberra, Australia. They work on a wide range of questions, from cosmology to life in the universe. Lineweaver, while at the University of California, Berkeley, in the early 1990s, was part of the Cosmic Background Explorer team, which discovered fluctuations in the cosmic microwave background radiation. He has degrees not just in astrophysics but also in history and English literature, used to play soccer semiprofessionally, and is the father of two young soccer stars, Colleen and Deirdre. Davis works on the Supernova/Acceleration Probe, a space observatory now being designed. She represents Australia in the sport of Ultimate Frisbee and has competed in two world championships.

CAN GALAXIES RECEDE FASTER THAN LIGHT?

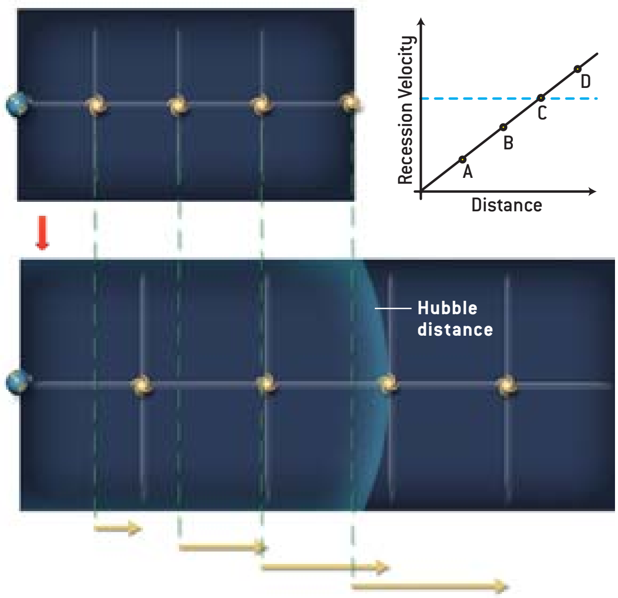
WRONG: **Of course not. Einstein's special theory of relativity forbids that.**

Consider a patch of space containing some galaxies. The galaxies move away from us—the farther the galaxy, the faster its velocity (*yellow arrows*). If light speed is the ultimate limit, the galaxy velocity must eventually plateau (*graph*).



RIGHT: **Sure they can. Special relativity does not apply to recession velocity.**

In expanding space, recession velocity keeps increasing with distance. Beyond a certain distance, known as the Hubble distance, it exceeds the speed of light. This is not a violation of relativity, because recession velocity is caused not by motion *through* space but by the expansion *of* space.



cast is going to help you around that kind of traffic jam. The congestion is everywhere.

Similarly, the big bang happened everywhere—in the room in which you are reading this article, in a spot just to the left of Alpha Centauri, everywhere. It was not a bomb going off at a particular spot that we can identify as the center of the explosion. Likewise, in the balloon analogy, there is no special place on the surface of the balloon that is the center of the expansion.

This ubiquity of the big bang holds no matter how big the universe is or even whether it is finite or infinite in size. Cosmologists sometimes state that the universe used to be the size of a grapefruit, but what they mean is that the part of the universe we can now see—our observable universe—used to be the size of a grapefruit.

Observers living in the Andromeda galaxy and beyond have their own observable universes that are different from but overlap with ours. Andromedans can see galaxies we cannot, simply by virtue of being slightly closer to them, and vice versa. Their observable universe also used to be the size of a grapefruit. Thus, we can conceive of the early universe as a pile of overlapping grapefruits that stretches infinitely in all directions. Correspondingly, the idea that the big bang was "small" is misleading. The totality of space could be infinite. Shrink an infinite space by an arbitrary amount, and it is still infinite.

Receding Faster Than Light

ANOTHER SET OF MISCONCEPTIONS involves the quantitative description of expansion. The rate at which the distance between galaxies increases follows a distinctive pattern discovered by American astronomer Edwin Hubble in 1929: the recession velocity of a galaxy away from us (v) is directly proportional to its distance from us (d), or $v = Hd$. The proportionality constant, H, is known as the Hubble constant and quantifies how fast space is stretching—not just around us but around any observer in the universe.

Some people get confused by the fact that some galaxies do not obey Hubble's law. Andromeda, our nearest large galactic neighbor, is actually moving toward us, not away. Such exceptions arise because Hubble's law describes only the average behavior of galaxies. Galaxies can also have modest local motions as they mill around and gravitationally pull on one another—as the Milky Way and Andromeda are doing. Distant galaxies also have small local velocities, but from our

ALFRED T. KAMAJIAN

perspective (at large values of d) these random velocities are swamped by large recession velocities (v). Thus, for those galaxies, Hubble's law holds with good precision.

Notice that, according to Hubble's law, the universe does not expand at a single speed. Some galaxies recede from us at 1,000 kilometers per second, others (those twice as distant) at 2,000 km/s, and so on. In fact, Hubble's law predicts that galaxies beyond a certain distance, known as the Hubble distance, recede faster than the speed of light. For the measured value of the Hubble constant, this distance is about 14 billion light-years.

Does this prediction of faster-than-light galaxies mean that Hubble's law is wrong? Doesn't Einstein's special theory of relativity say that nothing can have a velocity exceeding that of light? This question has confused generations of students. The solution is that special relativity applies only to "normal" velocities—motion through space. The velocity in Hubble's law is a recession velocity caused by the expansion of space, not a motion through space. It is a general relativistic effect and is not bound by the special relativistic limit. Having a recession velocity greater than the speed of light does not violate special relativity. It is still true that nothing ever overtakes a light beam.

Stretching and Cooling

THE PRIMARY OBSERVATION that the universe is expanding emerged between 1910 and 1930. Atoms emit and absorb light of specific wavelengths, as measured in laboratory experiments. The same patterns show up in the light from distant galaxies, except that the patterns have been shifted to longer wavelengths. Astronomers say that the galactic light has been redshifted. The explanation is straightforward: As space expands, light waves get stretched. If the universe doubles in size during the waves' journey, their wavelengths double and their energy is halved.

This process can be described in terms of temperature. The photons emitted by a body collectively have a temperature—a certain distribution of energy that reflects how hot the body is. As the photons travel through expanding space, they lose energy and their temperature decreases. In this way, the universe cools as it expands, much as compressed air in a scuba tank cools when it is released and allowed to expand. For example, the microwave background radiation currently has a temperature of about three kelvins, whereas the process that released the radiation occurred at a temperature of about 3,000 kelvins. Since the time of the emission of this radiation, the universe has increased in size by a factor of 1,000, so the temperature of the photons has decreased by the same factor. By observing the gas in distant galaxies, astronomers have directly measured the temperature of the radiation in the distant past. These measurements confirm that the universe has been cooling with time.

Misunderstandings about the relation between redshift and velocity abound. The redshift caused by the expansion is often confused with the more familiar redshift generated by the Doppler effect. The normal Doppler effect causes sound

A Wearying Hypothesis

Every time *Scientific American* publishes an article on cosmology, a number of readers write in to argue that galaxies are not really receding from us—that the expansion of space is an illusion. They suggest that galactic redshifts are instead caused by light getting "tired" on its long journey. Perhaps some novel process causes light to lose energy spontaneously, and thereby redden, as it propagates through space.

Scientists first proposed this hypothesis some 75 years ago, and like any good model, it makes predictions that can be tested. But like any bad model, its predictions do not fit the observations. For example, when a star explodes as a supernova, it brightens and then dims—a process that takes about two weeks for the type of supernova that astronomers have been using to map out space. During these two weeks, the supernova emits a train of photons. The tired-light hypothesis predicts that these photons lose energy as they propagate but that the observer always sees a train that lasts two weeks.

In expanding space, however, not only do individual photons get stretched (thereby losing energy) but the entire train of photons also gets stretched. Thus, it takes longer than two weeks for all the photons to arrive on Earth. Recent observations confirm this effect. A supernova in a galaxy of redshift 0.5 appears to last three weeks; one in a galaxy of redshift 1, four weeks.

The tired-light hypothesis also conflicts with observations of the spectrum of the cosmic microwave background radiation and of the surface brightness of distant galaxies. *—C.H.L. and T.M.D.*

SUPERNOVAE, such as this one (*indicated by arrow*) in the Virgo Cluster of galaxies, serve as tracers of cosmic expansion. Their observed properties rule out alternative theories of cosmology in which space does not expand.

P. CHALLIS *Center for Astrophysics/STScI/NASA* waves to get longer if the source of the sound is moving away—for example, a receding ambulance siren. The same principle also applies to light waves, which get longer if the source of the light is moving through space away from us.

This is similar, but not identical, to what happens to the light from distant galaxies. The cosmological redshift is not a normal Doppler shift. Astronomers frequently refer to it as such, and in doing so they have done their students a serious disservice. The Doppler redshift and the cosmological redshift are governed by two distinct formulas. The first comes from special relativity, which does not take into account the expansion of space, and the second comes from general relativity, which does. The two formulas are nearly the same for nearby galaxies but diverge for distant galaxies.

According to the usual Doppler formula, objects whose velocity through space approaches light speed have redshifts that approach infinity. Their wavelengths become too long to observe. If that were true for galaxies, the most distant visible objects in the sky would be receding at velocities just shy of the speed of light. But the cosmological redshift formula leads to a different conclusion. In the current standard model of cosmology, galaxies with a redshift of about 1.5—that is, whose light has a wavelength 150 percent longer than the laboratory reference value—are receding at the speed of light. Astronomers have observed about 1,000 galaxies with redshifts larger than 1.5. That is, they have observed about 1,000 objects receding from us faster than the speed of light. Equivalently, we are receding from those galaxies faster than the speed of light. The radiation of the cosmic microwave background has traveled even farther and has a redshift of about 1,000. When the hot plasma of the early universe emitted the radiation we now see, it was receding from our location at about 50 times the speed of light.

Running to Stay Still

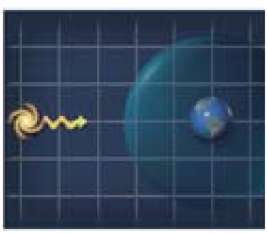
THE IDEA OF SEEING faster-than-light galaxies may sound mystical, but it is made possible by changes in the expansion rate. Imagine a light beam that is farther than the Hubble distance of 14 billion light-years and trying to travel in our direction. It is moving toward us at the speed of light with respect to its local space, but its local space is receding from us faster than the speed of light. Although the light beam is traveling toward us at the maximum speed possible, it cannot keep up with the stretching of space. It is a bit like a child trying to run the wrong way on a moving sidewalk. Photons at the Hubble distance are like the Red Queen and Alice, running as fast as they can just to stay in the same place.

One might conclude that the light beyond the Hubble distance would never reach us and that its source would be forever undetectable. But the Hubble distance is not fixed, because the Hubble constant, on which it depends, changes with time. In particular, the constant is proportional to the rate of increase in the distance between two galaxies, divided by that distance. (Any two galaxies can be used for this calculation.) In models of the universe that fit the observational data, the denominator increases faster than the numerator, so the Hubble constant decreases. In this way, the Hubble distance gets larger. As it does, light that was initially just outside the Hubble distance and receding from us can come within the Hubble distance. The photons then find themselves in a region of space that is receding slower than the speed of light. Thereafter they can approach us.

CAN WE SEE GALAXIES RECEDING FASTER THAN LIGHT?

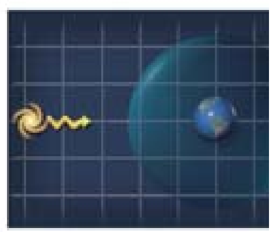
WRONG: **Of course not. Light from those galaxies never reaches us.**

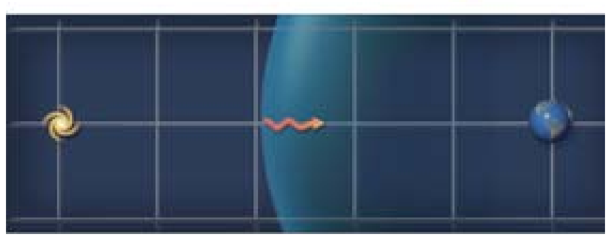
A galaxy farther than the Hubble distance (*sphere*) recedes from us faster than light. It emits a photon (*yellow squiggle*). As space expands, the photon is dragged away like someone trying to swim against the current. The photon never reaches us.



RIGHT: **Sure we can, because the expansion rate changes over time.**

The photon initially is unable to approach us. But the Hubble distance is not constant; it is increasing and can grow to encompass the photon. Once that happens, the photon approaches us and eventually reaches us.



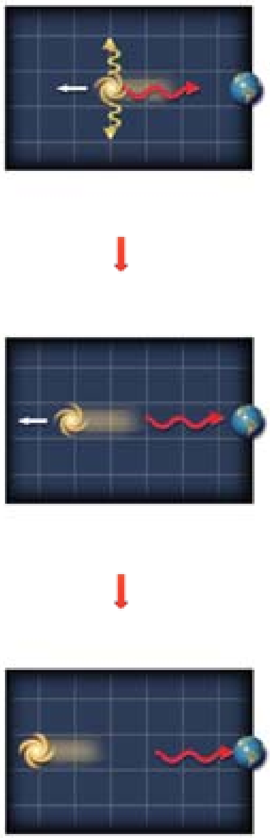


ALFRED T. KAMAJIAN

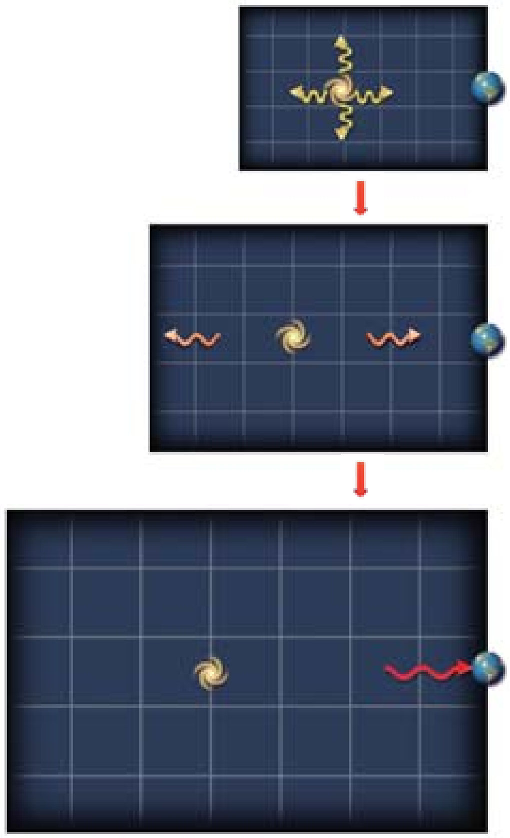
WHY IS THERE A COSMIC REDSHIFT?

***WRONG:* Because receding galaxies are moving through space and exhibit a Doppler shift.**

In the Doppler effect, a galaxy's movement away from the observer stretches the light waves, making them redder (*top*). The wavelength of light then stays the same during its journey through space (*middle*). The observer detects the light, measures its Doppler redshift and computes the galaxy velocity (*bottom*).



***RIGHT:* Because expanding space stretches all light waves as they propagate.**



Galaxies hardly move through space, so they emit light with nearly the same wavelength in all directions (*top*). The wavelength gets longer during the journey, because space is expanding. Thus, the light gradually reddens (*middle* and *bottom*). The amount of redshift differs from what a Doppler shift would produce.

ALFRED T. KAMAJIAN

The galaxy they came from, though, may continue to recede superluminally. Thus, we can observe light from galaxies that have always been and will always be receding faster than the speed of light. Another way to put it is that the Hubble distance is not fixed and does not mark the edge of the observable universe.

What does mark the edge of observable space? Here again there has been confusion. If space were not expanding, the most distant object we could see would now be about 14 billion light-years away from us, the distance light could have traveled in the 14 billion years since the big bang. But because the universe is expanding, the space traversed by a photon expands behind it during the voyage. Consequently, the current distance to the most distant object we can see is about three times farther, or 46 billion light-years.

The recent discovery that the rate of cosmic expansion is accelerating makes things even more interesting. Previously, cosmologists thought that we lived in a decelerating universe and that ever more galaxies would come into view. In an accelerating universe, however, we are surrounded by a boundary beyond which occur events we will never see—a cosmic event horizon. If light from galaxies receding faster than light is to reach us, the Hubble distance has to increase, but in an accelerating universe, it stops increasing. Distant events may send out light beams aimed in our direction, but this light is trapped beyond the Hubble distance by the acceleration of the expansion.

An accelerating universe, then, resembles a black hole in that it has an event horizon, an edge beyond which we cannot see. The current distance to our cosmic event horizon is 16 billion light-years, well within our observable range. Light emitted from galaxies that are now beyond the event horizon will never be able to reach us; the distance that currently corresponds to 16 billion light-years will expand too quickly. We will still be able to see events that took place in those galaxies before they crossed the horizon, but subsequent events will be forever beyond our view.

Is Brooklyn Expanding?

IN *ANNIE HALL*, the movie character played by the young Woody Allen explains to his doctor and mother why he can't do his homework. "The universe is expanding.... The universe is everything, and if it's expanding, someday it will break apart and that would be the end of everything!" But his mother knows better: "You're here in Brooklyn. Brooklyn is not expanding!"

His mother is right. Brooklyn is not expanding. People often assume that as space expands, everything in it expands as well. But this is not true. Expansion by itself—that is, a coasting expansion neither accelerating nor decelerating—produces no force. Photon wavelengths expand with the universe because, unlike atoms and cities, photons are not coherent objects whose size has been set by a compromise among forces. A changing rate of expansion does add a new force to the mix, but even this new force does not make objects expand or contract.

For example, if gravity got stronger, your spinal cord would compress until the electrons in your vertebrae reached a new equilibrium slightly closer together. You would be a shorter person, but you would not continue to shrink. In the same way, if we lived in a universe dominated by the attractive force of gravity, as most cosmologists thought until a few years ago, the expansion would decelerate, putting a gentle squeeze on bodies in the universe, making them reach a smaller equilibrium size. Having done so, they would not keep shrinking.

In fact, in our universe the expansion is accelerating, and that exerts a gentle outward force on bodies. Consequently, bound objects are slightly larger than they would be in a nonaccelerating universe, because the equilibrium among forces is reached at a slightly larger size. At Earth's surface, the outward acceleration away from the planet's center equals a tiny fraction (10^{-30}) of the normal inward gravitational acceleration. If this acceleration is constant, it does not make Earth expand; rather the planet simply settles into a static equilibrium size slightly larger than the size it would have attained.

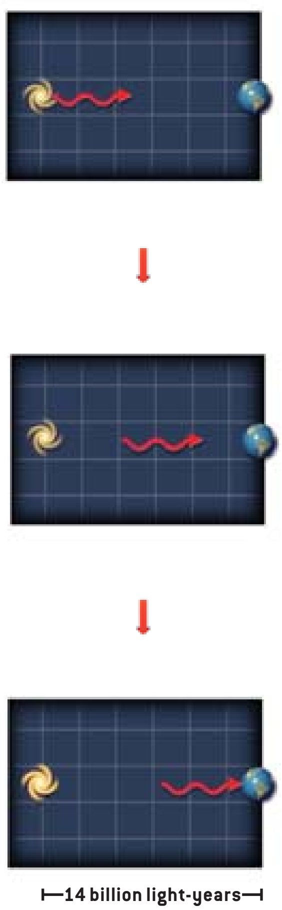
This reasoning changes if acceleration is not constant, as some cosmologists have speculated. If the acceleration itself increased, it could eventually grow strong enough to tear apart all structures, leading to a "big rip." But this rip would occur not because of expansion or acceleration per se but because of an accelerating acceleration.

The big bang model is based on observations of expan-

HOW LARGE IS THE OBSERVABLE UNIVERSE?

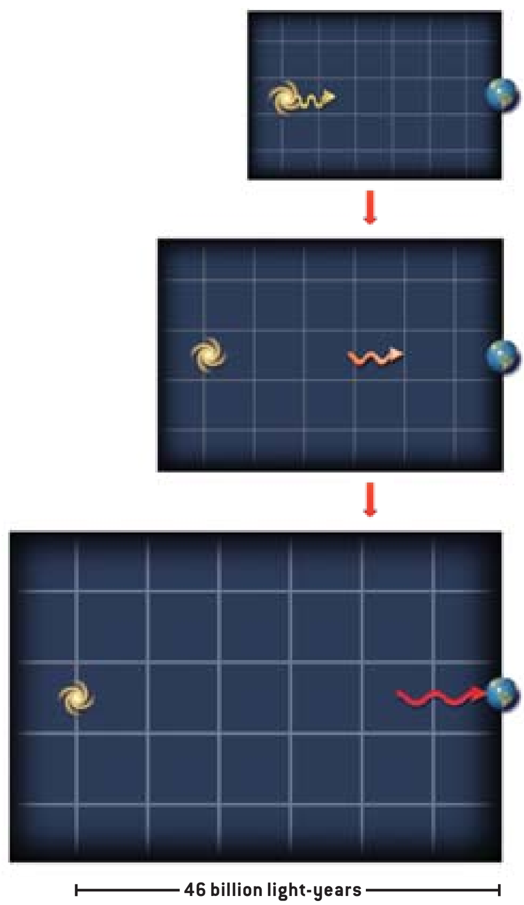
WRONG: **The universe is 14 billion years old, so the radius of the observable part is 14 billion light-years.**

Consider the most distant observable galaxy—one whose photons, emitted shortly after the big bang, are only now reaching us. A light-year is the distance photons travel in one year. So a photon from that galaxy has traveled 14 billion light-years.



RIGHT: **Because space is expanding, the observable part of our universe has a radius of more than 14 billion light-years.**

As a photon travels, the space it traverses expands. By the time it reaches us, the total distance to the originating galaxy is larger than a simple calculation based on the travel time might imply—about three times as large.

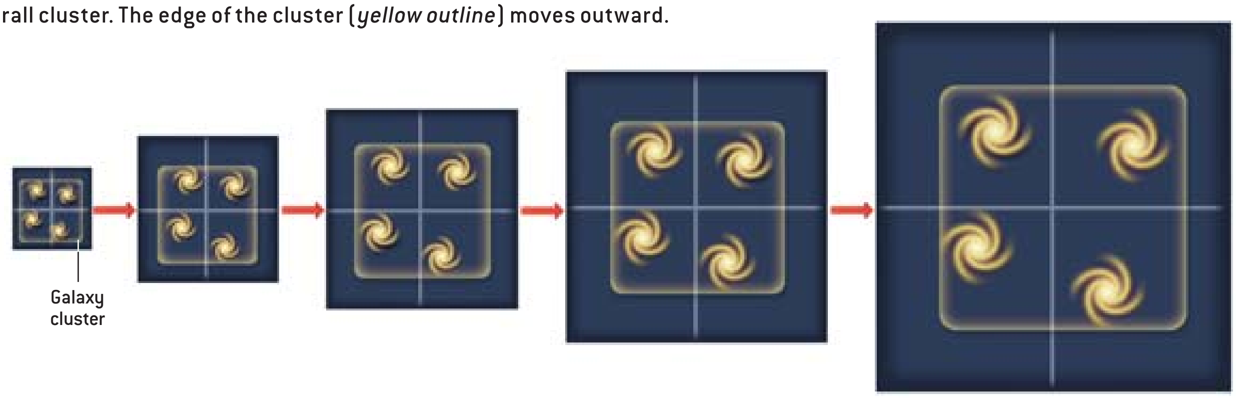


ALFRED T. KAMAJIAN

DO OBJECTS INSIDE THE UNIVERSE EXPAND, TOO?

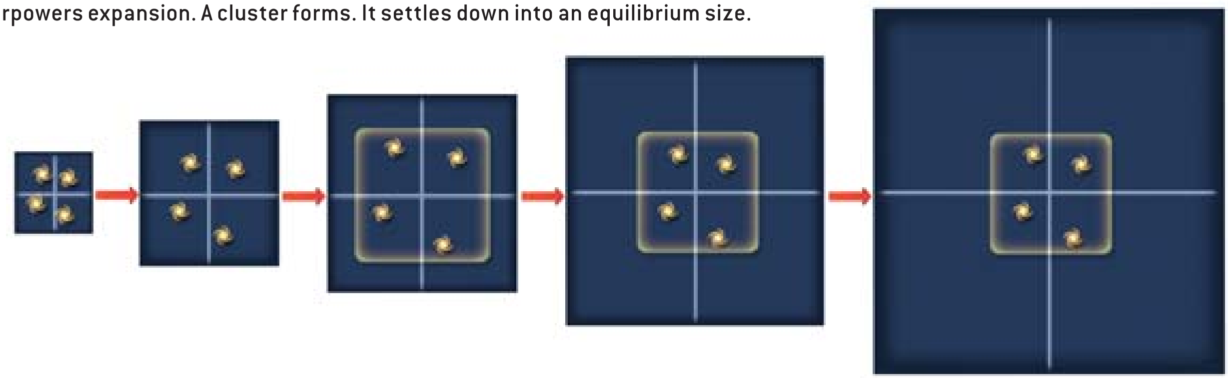
WRONG: **Yes. Expansion causes the universe and everything in it to grow.**

Consider galaxies in a cluster. As the universe gets bigger, so do the galaxies and the overall cluster. The edge of the cluster (*yellow outline*) moves outward.



RIGHT: **No. The universe grows, but coherent objects inside it do not.**

Neighboring galaxies initially get pulled apart, but eventually their mutual gravity overpowers expansion. A cluster forms. It settles down into an equilibrium size.



sion, the cosmic microwave background, the chemical composition of the universe and the clumping of matter. Like all scientific ideas, the model may one day be superseded. But it fits the current data better than any other model we have. As new precise measurements enable cosmologists to understand expansion and acceleration better, they can ask even more fundamental questions about the earliest times and largest scales of the universe. What caused the expansion? Many cosmologists attribute it to a process known as inflation, a type of accelerating expansion. But that can only be a partial answer, because it seems that to start inflating, the universe already had to be expanding. And what about the largest scales, beyond what we can see? Do different parts of the universe expand by different amounts, such that our universe is a single inflationary bubble of a much larger multiverse? Nobody knows. Although many questions remain, increasingly precise observations suggest that the universe will expand forever. We hope, though, the confusion about the expansion will shrink. SA

ALFRED T. KAMAJIAN

MORE TO EXPLORE

Cosmology: The Science of the Universe. Edward R. Harrison. Cambridge University Press, 2000.

The Cosmic Microwave Background Radiation Temperature at a Redshift of 2.34. R. Srianand, P. Petitjean and C. Ledoux in *Nature*, Vol. 408, No. 6815, pages 931–935; December 21, 2000. Available online at **arxiv.org/abs/astro-ph/0012222**

Solutions to the Tethered Galaxy Problem in an Expanding Universe and the Observation of Receding Blueshifted Objects. Tamara M. Davis, Charles H. Lineweaver and John K. Webb in *American Journal of Physics*, Vol. 71, No. 4, pages 358–364; April 2003. **astro-ph/0104349**

Expanding Confusion: Common Misconceptions of Cosmological Horizons and the Superluminal Expansion of the Universe. Tamara M. Davis and Charles H. Lineweaver in *Publications of the Astronomical Society of Australia*, Vol. 21, No. 1, pages 97–109; February 2004. **astro-ph/0310808**

An excellent resource for dispelling cosmological misconceptions is Ned Wright's Cosmology Tutorial at **www.astro.ucla.edu/~wright/cosmolog.htm**

AGRICULTURAL TERRACES have been constructed for some 2,000 years. Those on the opposite page are in Guizhou Province, China.

HOW DID HUMANS FIRST ALTER GLOBAL CLIMATE?

A bold new hypothesis suggests that our ancestors' farming practices kicked off global warming thousands of years before we started burning coal and driving cars

By William F. Ruddiman

The scientific consensus that human actions first began to have a warming effect on the earth's climate within the past century has become part of the public perception as well. With the advent of coal-burning factories and power plants, industrial societies began releasing carbon dioxide (CO_2) and other greenhouse gases into the air. Later, motor vehicles added to such emissions. In this scenario, those of us who have lived during the industrial era are responsible not only for the gas buildup in the atmosphere but also for at least part of the accompanying global warming trend. Now, though, it seems our ancient agrarian ancestors may have begun adding these gases to the atmosphere many millennia ago, thereby altering the earth's climate long before anyone thought.

New evidence suggests that concentrations of CO_2 started rising about 8,000 years ago, even though natural trends indicate they should have been dropping. Some 3,000 years later the same thing happened to methane, another heat-trapping gas. The consequences of these surprising rises have been profound. Without them, current temperatures in northern parts of North America and Europe would be cooler by three to four degrees Celsius—enough to make agriculture difficult. In addition, an incipient ice age—marked by the appearance of small ice caps—would probably have begun several thousand years ago in parts of northeastern Canada. Instead the earth's climate has remained relatively warm and stable in recent millennia.

GEORG GERSTER *Photo Researchers, Inc.*

Until a few years ago, these anomalous reversals in greenhouse gas trends and their resulting effects on climate had escaped notice. But after studying the problem for some time, I realized that about 8,000 years ago the gas trends stopped following the pattern that would be predicted from their past long-term behavior, which had been marked by regular cycles. I concluded that human activities tied to farming—primarily agricultural deforestation and crop irrigation—must have added the extra CO_2 and methane to the atmosphere. These activities explained both the reversals in gas trends and the ongoing increases right up to the start of the industrial era. Since then, modern technological innovations have brought about even faster rises in greenhouse gas concentrations.

My claim that human contributions have been altering the earth's climate for millennia is provocative and controversial. Other scientists have reacted to this proposal with the mixture of enthusiasm and skepticism that is typical when novel ideas are put forward, and testing of this hypothesis is now under way.

My claim that human contributions have been ALTERING THE EARTH'S CLIMATE FOR MILLENNIA is provocative and controversial.

The Current View

THIS NEW IDEA builds on decades of advances in understanding long-term climate change. Scientists have known since the 1970s that three predictable variations in the earth's orbit around the sun have exerted the dominant control over long-term global climate for millions of years. As a consequence of these orbital cycles (which operate over 100,000, 41,000 and 22,000 years), the amount of solar radiation reaching various parts of the globe during a given season can differ by more than 10 percent. Over the past three million years, these regular changes in the amount of sunlight reaching the planet's surface have produced a long sequence of ice ages (when great areas of Northern Hemisphere continents were covered with ice) separated by short, warm interglacial periods.

Dozens of these climatic sequences occurred over the millions of years when hominids were slowly evolving toward anatomically modern humans. At the end of the most recent glacial period, the ice sheets that had blanketed northern Europe and North America for the previous 100,000 years shrank and, by 6,000 years ago, had disappeared. Soon after, our ancestors built cities, invented writing and founded religions. Many scientists credit much of the progress of civilization to this naturally warm gap between less favorable glacial intervals, but in my opinion this view is far from the full story.

In recent years, cores of ice drilled in the Antarctic and Greenland ice sheets have provided extremely valuable evidence about the earth's past climate, including changes in the concentrations of the greenhouse gases. A three-kilometer-long ice core retrieved from Vostok Station in Antarctica during the 1990s contained trapped bubbles of ancient air that revealed the composition of the atmosphere (and the gases) at the time the ice layers formed. The Vostok ice confirmed that concentrations of CO_2 and methane rose and fell in a regular pattern during virtually all of the past 400,000 years.

Particularly noteworthy was that these increases and decreases in greenhouse gases occurred at the same intervals as variations in the intensity of solar radiation and the size of the ice sheets. For example, methane concentrations fluctuate mainly at the 22,000-year tempo of an orbital cycle called precession. As the earth spins on its rotation axis, it wobbles like a top, slowly swinging the Northern Hemisphere closer to and then farther from the sun. When this precessional wobble brings the northern continents nearest the sun during the summertime, the atmosphere gets a notable boost of methane from its primary natural source—the decomposition of plant matter in wetlands.

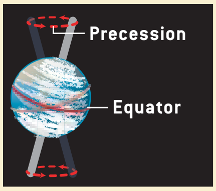
After wetland vegetation flourishes in late summer, it then dies, decays and emits carbon in the form of methane, sometimes called swamp gas. Periods of maximum summertime heating enhance methane production in two primary ways: In southern Asia, the warmth draws additional moisture-laden air in from the Indian Ocean, driving strong tropical monsoons that flood regions that might otherwise stay dry. In far northern Asia and Europe, hot summers thaw boreal wetlands for longer periods of the year. Both processes enable more vegetation to grow, decompose and emit methane every 22,000 years. When the Northern Hemisphere veers farther from

Overview/*Early Global Warming*

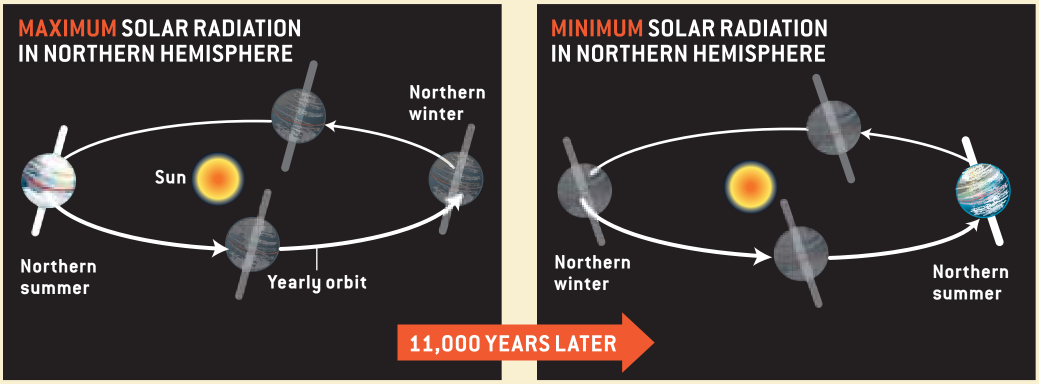
- A new hypothesis challenges the conventional assumption that greenhouse gases released by human activities have perturbed the earth's delicate climate only within the past 200 years.
- New evidence suggests instead that our human ancestors began contributing significant quantities of greenhouse gases to the atmosphere thousands of years earlier by clearing forests and irrigating fields to grow crops.
- As a result, human beings kept the planet notably warmer than it would have been otherwise—and possibly even averted the start of a new ice age.

Orbital Controls over Greenhouse Gases

Natural variations in the earth's orbit, such as those related to precession (*diagrams*), redistribute the sunlight that reaches the globe over long timescales. For the past million years, these subtle changes have driven major dips and swells in atmospheric concentrations of methane and carbon dioxide (*graphs*). Although scientists do not fully understand why, global concentrations of these greenhouse gases respond mainly to changes that occur during summer in the Northern Hemisphere, the time of year when the North Pole is pointed most directly at the sun.

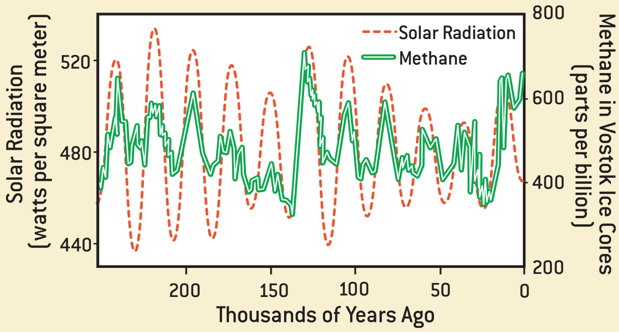


Wobble in the earth's axis of rotation, known as precession, is one of the three orbital cycles that account for sunlight variations in the Northern Hemisphere. Like a toy top about to fall, the earth's axis traces imaginary circles in space, making one revolution every 22,000 years.

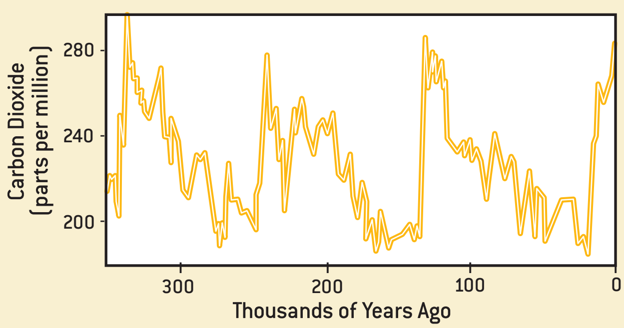


Summer warmth in the Northern Hemisphere peaks once every 22,000 years, when the yearly northern summer coincides with the earth's closest passage to the sun and the Northern Hemisphere receives the most intense sunlight.

Summer heat bottoms out 11,000 years later, after the earth's axis has shifted (precessed) to the opposite position. The Northern Hemisphere then receives the least summer sunlight, because the earth is farthest from the sun.



Methane concentrations rose and fell over the past 250,000 years in near harmony with the precession-induced ups and downs of solar radiation in the Northern Hemisphere. The highest temperatures stimulated extreme methane production in wetlands, which are the atmosphere's primary natural source of this greenhouse gas.



CO_2 concentrations, which fluctuated in cycles over the past 350,000 years, varied in response to precession as well as to shifts in the tilt of the earth's rotational axis and in the shape of its orbit. These other cycles occur every 41,000 and 100,000 years, respectively.

LUCY READING-IKKANDA

the sun, methane emissions start to decline. They bottom out 11,000 years later—the point in the cycle when Northern Hemisphere summers receive the least solar radiation.

Unexpected Reversals

EXAMINING RECORDS from the Vostok ice core closely, I spotted something odd about the recent part of the record. Early in previous interglacial intervals, the methane concentration typically reached a peak of almost 700 parts per billion (ppb) as precession brought summer radiation to a maximum. The same thing happened 11,000 years ago, just as the current interglacial period began. Also in agreement with prior cycles, the methane concentration then declined by 100 ppb as summer sunshine subsequently waned. Had the recent trend continued to mimic older interglacial intervals, it would have fallen to a value near 450 ppb during the current minimum in summer heating. Instead the trend reversed direction 5,000 years ago and rose gradually back to almost 700 ppb just before the start of the industrial era. In short, the methane concentration rose when it should have fallen, and it ended up 250 ppb higher than the equivalent point in earlier cycles.

Like methane, CO_2 has behaved unexpectedly over the past several thousand years. Although a complex combination of all three orbital cycles controls CO_2 variations, the trends during previous interglacial intervals were all surprisingly similar to one another. Concentrations peaked at 275 to 300 parts per million (ppm) early in each warm period, even before the last remnants of the great ice sheets finished melting. The CO_2 levels then fell steadily over the next 15,000 years to an average of about

245 ppm. During the current interglacial interval, CO_2 concentrations reached the expected peak around 10,500 years ago and, just as anticipated, began a similar decline. But instead of continuing to drop steadily through modern times, the trend reversed direction 8,000 years ago. By the start of the industrial era, the concentration had risen to 285 ppm—roughly 40 ppm higher than expected from the earlier behavior.

What could explain these unexpected reversals in the natural trends of both methane and CO_2? Other investigators suggested that natural factors in the climate system provided the answer. The methane increase has been ascribed to expansion of wetlands in Arctic regions and the CO_2 rise to natural losses of carbon-rich vegetation on the continents, as well as to changes in the chemistry of the ocean. Yet it struck me that these explanations were doomed to fail for a simple reason. During the four preceding interglaciations, the major factors thought to influence greenhouse gas concentrations in the atmosphere were nearly the same as in recent millennia. The northern ice sheets had melted, northern forests had reoccupied the land uncovered by ice, meltwater from the ice had returned sea level to its high interglacial position, and solar radiation driven by the earth's orbit had increased and then begun to decrease in the same way.

Why, then, would the gas concentrations have fallen during the last four interglaciations yet risen only during the current one? I concluded that something new to the natural workings of the climate system must have been operating during the past several thousand years.

The Human Connection

THE MOST PLAUSIBLE "new factor" operating in the climate system during the present interglaciation is farming. The basic timeline of agricultural innovations is well known. Agriculture originated in the Fertile Crescent region of the eastern Mediterranean around 11,000 years ago, shortly thereafter in northern China, and several thousand years later in the Americas. Through subsequent millennia it spread to other regions and increased in sophistication. By 2,000 years ago, every crop food eaten today was being cultivated somewhere in the world.

Several farming activities generate methane. Rice paddies flooded by irrigation generate methane for the same reason that natural wetlands do—vegetation decomposes in the stagnant standing water. Methane is also released as farmers burn grasslands to attract game and promote growth of berries. In addition, people and their domesticated animals emit methane with feces and belches. All these factors probably contributed to a gradual rise in methane as human populations grew slowly, but only one process seems likely to have accounted for the abruptness of the reversal from a natural methane decline to an unexpected rise around 5,000 years ago—the onset of rice irrigation in southern Asia.

Farmers began flooding lowlands near rivers to grow wet-adapted strains of rice around 5,000 years ago in the south of China. With extensive floodplains lying within easy reach of several large rivers, it makes sense that broad swaths of land could have been flooded soon after the technique was discovered, thus explaining the quick shift in the methane trend. Historical records also indicate a steady expansion in rice irrigation throughout the interval when methane values were rising. By 3,000 years ago the technique had spread south into Indochina and west to the Ganges River Valley in India, further increasing

Human Activities and Greenhouse Gases

Our human ancestors invented agriculture about 11,000 years ago—around the same time that atmospheric concentrations of methane and CO_2 peaked in the wake of the last ice age. Had the gas trends subsequently mimicked older interglacial intervals, as expected, they would have fallen right up through the start of the industrial era. Instead the declining trends of both gases reversed direction several thousand years ago and have risen steadily ever since. The timing of key agricultural innovations—namely, deforestation and rice irrigation—may explain these surprising reversals. —W.F.R.

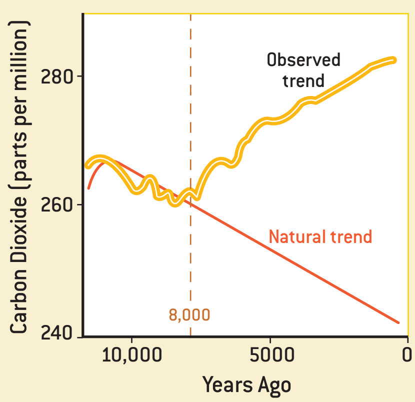
11,000 years ago: Early peoples invent agriculture in Mesopotamia and China

Paleolithic sickle blade

Carbonized wheat

8,000 years ago: Late Stone Age Europeans begin clearing forests to grow wheat, barley, peas and other nonindigenous crop plants

10,000 YEARS AGO — 8,000 YEARS AGO



8,000 years ago: CO_2 trend, which has been falling for 2,500 years, bottoms out and suddenly reverses direction

7,500 years ago: Humans adapt wild rice for cultivation

PETRIE MUSEUM OF EGYPTIAN ARCHAEOLOGY, UNIVERSITY COLLEGE LONDON (*sickle blade* and *carbonized wheat*); JONATHAN BLAIR *Corbis* (*rice*)

THE AUTHOR

WILLIAM F. RUDDIMAN is a marine geologist and professor emeritus of environmental sciences at the University of Virginia. He joined the faculty there in 1991 and served as department chair from 1993 to 1996. Ruddiman first began studying records of climate change in ocean sediments as a graduate student at Columbia University, where he received his doctorate in 1969. He then worked as a senior scientist and oceanographer with the U.S. Naval Oceanographic Office in Maryland and later as a senior research scientist at Columbia's Lamont-Doherty Earth Observatory.

methane emissions. After 2,000 years, farmers began to construct rice paddies on the steep hillsides of Southeast Asia.

Future research may provide quantitative estimates of the amount of land irrigated and methane generated through this 5,000-year interval. Such estimates will be probably be difficult to come by, however, because repeated irrigation of the same areas into modern times has probably disturbed much of the earlier evidence. For now, my case rests mainly on the basic fact that the methane trend went the "wrong way" and that farmers began to irrigate wetlands at just the right time to explain this wrong-way trend.

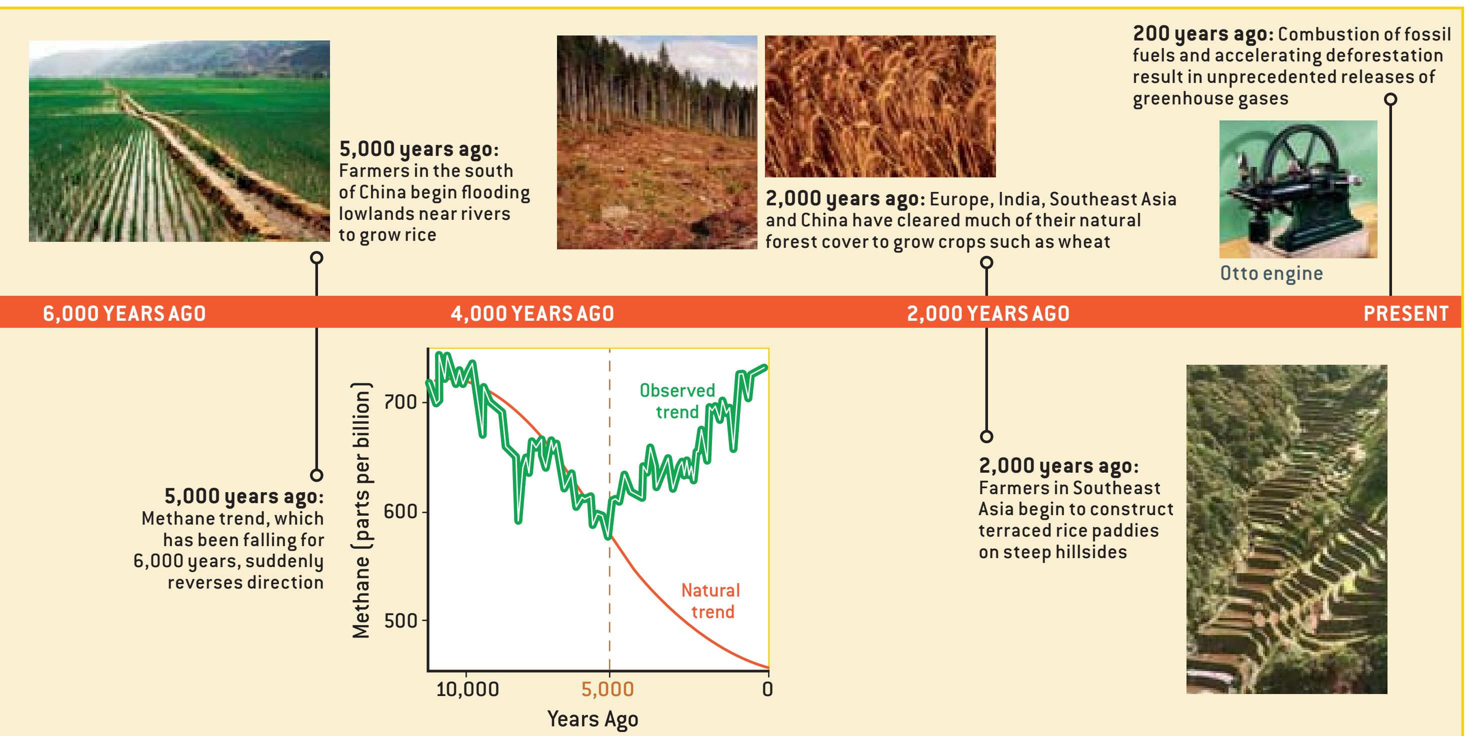
Another common practice tied to farming—deforestation—provides a plausible explanation for the start of the anomalous CO_2 trend. Growing crops in naturally forested areas requires cutting trees, and farmers began to clear forests for this purpose in Europe and China by 8,000 years ago, initially with axes made of stone and later from bronze and then iron. Whether the fallen trees were burned or left to rot, their carbon would have soon oxidized and ended up in the atmosphere as CO_2.

Scientists have precisely dated evidence that Europeans began growing nonindigenous crop plants such as wheat, barley and peas in naturally forested areas just as the CO_2 trend reversed 8,000 years ago. Remains of these plants, initially cultivated in the Near East, first appear in lake sediments in southeastern Europe and then spread to the west and north over the next several thousand years. During this interval, silt and clay began to wash into rivers and lakes from denuded hillsides at increasing rates, further attesting to ongoing forest clearance.

The most unequivocal evidence of early and extensive deforestation lies in a unique historical document—the Domesday Book. This survey of England, ordered by William the Conqueror, reported that 90 percent of the natural forest in lowland, agricultural regions was cleared as of A.D. 1086. The survey also counted 1.5 million people living in England at the time, indicating that an average density of 10 people per square kilometer was sufficient to eliminate the forests. Because the advanced civilizations of the major river valleys of China and India had reached much higher population densities several thousand years prior, many historical ecologists have concluded that these regions were heavily deforested some two or even three thousand years ago. In summary, Europe and southern Asia had been heavily deforested long before the start of the industrial era, and the clearance process was well under way throughout the time of the unusual CO_2 rise.

An Ice Age Prevented?

IF FARMERS WERE responsible for greenhouse gas anomalies this large—250 ppb for methane and 40 ppm for CO_2 by the 1700s—the effect of their practices on the earth's climate would have been substantial. Based on the aver-



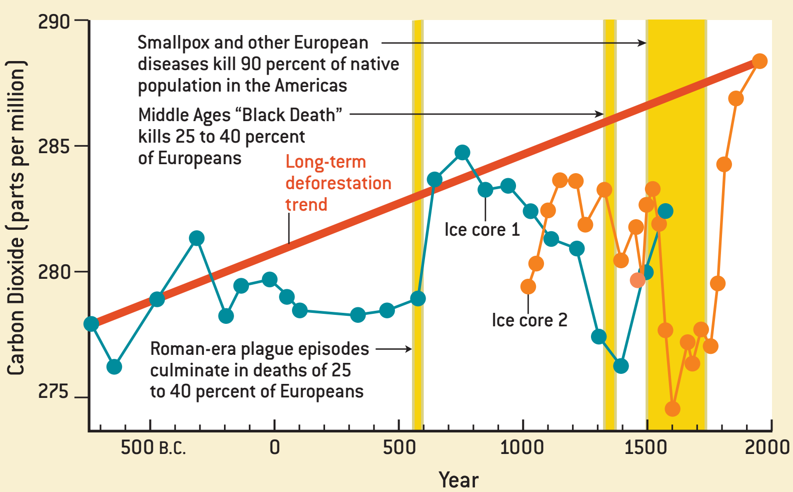
JULIA WATERLOW *Eye Ubiquitous/Corbis* (*irrigation*); THE IMAGE BANK (*deforestation*); VINCE STREANO *Corbis* (*wheat field*); DAVID GREEDY *Getty Images* (*rice terraces*); SCIENCE LIBRARY/SSPL (*combustion engine*); LUCY READING-IKKANDA (*graphs*)

Human Disease and Global Cooling

Concentrations of CO_2 in the atmosphere have been climbing since about 8,000 years ago. During the past two millennia, however, that steady increase at times reversed direction, and the CO_2 levels fell for decades or more. Scientists usually attribute such CO_2 drops—and the accompanying dips in global temperature—to natural reductions in the sun's energy output or to volcanic eruptions. These factors have been regarded as major drivers of climate change over decades or centuries, but for the CO_2 patterns, such explanations fall short—which implies that an additional factor forced CO_2 levels downward. Because I had already concluded that our human ancestors had caused the slow rise in CO_2 for thousands of years by clearing forests for agriculture (*see main article*), this new finding made me wonder whether some kind of reversal of the ongoing clearance could explain the brief CO_2 drops.

The most likely root cause turns out to be disease—the massive human mortality accompanying pandemics. Two severe outbreaks of bubonic plague, the single most devastating killer in human history, correlate well with large CO_2 drops at approximately A.D. 540 and 1350 (*graph*). Plague first erupted during the Roman era, with the most virulent pandemic, the Plague of Justinian, in A.D. 540 to 542. The infamous "Black Death" struck between 1347 and 1352, followed by lesser outbreaks for more than a century. Each of these pandemics killed some 25 to 40 percent of the population of Europe. An even worse catastrophe followed in the Americas after 1492, when Europeans introduced smallpox and a host of other diseases that killed around 50 million people, or about 90 percent of the pre-Columbian population. The American pandemic coincides with the largest CO_2 drop of all, from 1550 to 1800.

Observers at the time noted that the massive mortality rates produced by these pandemics caused widespread abandonment of rural villages and farms, leaving untended farmland to revert to the wild. Ecologists have shown that forests will reoccupy abandoned land in just 50 years. Coupled with estimates of human population and the acreage cultivated by each farmer, calculations of forest regrowth in pandemic-stricken regions indicate that renewed forests could have sequestered enough carbon to reduce concentrations of CO_2 in the atmosphere by the amounts observed. Global climate would have cooled as a result, until each pandemic passed and rebounding populations began cutting and burning forests anew. *—W.F.R.*



MOST DRAMATIC DROPS in atmospheric CO_2 concentrations during the past 2,000 years (as recorded in two Antarctic ice cores) occurred around the same periods that disease outbreaks were taking the greatest toll on human life (*yellow bars*).

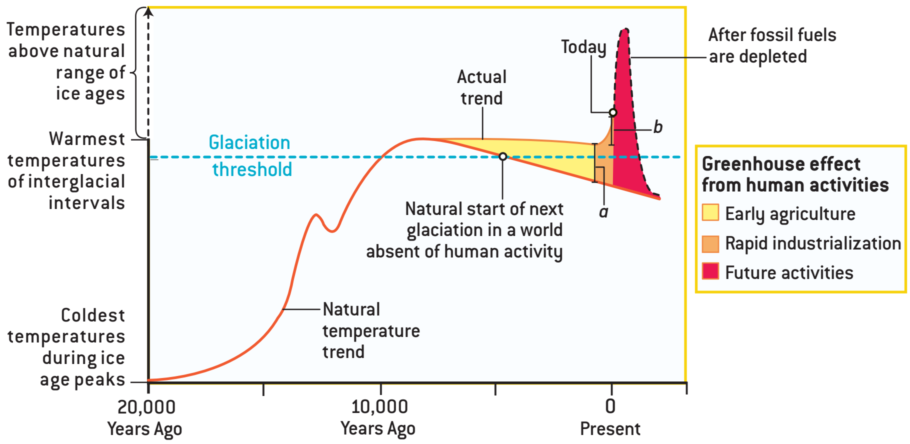
age sensitivity shown by a range of climate models, the combined effect from these anomalies would have been an average warming of almost 0.8 degree C just before the industrial era. That amount is larger than the 0.6 degree C warming measured during the past century—implying that the effect of early farming on climate rivals or even exceeds the combined changes registered during the time of rapid industrialization.

How did this dramatic warming effect escape recognition for so long? The main reason is that it was masked by natural climatic changes in the opposite direction. The earth's orbital cycles were driving a simultaneous natural cooling trend, especially at high northern latitudes. The net temperature change was a gradual summer cooling trend lasting until the 1800s.

Had greenhouse gases been allowed to follow their natural tendency to decline, the resulting cooling would have augmented the one being driven by the drop in summer radiation, and this planet would have become considerably cooler than it is now. To explore this possibility, I joined with Stephen J. Vavrus and John E. Kutzbach of the University of Wisconsin–Madison to use a climate model to predict modern-day temperature in the absence of all human-generated greenhouse gases. The model simulates the average state of the earth's climate—including temperature and precipitation—in response to different initial conditions.

For our experiment, we reduced the greenhouse gas levels in the atmosphere to the values they would have reached today without early farming or industrial emissions. The resulting simulation showed that our planet would be almost two degrees C cooler than it is now—a significant difference. In comparison, the global mean temperature at the last glacial maximum 20,000 years ago was only five to six degrees C colder than it is today. In effect, current temperatures would be well on the way toward typical glacial temperatures had it not been for the greenhouse gas contributions from early farming practices and later industrialization.

LUCY READING-IKKANDA



GREENHOUSE EFFECT from human activities has warded off a glaciation that otherwise would have begun about 5,000 years ago. Early human agricultural activities produced enough greenhouse gases to offset most of the natural cooling trend during preindustrial times (*yellow*), warming the planet by an average of almost 0.8 degree Celsius. That early warming effect (*a*) rivals the 0.6 degree Celsius (*b*) warming measured in the past century of rapid industrialization (*orange*). Once most fossil fuels are depleted and the temperature rise caused by greenhouse gases peaks, the earth will cool toward the next glaciation—now thousands of years overdue.

I had also initially proposed that new ice sheets might have begun to form in the far north if this natural cooling had been allowed to proceed. Other researchers had shown previously that parts of far northeastern Canada might be ice covered today if the world were cooler by just 1.5 to two degrees C—the same amount of cooling that our experiment suggested has been offset by the greenhouse gas anomalies. The later modeling effort with my Wisconsin colleagues showed that snow would now persist into late summer in two areas of northeastern Canada: Baffin Island, just east of the mainland, and Labrador, farther south. Because any snow that survives throughout the summer will accumulate in thicker piles year by year and eventually become glacial ice, these results suggest that a new ice age would have begun in northeast Canada several millennia ago, at least on a small scale.

This conclusion is startlingly different from the traditional view that human civilization blossomed within a period of warmth that nature provided. As I see it, nature would have cooled the earth's climate, but our ancestors kept it warm by discovering agriculture.

Implications for the Future

THE CONCLUSION THAT humans prevented a cooling and arguably stopped the initial stage of a glacial cycle bears directly on a long-running dispute over what global climate has in store for us in the near future. Part of the reason that policymakers had trouble embracing the initial predictions of global warming in the 1980s was that a number of scientists had spent the previous decade telling everyone almost exactly the opposite—that an ice age was on its way. Based on the new confirmation that orbital variations control the growth and decay of ice sheets, some scientists studying these longer-scale changes had reasonably concluded that the next ice age might be only a few hundred or at most a few thousand years away.

In subsequent years, however, investigators found that greenhouse gas concentrations were rising rapidly and that the earth's climate was warming, at least in part because of the gas increases. This evidence convinced most scientists that the relatively near-term future (the next century or two) would be dominated by global warming rather than by global cooling. This revised prediction, based on an improved understanding of the climate system, led some policymakers to discount all forecasts—whether of global warming or an impending ice age—as untrustworthy.

My findings add a new wrinkle to each scenario. If anything, such forecasts of an "impending" ice age were actually understated: new ice sheets should have begun to grow several millennia ago. The ice failed to grow because human-induced global warming actually began far earlier than previously thought—well before the industrial era.

In these kinds of hotly contested topics that touch on public policy, scientific results are often used for opposing ends. Global-warming skeptics could cite my work as evidence that human-generated greenhouse gases played a beneficial role for several thousand years by keeping the earth's climate more hospitable than it would otherwise have been. Others might counter that if so few humans with relatively primitive technologies were able to alter the course of climate so significantly, then we have reason to be concerned about the current rise of greenhouse gases to unparalleled concentrations at unprecedented rates.

The rapid warming of the past century is probably destined to persist for at least 200 years, until the economically accessible fossil fuels become scarce. Once that happens, the earth's climate should begin to cool gradually as the deep ocean slowly absorbs the pulse of excess CO_2 from human activities. Whether global climate will cool enough to produce the long-overdue glaciation or remain warm enough to avoid that fate is impossible to predict. SA

MORE TO EXPLORE

Plagues and Peoples. William McNeill. Doubleday, 1976.

Ice Ages: Solving the Mystery. John Imbrie and Katherine Palmer Imbrie. Enslow, 1979.

Guns, Germs, and Steel: The Fates of Human Societies. Jared Diamond. W. W. Norton, 1999.

Earth's Climate: Past and Future. William F. Ruddiman. W. H. Freeman, 2001.

The Anthropogenic Greenhouse Era Began Thousands of Years Ago. William F. Ruddiman in *Climatic Change,* Vol. 61, No. 3, pages 261–293; 2003.

Deforesting the Earth: From Prehistory to Global Crisis. Michael A. Williams. University of Chicago Press, 2003.

Plows, Plagues, and Petroleum: How Humans Took Control of Climate. William F. Ruddiman. Princeton University Press (in press).

LUCY READING-IKKANDA

IF SMALLPOX STRIKES PORTLAND ...

BY CHRIS L. BARRETT, STEPHEN G. EUBANK AND JAMES P. SMITH

"EPISIMS" UNLEASHES VIRTUAL PLAGUES IN REAL CITIES TO SEE HOW SOCIAL NETWORKS SPREAD DISEASE. THAT KNOWLEDGE MIGHT HELP STOP EPIDEMICS

SIMULATING the social interactions that spread disease shows the course a pathogen might take from an individual (*circled*) through a population.

Suppose terrorists were to release plague in Chicago, and health officials, faced with limited resources and personnel, had to quickly choose the most effective response. Would mass administration of antibiotics be the best way to halt an outbreak? Or mass quarantines? What if a chance to nip a global influenza pandemic in the bud meant sending national stockpiles of antiviral drugs to Asia where a deadly new flu strain was said to be emerging? If the strategy succeeded, a worldwide crisis would be averted; if it failed, the donor countries would be left with less protection.

Public health officials have to make choices that could mean life or death for thousands, even millions, of people, as well as massive economic and social disruption. And history offers them only a rough guide. Methods that eradicated smallpox in African villages in the 1970s, for example, might not be the most effective tactics against smallpox released in a U.S. city in the 21st century. To identify the best responses under a variety of conditions in advance of disasters, health officials need a laboratory where "what if" scenarios can be tested as realistically as possible. That is why our group at Los Alamos National Laboratory (LANL) set out to build EpiSims, the largest individual-based epidemiology simulation model ever created.

Modeling the interactions of each individual in a population allows us to go beyond estimating the number of people likely to be infected; it lets us simulate the paths a disease would take through the population and thus where the outbreak could be intercepted most effectively. The networks that support everyday life and provide employment, transportation infrastructure, necessities and luxuries are the same ones that infectious diseases exploit to spread among human hosts. By modeling this social network in fine detail, we can understand its structure and how to alter it to disrupt the spread of disease while inflicting the least damage to the social fabric.

Virtual Epidemiology

LONG BEFORE the germ theory of disease, London physician John Snow argued that cholera, which had killed tens of thousands of people in England during the preceding 20 years, spread via the water supply. In the summer of 1854 he tested that theory during an outbreak in the Soho district. On a map, he marked the location of the homes of each of the

500 victims who had died in the preceding 10 days and noted where each victim had gotten water. He discovered that every one of them drank water from the Broad Street pump, so Snow convinced officials to remove the pump handle. His action limited the death toll to 616.

Tracing the activities and contacts of individual disease victims, as Snow did, remains an important tool for modern epidemiologists. And it is nothing new for health authorities to rely on models when developing policies to protect the public. Yet most mathematical models for understanding and predicting the course of disease outbreaks describe only the interactions of large numbers of people in aggregate. One reason is that modelers have often lacked detailed knowledge of how specific contagious diseases spread. Another is that they have not had realistic models of the social interactions in which people have contact with one another. And a third is that they have not had the computational and methodological means to build models of diseases interacting with dynamic human populations.

As a result, epidemiology models typically rely on estimates of a particular disease's "reproductive number"—the number of people likely to be infected by one contagious person or contaminated location. Often this reproductive number is a best guess based on historical situations, even though the culture, physical conditions and health status of people in those events may differ greatly from the present situation.

In real epidemics, these details matter. The rate at which susceptible people become infected depends on their individual state of health, the duration and nature of their interactions with contagious people, and specific properties of the disease pathogen itself. Truer models of outbreaks must capture the probability of disease transmission from one person to another, which means simulating not only the properties of the disease and the health of each individual but also detailed interactions between every pair of individuals in the group.

Attempts to introduce such epidemiological models have, until recently, considered only very small groups of 100 to 1,000 people. Their size has been limited because they are based on actual populations, such as the residents, visitors and staff of a nursing home, so they require detailed data about individuals and their contacts over days or weeks. Computing such a large number of interactions also presents substantial technical difficulties.

Truer models must capture the probability of disease transmission from one person to another.

Our group was able to construct this kind of individual-based epidemic model on a scale of millions of people by using high-performance supercomputing clusters and by building on an existing model called TRANSIMS developed over more than a decade at Los Alamos for urban planning [see "Unjamming Traffic with Computers," by Kenneth R. Howard; SCIENTIFIC AMERICAN, October 1997]. The TRANSIMS project started as a means of better understanding the potential effects of creating or rerouting roads and other transportation infrastructure. By giving us a way to simulate the movements of a large population through a realistic urban environment, TRANSIMS provided the foundation we needed to model the interactions of millions of individuals for EpiSims.

Although EpiSims can now be adapted to different cities, the original TRANSIMS model was based on Portland, Ore. The TRANSIMS virtual version of Portland incorporates detailed digital maps of the city, including representations of its rail lines, roads, signs, traffic signals and other transportation infrastructure, and produces information about traffic patterns and travel times. Publicly available data were used to generate 180,000 specific locations, a synthetic population of 1.6 million residents, and realistic daily activities for those people [*see box on opposite page*].

Integrating all this information into a computer model provides the best estimate of physical contact patterns for large human populations ever created. With EpiSims, we can release a virtual pathogen into these populations, watch it spread and test the effects of different interventions. But even without simulating a disease outbreak, the model provides intriguing insights into human social networks, with potentially important implications for epidemic response.

Social Networks

TO UNDERSTAND what a social network really is and how it can be used for epidemiology, imagine the daily activities and contacts of a single hypothetical adult, Ann. She has short brushes with family members during breakfast and then with other commuters or carpoolers on her way to work. Depending on her job, she might meet dozens of people

Overview/*Simulating Society*

- Epidemiological simulations provide virtual laboratories where health officials can test the effectiveness of different responses in advance of disease outbreaks.
- Modeling the movements of every individual in a large population produces a dynamic picture of the social network—the same network of contacts used by infectious diseases to spread among human hosts.
- Knowing the paths a disease could take through society enables officials to alter the social network through measures such as school closings and quarantines or by targeting individuals for medical treatment.

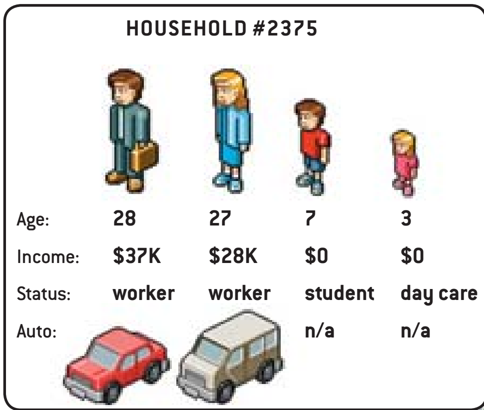
ADEPT VORMGEVING (*preceding pages*)

CREATING THE EPISIMS

The original EpiSims model was based on Portland, Ore., but gathering sufficiently detailed information about 1.6 million real people and their activities would have been difficult and intrusive. A synthetic population, statistically indistinguishable from the real one, could nonetheless be constructed and given realistic daily lives using publicly available data.

SYNTHETIC HOUSEHOLDS

The U.S. Census Bureau provided demographic information, such as age, household composition and income, for the entire city as well as 5 percent of its complete records for smaller study areas of a few square blocks. Through a statistical technique called iterative proportional fitting, these two data sets were combined to create households and individuals with statistically correct demographics and geographic distribution.

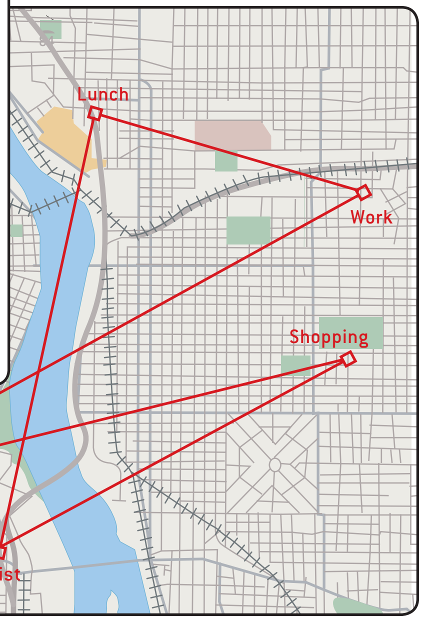


HH2375

HH2375

HH2375 **DAILY ACTIVITIES**

8:00 A.M. Leave home	4:45 P.M. Leave dentist
8:40 A.M. Arrive at work	5:30 P.M. Go shopping
2:00 P.M. Have lunch	6:40 P.M. Leave shopping
3:20 P.M. Go to the dentist	7:20 P.M. Arrive home



ACTIVITIES

Most metropolitan planning offices conduct detailed traveler activity surveys for small population samples of a few thousand. These logs track the movements of each household member over the course of one or more days, noting the time of each activity. By matching the demographics of survey respondents to the entire synthetic population, realistic daily activities can be generated for every synthetic household member.

LOCATIONS

Setting the population in motion requires assigning locations to every household's activities. Land-use data for buildings, parking lots, parks and other places were associated with 180,000 locations in the model, providing estimates of the number of people performing various types of activities there. Activities were anchored to individuals' work or school locations, and then places were chosen for additional activities, such as grocery shopping or recreation, taking into account their distance and other measures of their appeal.

ADEPT VORMGEVING (*human figures*); LUCY READING-IKKANDA (*map*)

at work, with each encounter having a different duration, proximity and purpose. During lunch or a shopping trip after work, Ann might have additional short contacts with strangers in public places before returning home.

We can visually represent Ann's contacts as a network with Ann in the center and a line connecting Ann to each of them [*see box on next page*]. All Ann's contacts engage in various activities and meet other people as well. We can represent these "contacts of contacts" by drawing lines from each—for example, Ann's colleague named Bob—to all his contacts. Unless they are also contacts of Ann, Bob's contacts are two "hops" away from Ann. The number of hops on the shortest path between people is sometimes called the graph distance or degree of separation between those people.

The popular idea that everyone on the earth is connected to everyone else by at most six degrees of separation means that if we continued building our social network until it included everyone on the planet, no two people would be more than six hops from one another. The idea is not strictly true, but it makes for a good story and has even led to the well-known game involving the social network of actors who have appeared in films with Kevin Bacon. In academic circles, another such social network traces mathematicians' co-authorship connections, with one's "Erdös number" defined by graph distance from the late, brilliant and prolific Paul Erdös.

Other types of networks, including the Internet, the links among scientific article citations and even the interactions among proteins within living cells, have been found to display this same tendency toward having "hubs": certain locations, people or even molecules with an unusually high number of connections to the rest of the network. The shortest path between any two nodes in the network is typically through one of these hubs, much as in a commercial airline's route system. Technically, such networks are called "scale-free" when the number of hubs with exactly k connections, $N(k)$, is proportional to a power of k [see "Scale-Free Networks," by Albert-László Barabási and Eric Bonabeau; SCIENTIFIC AMERICAN, May 2003].

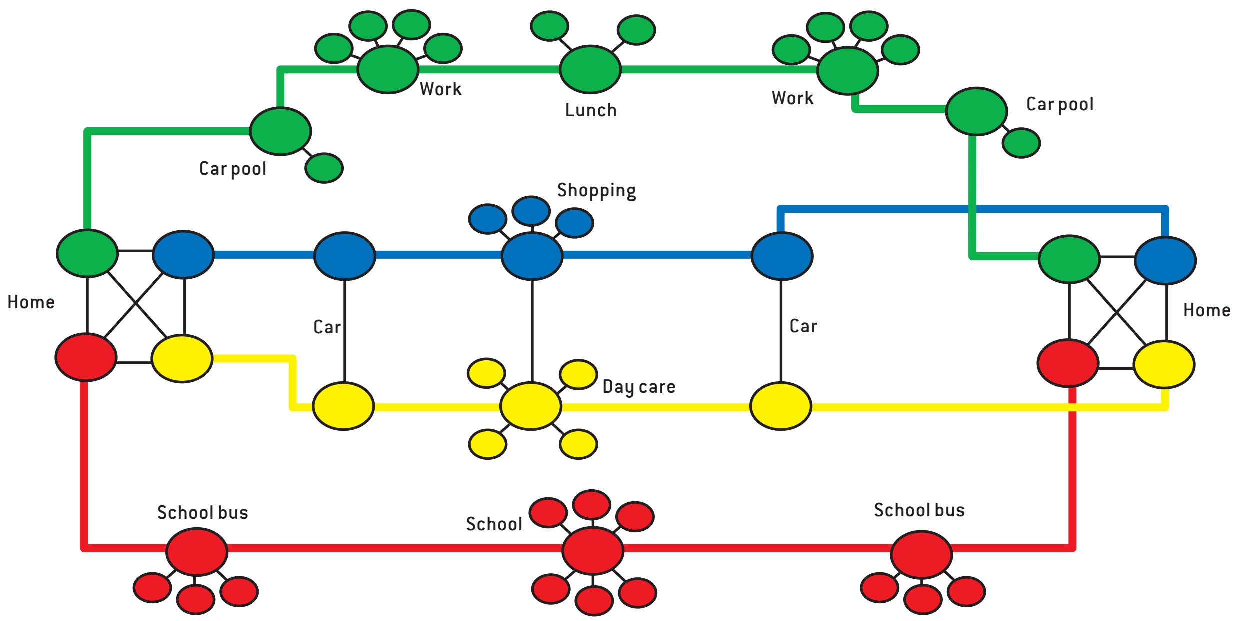
Because a scale-free network can be severely damaged if one or more of its hubs are disabled, some researchers have extrapolated this observation to disease transmission. If infected "hub" individuals, such as the most gregarious

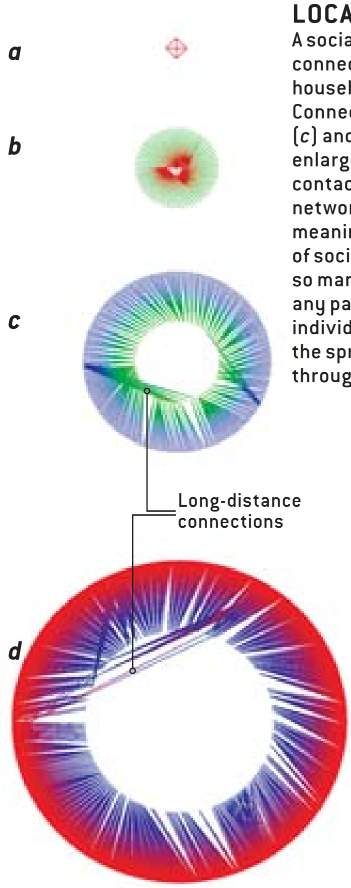
BUILDING SOCIAL NETWORKS

TYPICAL HOUSEHOLD'S CONTACTS

Constructing a social network for a household of two adults and two children starts by identifying their contacts with other people throughout a typical day.

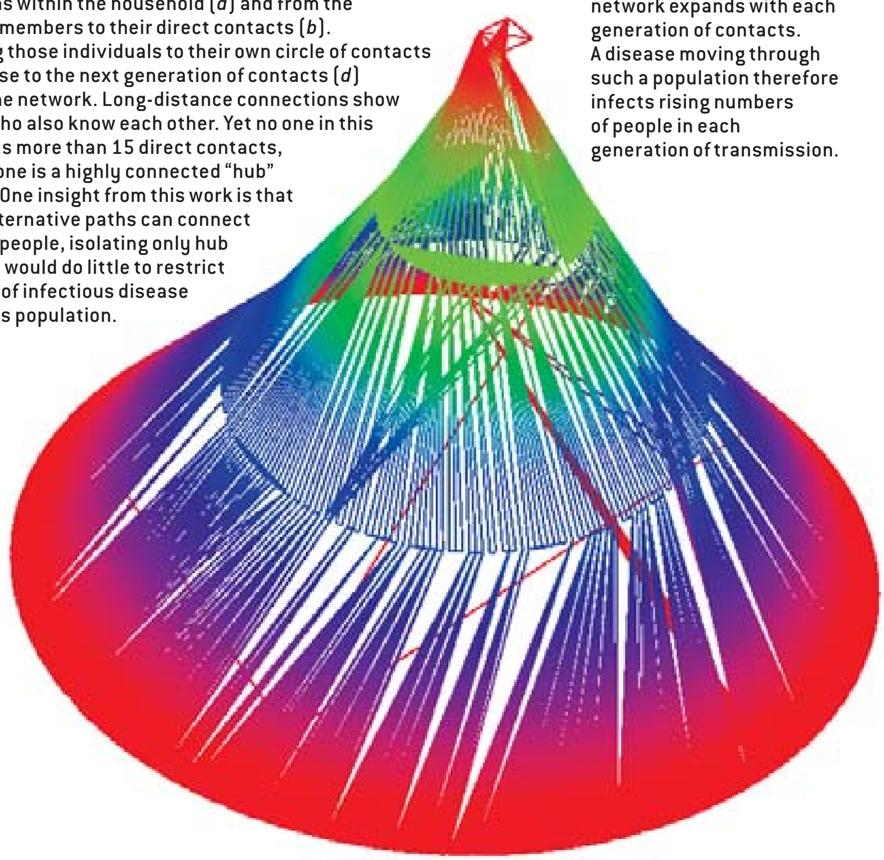
This diagram shows where the household members go and what they do all day but reveals little about how their individual contacts might be interconnected or connected to others.





LOCAL SOCIAL NETWORK

A social network emerges by drawing lines to represent connections within the household (*a*) and from the household members to their direct contacts (*b*). Connecting those individuals to their own circle of contacts (*c*) and those to the next generation of contacts (*d*) enlarges the network. Long-distance connections show contacts who also know each other. Yet no one in this network has more than 15 direct contacts, meaning none is a highly connected "hub" of society. One insight from this work is that so many alternative paths can connect any pair of people, isolating only hub individuals would do little to restrict the spread of infectious disease through this population.



EXPANDER GRAPH

The shape of this small network expands with each generation of contacts. A disease moving through such a population therefore infects rising numbers of people in each generation of transmission.

LUCY READING-IKKANDA (*top*); STEPHEN G. EUBANK (*bottom*) people in a population, could somehow be identified and treated or removed from the network, the reasoning goes, then an epidemic could be halted without having to isolate or treat everyone in the population. But our analyses of the social networks used by EpiSims suggest that society is not so easily disabled as physical infrastructure.

The network of physical locations in our virtual Portland, defined by people traveling between them, does indeed exhibit the typical scale-free structure, with certain locations acting as important hubs. As a result, these locations, such as schools and shopping malls, would be good spots for disease surveillance or for placing sensors to detect the presence of biological agents.

The urban social networks in the city also have human hubs with higher than average contacts, many because they work in the physical hub locations, such as teachers or sales clerks. Yet we have also found an unexpectedly high number of "short paths" in the social networks that do not go through hubs, so a policy of targeting only hub individuals would probably do little to slow the spread of a disease through the city.

In fact, another unexpected property we have found in realistic social networks is that everyone but the most devoted recluse is effectively a small hub. That is to say, when we look at the contacts of any small group, such as four students, we find that they are always connected by one hop to a much larger group. Depicting this social network structure results in what is known as an expander graph [*see box on opposite page*], which has a cone shape that widens with each hop. Its most important implication for epidemiology is that diseases can disseminate exponentially fast because the number of people exposed in each new generation of transmission is always larger than the number in the current generation.

Theoretically, this should mean that whatever health officials do to intervene in a disease outbreak, speed will be one of the most important factors determining their success. Simulating disease outbreaks with EpiSims allows us to see whether that theory holds true.

Smallpox Attack

AFTER WE BEGAN developing EpiSims in 2000, smallpox was among the first diseases we chose to model because government officials charged with bioterrorism planning and response were faced with several questions and sometimes conflicting recommendations. In the event that smallpox was released into a U.S. population, would mass vaccination be necessary to prevent an epidemic? Or would targeting only exposed individuals and their contacts for vaccination be enough? How effective is mass quarantine? How feasible are any of these options with the existing numbers of health workers, police and other responders?

To answer such questions, we constructed a model of smallpox that we could release into our synthetic population. Smallpox transmission was particularly difficult to model because the virus has not infected humans since its eradication in the 1970s. Most experts agree, though, that the virus normally requires significant physical contact with an infectious person or contaminated object. The disease has an average incubation period of approximately 10 days before flulike symptoms begin appearing, followed by skin rash. Victims are contagious once symptoms have appeared and possibly for a short time before they develop fever. Untreated, some 30 percent of those infected would die, but the rest would recover and be immune to reinfection.

Vaccination before exposure or within four days of infection can stop smallpox from developing. We assumed in all our simulations that health workers and people charged with tracking down the contacts of infected people had already been vaccinated and thus were immune. Unlike many epidemiological models, our realistic simulation also ensures that the chronology of contacts will be considered. If Ann contracted the disease, she could not infect her co-worker Bob a week earlier. Or, if Ann does infect Bob after she herself becomes infected and if Bob in turn infects his family member Cathy, the infection cannot pass from Ann to Cathy in less than twice the minimum incubation period between disease exposure and becoming contagious.

Our analyses suggest that society is not so easily disabled as infrastructure.

With our disease model established and everyone in our synthetic population assigned an immune status, we simulated the release of smallpox in several hub locations around the city, including a university campus. Initially, 1,200 people were unwittingly infected, and within hours they had moved throughout the city, going about their normal activities.

We then simulated several types of official responses, including mass vaccination of the city's population or contact tracing of exposed individuals and their contacts who could then be targeted for vaccination and quarantine. Finally, we simulated no response at all for the purpose of comparison.

In each of these circumstances, we also simulated delays of four, seven and 10 days in implementing the response after the first victims became known. In

THE AUTHORS

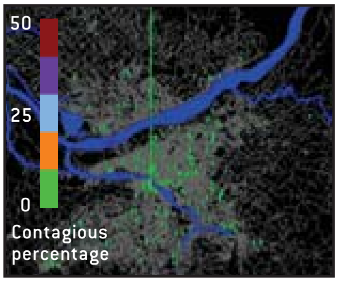
CHRIS L. BARRETT, STEPHEN G. EUBANK and JAMES P. SMITH worked for five years together at Los Alamos National Laboratory (LANL) to develop the EpiSims simulation. Barrett, who oversaw a predecessor project, TRANSIMS, is a bioinformatics specialist who now directs the Simulation Science Laboratory at the Virginia Bioinformatics Institute (VBI) in Blacksburg. Eubank, a physicist, is deputy director of the VBI simulation lab and was EpiSims team leader at Los Alamos. Smith, also a physicist, continues to work with simulations related to TRANSIMS as the project office leader for Discrete Simulation Science in the LANL Computer and Computational Sciences Division.

SIMULATED SMALLPOX ATTACKS

EpiSims animations depict simulated outbreaks and the effects of official interventions. In the still frames below, vertical lines indicate the number of infected people present at a location, and color shows the percentage of them who are contagious. In both scenarios shown, smallpox is released at a university in central Portland, but the attack is not detected until victims start experiencing symptoms 10 days later. The left-hand images show no public health response as a baseline. In the right-hand images, infected and exposed individuals are targeted for vaccination and quarantine. Results from a series of such simulations (*bottom*) show that people withdrawing to their homes early in an outbreak makes the biggest difference in death toll. The speed of official response, regardless of the strategy chosen, proved to be the second most important factor.

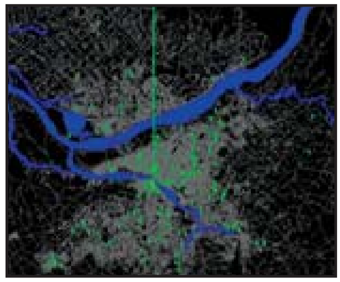
DAY 1: UNDETECTED SMALLPOX RELEASE

NO RESPONSE



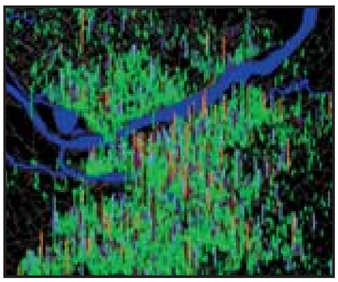
INFECTED: 1,281
DEAD: 0

TARGETED VACCINATION AND QUARANTINE STARTING DAY 14

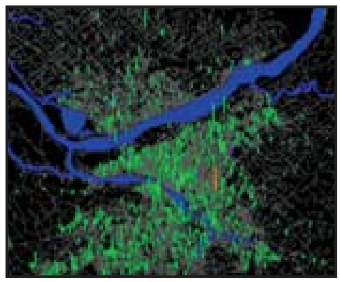


INFECTED: 1,281
QUARANTINED: 0
VACCINATED: 0
DEAD: 0

DAY 35: SMALLPOX EPIDEMIC

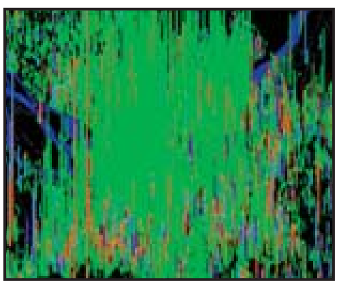


INFECTED: 23,919
DEAD: 551

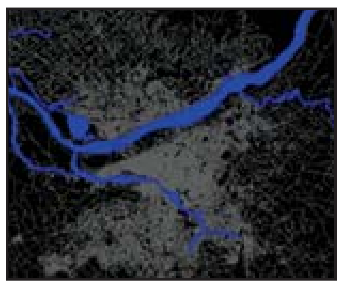


INFECTED: 2,564
QUARANTINED: 29,910
VACCINATED: 30,560
DEAD: 312

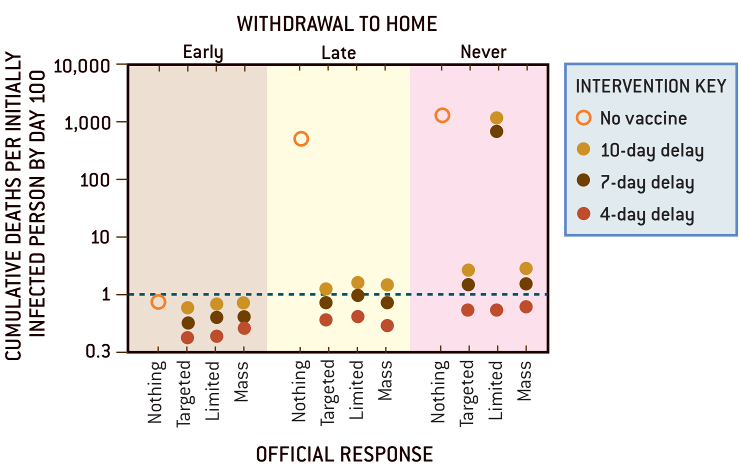
DAY 70: EPIDEMIC UNCONTAINED OR CONTAINED



INFECTED: 380,582
DEAD: 12,499



INFECTED: 2,564
QUARANTINED: 36,725
VACCINATED: 37,207
DEAD: 435



RESPONSE EFFECTIVENESS

Simulations allowed people to withdraw to their homes because they felt ill or were following officials' instructions. Withdrawal could be "early," before anyone became contagious, or "never," meaning people continued moving about unless they died. "Late" withdrawal, 24 hours after becoming contagious, was less effective than early withdrawal, which prevented an epidemic without other intervention. Official responses included doing nothing, or targeted vaccination and quarantine with unlimited personnel, or targeted vaccination limited by only half the necessary personnel being available, or mass vaccination of the entire population. The interventions began four, seven or 10 days after the first victims became symptomatic.

PHILLIP ROMERO *Los Alamos National Laboratory* (*simulation series*); LUCY READING-IKKANDA (*graph*) addition, we allowed infected individuals to isolate themselves by withdrawing to their homes.

Each simulation ran for a virtual 100 days [*see box on opposite page*], and the precise casualty figures resulting from each scenario were less important than the relative effect different responses had on the death tolls. The results upheld our theoretical prediction based on the expander-graph structure of the social network: time was by far the most important factor in limiting deaths. The speed with which people withdrew to their homes or were isolated by health officials was the strongest determinant of the outbreak's extent. The second most influential factor was the length of the delay in officials' response. The actual response strategy chosen made little difference compared with the time element.

In the case of a smallpox outbreak, these simulations indicate that mass vaccination of the population, which carries its own risks, would be unnecessary. Targeted vaccination would be just as effective so long as it was combined with rapid detection of the outbreak and rapid response. Our results also support the importance of measures such as quarantine and making sure that health officials give enforcement adequate priority during highly infectious disease outbreaks.

Of course, appropriate public health responses will always depend on the disease, the types of interventions available and the setting. For example, we have simulated the intentional release of an inhalable form of plague in the city of Chicago to evaluate the costs and effects of different responses. In those simulations we found that contact tracing, school closures and city closures each incurred economic losses of billions of dollars but did not afford many health benefits over voluntary mass use of rapidly available antibiotics at a much lower economic cost.

Most recently, as part of a research network organized by the National Institute of General Medical Sciences called the Models of Infectious Disease Agent Study (MIDAS), we have been adapting EpiSims to model a naturally occurring disease that may threaten the entire planet: pandemic influenza.

Flu and the Future

OVER THE PAST YEAR, a highly virulent strain of influenza has raged through bird populations in Asia and has infected more than 40 human beings in Japan, Thailand and Vietnam, killing more than 30 of those people. The World Health Organization has warned that it is only a matter of time before this lethal flu strain, designated H5N1, more easily infects people and spreads between them. That development could spark a global flu pandemic with a death toll reaching tens of millions [see SA Perspectives, SCIENTIFIC AMERICAN, January].

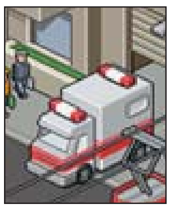
MIDAS collaborators will be studying the possibility that an H5N1 virus capable of spreading in humans might be contained or even eradicated by rapid intervention while it is still confined to a small population. To simulate the appropriate conditions in which the strain would likely emerge among humans, we are constructing a model representing a hypothetical Southeast Asian community of some 500,000 people living on farms and in neighboring small towns. Our model of the influenza virus itself will be based both on historical data about pandemic flu strains and information about the H5N1 virus, whose biology is currently a subject of intense investigation.

We know, for example, that H5N1 is sensitive to antiviral drugs that inhibit one of its important enzymes, called neuraminidase. In our simulations, we will be able to use neuraminidase inhibitors as both treatment and prophylaxis. (A vaccine against H5N1 has been developed and recently began clinical trials but because the vaccine is not yet proven or available, we will focus our simulations on seeing whether the antiviral drugs together with traditional public health measures might stop an epidemic.)

Preliminary results announced in late February are reported at www.sciam.com. In April, we will complete similar flu pandemic simulations in the EpiSims Portland model.

Our hope is that the ability to realistically model populations and disease outbreaks can help health officials make difficult decisions based on the best possible answers to "what if" questions.

The creation of models such as TRANSIMS that simulate human movements through urban environments was the computational breakthrough that made EpiSims possible, and epidemiology is only one potential application for this kind of individual-based modeling. We are also in the process of creating and linking simulations of other sociotechnical systems, including environmental and atmospheric pollution, telecommunications, transportation, commodity markets, water supplies and power grids, to provide virtual laboratories for exploring solutions to a wide variety of real-world problems. SA



The actual response chosen made little difference compared with the time element.

MORE TO EXPLORE

Scalable, Efficient Epidemiological Simulation. Stephen Eubank in *Proceedings of the 2002 ACM Symposium on Applied Computing,* pages 139–145; 2002.

Six Degrees: The Science of a Connected Age. Duncan J. Watts. W. W. Norton, 2004.

Containing Pandemic Influenza with Antiviral Agents. Ira M. Longini, Jr., et al. in *American Journal of Epidemiology,* Vol. 159, No. 7, pages 623–633; April 1, 2004.

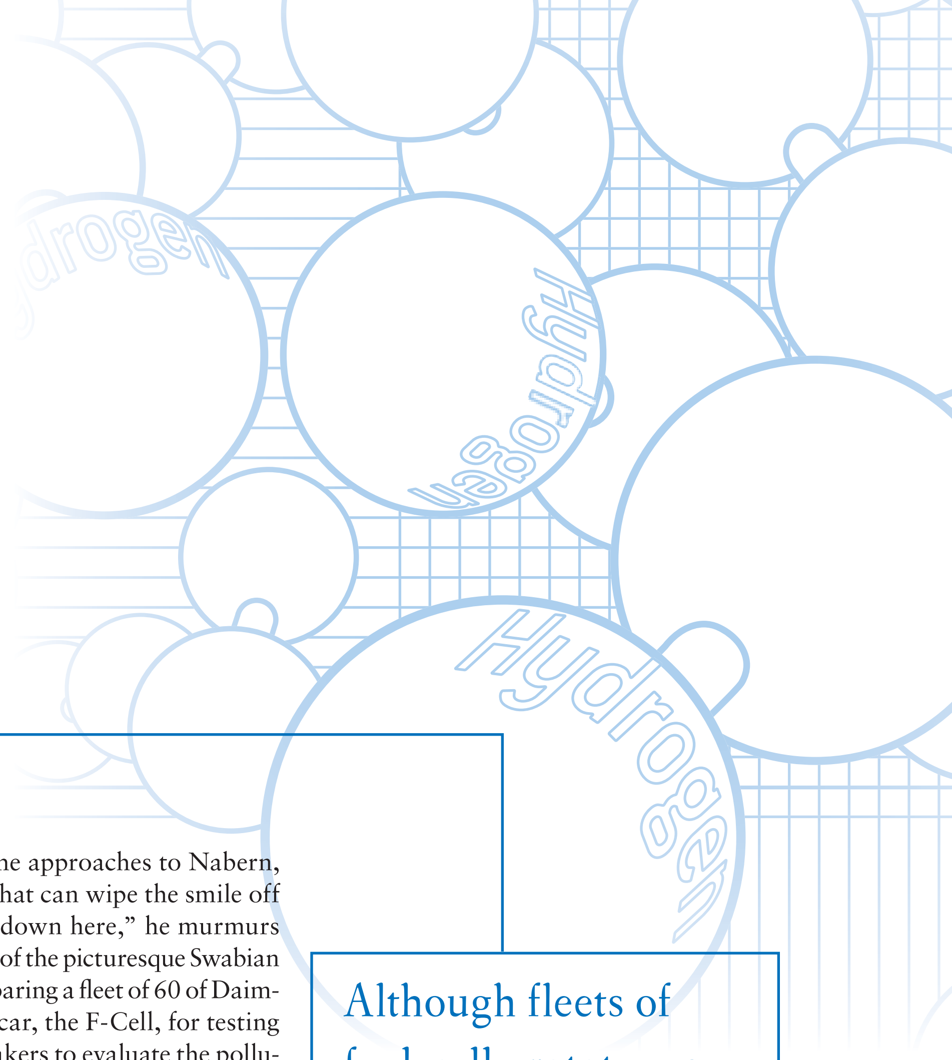
Modelling Disease Outbreaks in Realistic Urban Social Networks. Stephen Eubank et al. in *Nature,* Vol. 429, pages 180–184; May 13, 2004.

A sample EpiSims animation and additional data from the Portland smallpox simulations can be viewed at **http://episims.lanl.gov**

TEST FLEETS of DaimlerChrysler F-Cell hydrogen fuel-cell cars are now undergoing driving trials.

DAIMLERCHRYSLER

On the road to FUEL-CELL CARS



Although fleets of fuel-cell prototypes are hitting the streets, basic technical and market obstacles must be hurdled before the clean, hydrogen-powered cars reach dealer showrooms

By Steven Ashley

The automated speed traps that ward the approaches to Nabern, Germany, seem to be the only things that can wipe the smile off Rosario Berretta's face. "Please slow down here," he murmurs darkly as our vehicle nears the outskirts of the picturesque Swabian village. Berretta leads a team that is preparing a fleet of 60 of DaimlerChrysler's latest hydrogen fuel-cell car, the F-Cell, for testing worldwide. The aim is to allow automakers to evaluate the pollution-free, energy-efficient vehicles in diverse driving conditions. The curly-headed engineer is eager for visitors to try out the F-Cell's quick pickup off the line, one of the benefits of having an electric motor under the hood. But such maneuvers have to wait until the sharp eyes of the camera traps get small in the rearview mirror.

Despite its high-tech propulsion system, the F-Cell looks, performs and handles like a Toyota Corolla, a Ford Focus or any other conventional small car. Thus, the F-Cell seems less like a next-generation prototype and more like a real-world car. The sole clue of anything out of the ordinary is the unfamiliar whir of a compressor—a noise that Berretta vows company engineers will soon muffle.

DaimlerChrysler is not alone in its quest for the ultimate clean vehicle. After a decade of focused research and development, the auto industry worldwide has passed a milestone with the arrival of the first test fleets of seemingly roadworthy fuel-cell cars. Twenty of Honda's latest FCX and 30 of Ford's Focus FCV fuel-cell-powered compacts will soon be on the highways. General Motors plans to provide 13 fuel-cell-powered vehicles to the New York City metropolitan area for evaluation next year. Already 30 DaimlerChrysler-built fuel-cell buses are plying the streets of 10 European cities, and three more will shortly each be servicing Beijing and Perth.

Meanwhile nearly every other car company—particularly, Toyota but also Nissan, Renault, Volkswagen, Mitsubishi and Hyundai, among others—is operating at least a few prototype vehicles as well, one indication of the substantial funds carmakers are investing to perfect the technology. Today between 600 and 800 fuel-cell vehicles are reportedly under trial across the globe. And suppliers have emerged to develop and provide the components needed to build the prototypes. If all goes well, these developments will mark a midway milestone on the road to the initial commercialization of the fuel-cell car by the early part of the next decade.

Faced with ever tighter governmental regulatory limits on exhaust emissions, forecasts of impending oil shortages and a potential global warming catastrophe caused by greenhouse gases, the motor vehicle industry and national governments have invested tens of billions of dollars during the past 10 years to bring to reality a clean, efficient propulsion technology that is intended to replace the venerable internal-combustion (IC) engine [see "Vehicle of Change," by Lawrence D. Burns, J. Byron McCormick and Christopher E. Borroni-Bird; SCIENTIFIC AMERICAN, October 2002]. Critics, however, still question the industry's actual interest in producing a truly green car and whether this R&D effort is really enough to yield success anytime soon. Suspicions linger that work on fuel-cell vehicles is a smokescreen intended to shield business as usual long into the future. Car company executives reply that they foresee no better option to the hydrogen fuel-cell vehicle in the long run, because all alternatives, such as hybrid vehicles (which combine IC engines with electrochemical batteries), still burn petrochemical fuels and produce carbon dioxide and pollutants.

> Tens of billions of dollars have been spent on fuel-cell vehicles during the past 10 years.

Overview/*Green Machines*

- The motor vehicle industry recently passed a milestone when it fielded test fleets of reasonably practical fuel-cell cars some 10 years after the first prototypes hit the road. During that period, carmakers and governments spent several tens of billions of dollars on research and development, but much more will be needed before initial commercialization can take place.
- Despite stricter pollution limits, potential oil shortages and the threat of global warming, volume production of fuel-cell vehicles is not expected before midway through the next decade and, perhaps, much later.
- Significant improvements in onboard hydrogen storage capacity, fuel-cell durability and power as well as substantially lower costs will be required before fuel-cell cars can approach marketability. A hydrogen production and distribution system must also be built.

Stumbling Blocks

A TWO-HOUR DRIVE, say, the 140 or so miles from Nabern to Frankfurt am Main on the German autobahn, would be enough to reveal the most telling distinction between the F-Cell and your typical IC engine car. In something less than 90 minutes, you would be stuck on the roadside out of fuel and with little prayer of finding a fill-up. Neither the F-Cell nor any of its hydrogen-powered kindred carries enough fuel to get anywhere near the 300-mile minimum driving range that car owners expect. And because hydrogen service stations are still few and far between, refueling would be problematic at best. So despite bright hopes and the upbeat pronouncements by automakers, considerable technical and market challenges remain that could delay introduction of the fuel-cell family car for years, if not decades.

Before early adopters can trade in their Toyota Priuses and Honda Accord Hybrids for something even greener, car manufacturers and their suppliers must somehow figure out how to do several things: boost onboard hydrogen storage capacity substantially, cut the price tags of fuel-cell drive trains to a hundredth of the current costs, increase the power plants' operating lifetimes fivefold, and enhance their energy output for SUVs and other heavy vehicles. Finally, to operate these vehicles, a hydrogen fueling infrastructure will be required to replace the international network of gas stations.

Even some of the automakers remain unconvinced that all this will happen soon: "High-volume production could be 25 years off," says Bill Reinert, national manager for Toyota's advanced technology group. "I'm less than hopeful about reducing costs sufficiently, and I'm quite pessimistic about solving hydrogen storage issues and packaging these large systems in a marketable vehicle." One telling sign that fuel-cell vehicles are still works in progress: nearly all car company representatives call for more government investment in basic research and hydrogen distribution systems to help overcome these roadblocks.

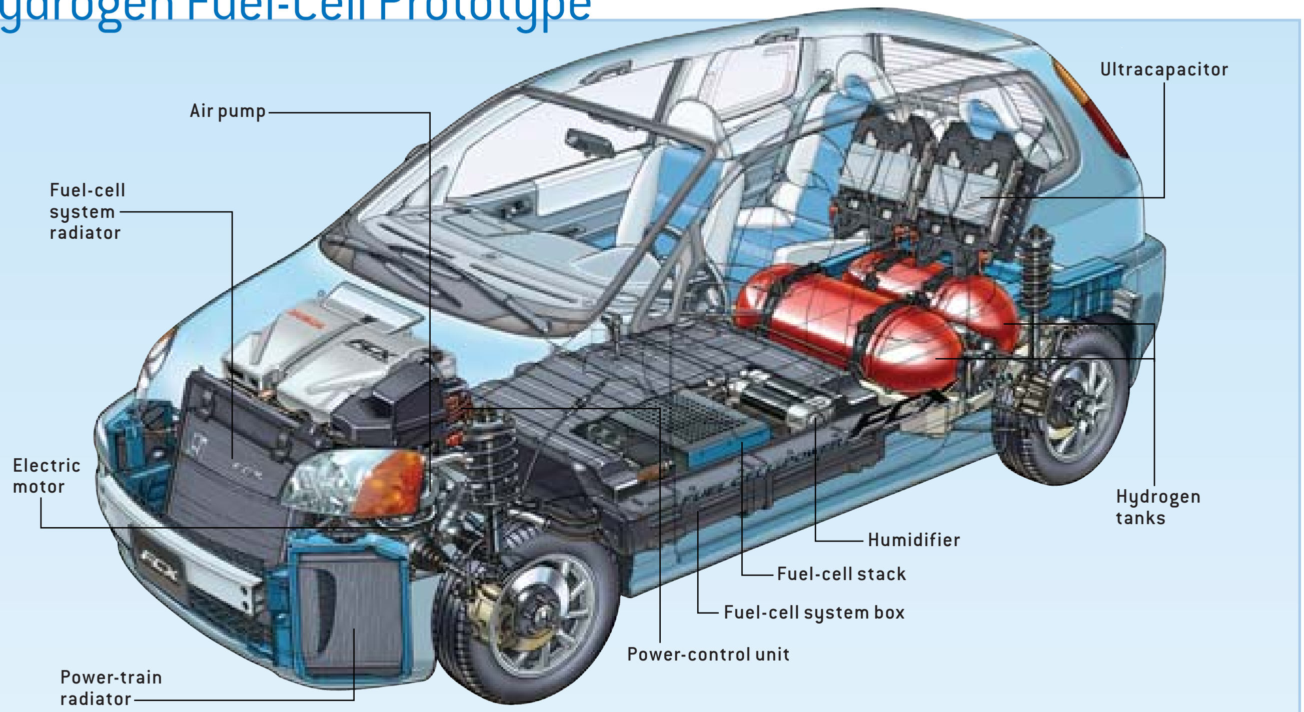
Stack Issues

A FUEL-CELL CAR, bus or truck is essentially an electric vehicle powered by a device that operates like a refuelable battery. Unlike a battery, though, a fuel cell does not store energy; it uses an electrochemical process to generate electricity and will run as long as hydrogen fuel and oxygen are fed to it [*see box on page 66*].

At the core of the automotive fuel cell is a thin, fluorocarbon-based polymer—a proton-exchange membrane (PEM)—that serves as both the electrolyte (for charge transport) and a physical barrier to prevent mixing of the hydrogen fuel and the oxygen. Electricity for powering a fuel-cell car is produced when electrons are stripped from hydrogen atoms at catalysis sites on the membrane surface. The charge carriers—hydrogen ions or protons—then migrate through the membrane and combine with oxygen and an electron to form water, the only exhaust produced. Individual cells are assembled into what are called stacks.

Engineers chose PEM fuel cells because they convert up to

Hydrogen Fuel-Cell Prototype



Honda's 2005 FCX model is typical of current hydrogen fuel-cell technology. The four-seat compact, which has a top speed of 93 miles per hour, offers a driving range greater than 200 miles. Equivalent fuel economy is 62 miles per gallon in city driving and 51 mpg on the highway. The FCX's fuel-cell stack, which was designed by Honda for low-cost manufacturing, features a hydrocarbon polymer membrane that offers improved durability. An ultracapacitor—a device that stores energy in the fields between electrically charged plates—provides extra power during passing maneuvers or hill climbing. Reclaimed energy from a regenerative braking system is stored by the ultracapacitor.

55 percent of the fuel energy put into them into work output; the efficiency figure for an IC engine is approximately 30 percent. Other benefits include relatively low-temperature operation (80 degrees Celsius); reasonably safe, quiet performance; easy operation; and low maintenance requirements.

The prospect of a commercial fuel-cell car by 2015 will depend on improvements in membrane technology, which makes up as much as 35 percent of the cost of a fuel-cell stack. Researchers list several needed enhancements such as low fuel crossover from one side of a membrane to the other, augmented chemical and mechanical stability of the membrane for greater durability, control over undesired by-reactions, and higher tolerance to contamination by fuel impurities or from unwanted reaction by-products such as carbon monoxide. Most of all, what is required is an across-the-board reduction in costs.

News of a "breakthrough" in membrane technology created a considerable stir in fuel-cell research circles last fall. PolyFuel, a small company in Mountain View, Calif., announced that it had created a hydrocarbon polymer membrane that it says offers superior performance and lower costs than current perfluorinated membranes. "It looks like a piece of sandwich wrap," James Balcom says, chuckling. The PolyFuel chief executive boasts a variety of reasons why his cellophanelike film performs better than the more common perfluorinated membranes, notably DuPont's Nafion material. The hydrocarbon membrane can run at higher temperatures than current membranes—up to 95 degrees C, which allows the use of smaller radiators to dissipate heat. It lasts 50 percent longer than fluorocarbon versions, he claims, while generating 10 to 15 percent more power and operating at lower (less troublesome) humidity levels. And whereas fluorocarbon membranes cost about $300 per square meter, the PolyFuel materials potentially cost half the price [*see box on next page*]. Although many other researchers remain skeptical about hydrocarbon membranes, Honda's newest FCX fuel-cell cars incorporate them.

Catalyst Conundrum

THE OTHER KEY to the operation of a PEM membrane is the thin layer of platinum-based catalyst that coats both of its sides and that represents 40 percent of the stack cost. The catalyst prepares hydrogen (from the fuel) and oxygen (from the air) to take part in an oxidation reaction by assisting both molecules to split, ionize, and release or accept protons and electrons. On the hydrogen side of the membrane, a hydrogen molecule (containing two hydrogen atoms) must attach to two adjacent catalyst sites, thereby freeing positive hydrogen ions (protons) to travel across the membrane. The complex reaction on the oxygen side occurs when a hydrogen ion and an electron mate with

HONDA MOTOR COMPANY

oxygen to produce water. This latter sequence must be finely controlled because it can yield destructive by-products such as hydrogen peroxide, which degrades fuel-cell components.

Because of the high cost of the precious metal ingredients, researchers are searching for ways to lower the platinum content. Their efforts include not only finding methods to raise the activity of the catalyst so less can be used for the same power output but also determining how to form a stable catalyst structure that does not degrade over time and avoiding side reactions that contaminate the membrane. One recent success in boosting catalytic activity was achieved by 3M Corporation researchers, who created nanotextured membrane surfaces covered with "forests of tiny columns" that significantly increased the catalysis area. Other work has concentrated on materials ranging from nonprecious metal catalysts such as cobalt and chromium to catalysts consisting of fine dispersions of particles embedded in porous composite structures.

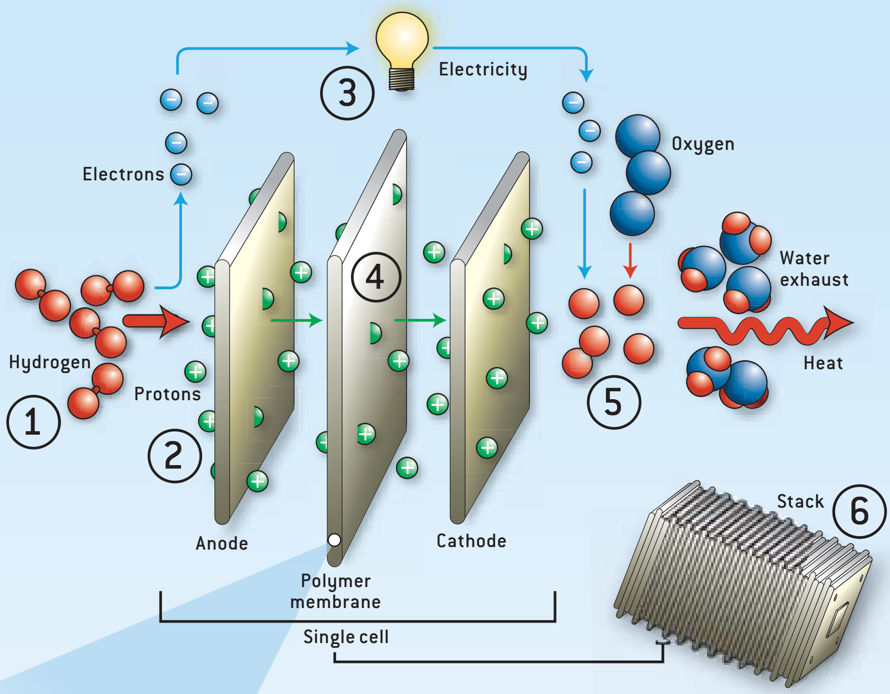
Onboard Storage

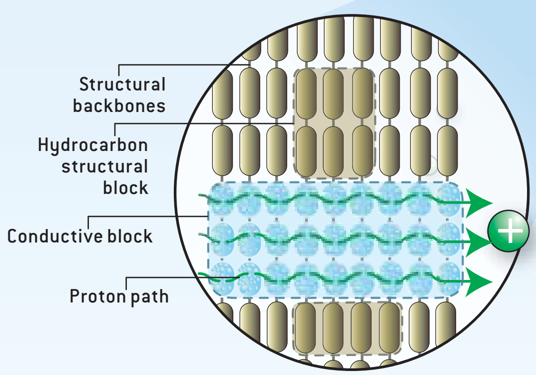
ONE OF THE BIGGEST WORRIES among proponents of fuel-cell vehicles is how engineers will manage to stuff enough hydrogen onboard to provide the driving range that consumers demand. Five to seven kilograms will take a car up to 400 miles, but current fuel-cell prototypes hold from 2.5 to 3.5 kilograms. "Nobody really knows how to store twice that amount in a reasonable volume," says Dennis Campbell, chief executive of Ballard Power Systems in Vancouver, the dominant fuel-cell-stack maker.

Typically hydrogen is stored in pressure tanks as a highly compressed gas at ambient temperature. Many engineering teams are working on doubling the pressure capacity of today's 5,000-psi (pounds per square inch) composite pressure tanks. But twice the pressure does not increase the storage twofold. Liquid-hydrogen systems, which store the fuel at temperatures below –253 degrees C, have been tested successfully

INSIDE FUEL CELLS

A fuel cell operates like a refuelable battery; it will generate electricity as long as it is supplied with hydrogen and oxygen. A proton-exchange membrane (PEM) fuel cell (*right*) is composed of two thin, porous electrodes, an anode and a cathode, separated by a solid polymer membrane electrolyte. Platinum-based catalysts coat one side of each electrode. After hydrogen atoms enter the cell (*1*), the anode catalyst splits them into electrons and protons (*2*). The electrons move along an external circuit to power a drive motor (*3*), while the protons migrate through the membrane (*4*) to the cathode. The catalyst on that side combines the protons with returning electrons and with oxygen from the air to generate water and heat (*5*). Many cells are piled in stacks to produce higher voltages (*6*).



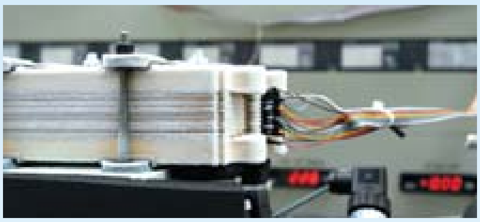


Hydrocarbon membranes last longer, generate more energy and cost less than current fluorocarbon types, maker PolyFuel claims. The company's concept incorporates blocks of highly conductive polymer species to promote the passage of protons, increasing energy production. These conductive materials are tied to blocks of high-strength polymers that reinforce the membrane's structure, improving durability. Because the two types of polymers have a low chemical affinity for each other, they segregate themselves during processing into the different functional blocks, easing manufacture.

LUCY READING-IKKANDA

Freeze-Proof Fuel Cells

Resistance to subzero temperatures has long been a key goal for developers of fuel-cell stacks. When stacks freeze, the water inside turns to ice, which can puncture membranes and block pipes. Last year Honda engineers demonstrated that the fuel-cell power plant in its latest FCX hatchback (*right*) will start up repeatedly at –20 degrees Celsius. Researchers at DaimlerChrysler and General Motors have shown similar results with frozen stacks in the laboratory (*below*). The trick seems to lie in keeping all water inside the system in the vapor state.



DAIMLERCHRYSLER (*left*); HONDA MOTOR COMPANY (*right*)

but suffer from significant drawbacks: about one third of the energy available from the fuel is needed to keep the temperature low enough to preserve the element in a liquid state. And despite bulky insulation, evaporation through seals robs these systems every day of about 5 percent of the total stored hydrogen.

Several alternative storage technologies are under development, but no surefire advances have occurred. "There's quite a good distance between what can be demonstrated in the lab and a fully engineered storage system that's affordable, long-lasting and compact," says Lawrence Burns, vice president for research and development and planning at GM.

Probably the foremost candidates for a storage technology are metal hydride systems in which various metals and alloys hold hydrogen on their surfaces until heat releases it for use. "Think of a sponge for hydrogen," explains Robert Stempel, chairman of ECD Ovonic, a part of Texaco Ovonic Hydrogen Systems, the leader in this area. The hydrogen gas is fed into the storage tank under pressure and chemically bonds to the crystal lattice of the metal in question through a reaction that absorbs heat. The resulting compounds are called metal hydrides. Waste heat from the stack is used to reverse the reaction and release the fuel. In January, GM and Sandia National Laboratories launched a four-year, $10-million program to develop metal hydride storage systems based on sodium aluminum hydride.

Because metal hydride storage systems tend to be heavy (about 300 kilograms), researchers at Delft University of Technology in the Netherlands have developed a way to store hydrogen in water ice—as a hydrogen hydrate, in which hydrogen is trapped in molecule-size cavities in ice. Water, of course, is significantly lighter than metal alloys. This approach is unexpected because hydrogen hydrates are notoriously difficult to make, typically requiring low temperatures and extremely high pressures, on the order of 36,000 psi. Working with scientists at the Colorado School of Mines, the Delft team came up with a "promoter" chemical—tetrahydrofuran—that stabilizes gas hydrates under much less extreme pressure conditions, only 1,450 psi. Theoretically, it should be possible to get about 120 liters (120 kilograms) of water to store about six kilograms of hydrogen.

Freezing Stacks

SEVERAL HUNDRED people gathered behind the state capitol building in Albany, N.Y., to hear Governor George E. Pataki welcome the lease by New York State of a pair of Honda FCX hydrogen fuel-cell cars one cold, blustery late November morning in 2004. What made the event notable was the temperature of the air. All previous fuel-cell vehicle demonstration programs had been situated in warmer climes to ensure that the fuel-cell stacks would not freeze up. In previous designs, subzero temperatures could convert any liquid water into expanding ice crystals that can puncture membranes or rupture water lines. Early in the year Honda engineers demonstrated that their fuel-cell units could withstand winter conditions, an important engineering achievement for the fuel-cell research community.

> Nobody really knows how to store enough hydrogen fuel in a reasonable volume.

After the speech, Ben Knight, vice president of R&D for American Honda, explained that the new freeze-resistant 2005 FCX models will start up repeatedly at –20 degrees C. Other car companies, including DaimlerChrysler and GM, have also claimed success with cold-starting test stacks in the lab [*see box on preceding page*].

Besides its ability to start up in midwinter temperatures, the 2005 version of Honda's FCX fuel-cell car—a four-seat compact hatchback—showcases other technical advances over the model released two years earlier. The new FCX is unusual, for example, because it employs an ultracapacitor—a device that stores energy in the electric fields between charged electrode plates—to provide short bursts of supplementary power for passing and hill climbing. Most other automakers use batteries for this purpose.

Infrastructure Issues

LATER ON that November day an even more enthusiastic crowd assembled for the second half of the planned ceremonies at the nearby headquarters of Plug Power, the Latham, N.Y.–based maker of stationary hydrogen fuel-cell energy units for backup power applications. The cheering group of mostly Plug Power workers were there to celebrate the opening of a hydrogen fueling station that they had co-developed with Honda engineers. The Home Energy Station II contains a miniature chemical plant—a steam reformer—that extracts hydrogen fuel from piped-in natural gas using a steam-based process. "It's half the size of the previous version," said Roger Saillant, CEO of Plug Power. "Besides refueling vehicles, the system feeds some of the hydrogen into a fuel-cell stack to produce electricity for our headquarters building, which is also warmed in part by waste heat generated by the unit."

The hydrogen infrastructure is the classic chicken-and-egg dilemma.

With great fanfare, one of the FCXs wheeled up to the fuel-dispensing pump—a metal box the size of a luxury kitchen stove that had been installed in the company parking lot. A state official first grounded the car by attaching a wire to the vehicle. He then dragged the fuel hose from the pump to the FCX's refueling port, inserted the nozzle and locked it into place. The unit finished filling the car's tank after about five or six minutes. Knight explained that the pump produces enough purified hydrogen to refill a single fuel-cell vehicle a day.

Afterward, Knight discussed the problems facing the development of a hydrogen infrastructure: "It's the classic chicken-and-egg dilemma," he said. "There's no demand for cars and trucks with limited fueling options, but no one wants to make the huge investment to create a fueling infrastructure unless there are fleets of vehicles on the road. So the question is: How do we create demand?" [see "Questions about a Hydrogen Economy," by Matthew L. Wald; SCIENTIFIC AMERICAN, May 2004].

A study by GM has estimated that $10 billion to $15 billion would pay to build 11,700 new fueling stations—enough so a driver would always be within two miles of a hydrogen station in major urban areas and so there would be a station every 25 miles along main highways. That concentration of mostly urban hydrogen stations would support an estimated one million fuel-cell vehicles, it says. "Twelve billion dollars, that's chump change when cable operators are plunking down $85 billion for cable system installations," exclaims Ballard's Campbell.

The Latham filling station—along with several dozen others scattered from Europe to California to Japan—embodies the first halting steps toward the construction of an infrastructure. Soon, Campbell says, about 70 hydrogen refueling stations will be operating worldwide, and California's Hydrogen Highway program has set a goal of 200 stations.

A National Academy of Sciences committee recently estimated that the transition to a "hydrogen economy" will probably take decades, because tough challenges remain. These include how to produce, store and distribute hydrogen in sufficient quantities and at reasonable cost without releasing greenhouse gases that contribute to atmospheric warming. Unfortunately, the extraction of hydrogen from methane generates carbon dioxide, a major greenhouse gas. If the energy sources for electrolysis (the splitting of water into hydrogen and oxygen using electricity) burn fossil fuels, they, too, would generate carbon dioxide. And hydrogen is a highly leak-prone gas that could escape from cars and production plants into the atmosphere,

Hydrogen Gas Stations

Filling stations that dispense hydrogen fuel are still rare. Currently about 70 hydrogen refueling units are operating worldwide: two dozen each in the U.S. and Europe, a dozen in Japan and 10 elsewhere. Filling up a car with pressurized hydrogen, demonstrated above by a Ford Focus FCV fuel-cell car, typically takes about five minutes. An electrical ground wire must be attached to the car beforehand to avoid sparks. At its Torrance, Calif., headquarters, American Honda has built a service station (*below*) that splits water into hydrogen fuel and oxygen using power generated by a solar photovoltaic array. This would be the ultimate in green hydrogen production.

FORD MOTOR COMPANY (*top*); HONDA MOTOR COMPANY (*bottom*)

FUEL-CELL-DRIVEN DESIGN FREEDOM

General Motors's new Sequel fuel-cell concept vehicle (*right*) contains enough fuel to drive 300 miles, the minimum acceptable range. It does so by fitting about seven kilograms of hydrogen into its 11-inch-thick "skateboard" chassis (*bottom left*), which also contains almost all the crossover SUV's operating systems. The Sequel demonstrates how all-electric power trains will free auto designers to rethink the configuration of future models. Because strictly mechanical components can be replaced by fully electronic counterparts, interior layouts can be opened up (*bottom right*). "Look at all the space you get when you don't need to work around a big steering column," says Robert Bonaface, GM's director of advanced design. "We even had enough space to place a good-size storage bin in the dashboard, which is unheard of. Parents are going to love this."

GENERAL MOTORS CORPORATION

which could set off chemical reactions that generate greenhouse gases. Finally, using fossil fuels to make hydrogen takes more energy than that contained in the resulting hydrogen itself.

Researchers at the Idaho National Engineering and Environmental Laboratory and Cerametec in Salt Lake City have developed a way to electrolyze water and produce pure hydrogen with far less energy than other methods. The team's work points to the highest-known production rate of hydrogen by high-temperature electrolysis. Their new method involves running electricity through water that has been heated to about 1,000 degrees C. As the water molecules break up, a ceramic sieve separates the oxygen from the hydrogen. The resulting hydrogen has about half the energy value of the energy put into the process, which is better than competing processes.

Hydrogen proponents contend that arguments over infrastructure constitute a red herring. "U.S. industry currently produces 50 million to 60 million tons of hydrogen per year, so it's not like there's no expertise in handling hydrogen out there," Campbell notes. But automakers have a somewhat different perspective. "Fifty to 60 percent of the problems we have with our fuel cells arise from impurities in the hydrogen we buy from industry," complains Herbert Kohler, vice president of body and power-train research at DaimlerChrysler. "The chemical industry needs to do their homework."

Byron McCormick, GM's executive director of fuel-cell activities, likens investment in building a hydrogen infrastructure in the 21st century to the investment in railroads in the 19th century or to the creation of the interstate highway system in the 20th century: "There'll be a point relatively soon at which these kinds of how-do-you-get-it-funded decisions will be more important than the technology," he predicts.

Resolution of the myriad remaining technical and market issues will determine whether the transportation linchpin of the proposed hydrogen economy, the commercial fuel-cell vehicle, arrives in 10 years or 50. SA

Steven Ashley is a staff technology writer and editor.

MORE TO EXPLORE

Available online at:

Ballard Power Systems: **www.ballard.com/**

DaimlerChrysler: **www.daimlerchrysler.com/dccom**

ECD Ovonics: **www.ovonic.com/**

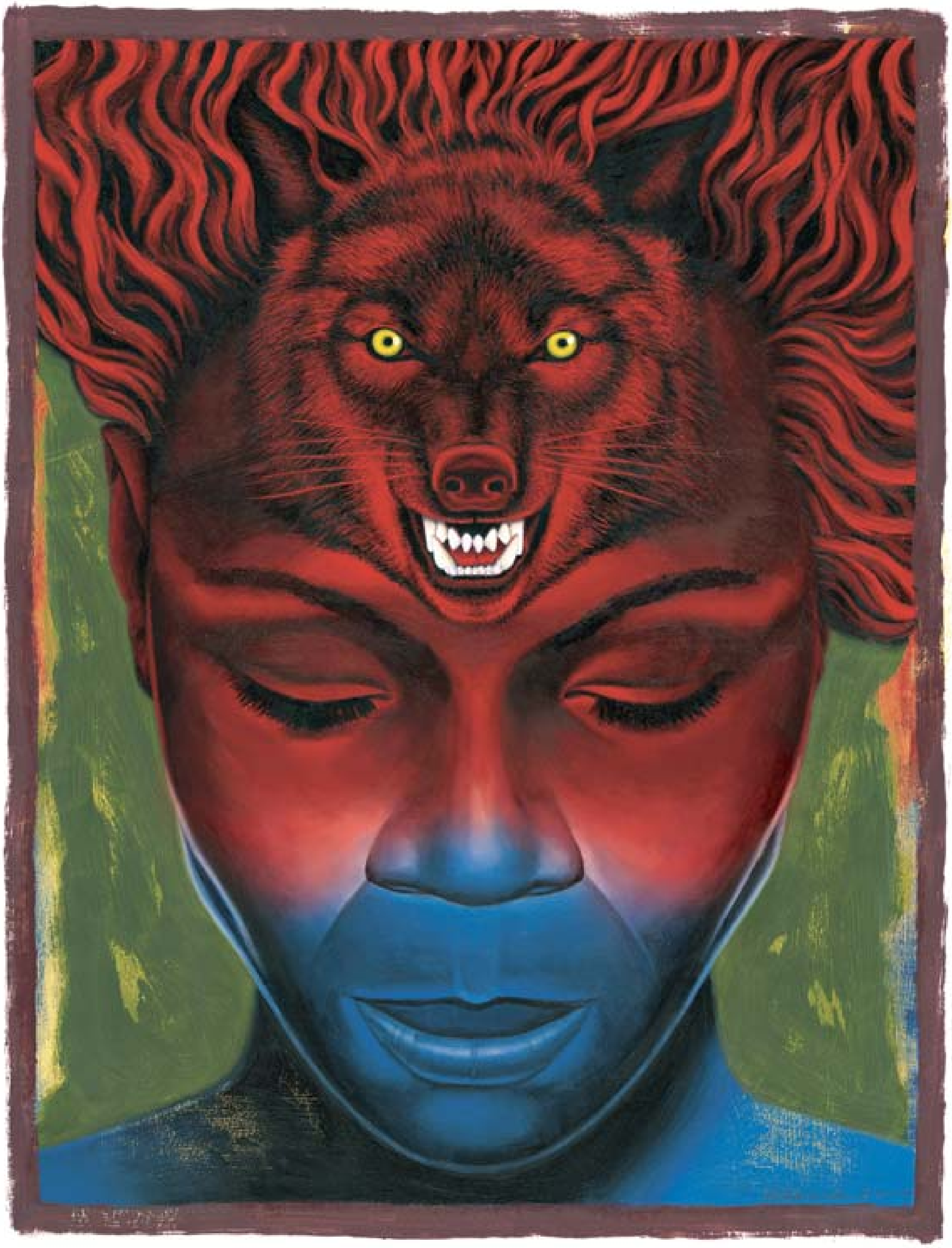
Ford: **www.ford.com/en/default.htm**

General Motors: **www.gm.com/**

Honda: **www.honda.com/index.asp?bhcp=1**

PolyFuel: **www.polyfuel.com/**

Toyota: **www.toyota.com/**



ALAN WITSCHONKE

Taming Lupus

Teasing out the causes of this autoimmune disorder is a daunting challenge. But the payoff should be better, more specific treatments

By Moncef Zouali

A 24-year-old woman undergoes medical evaluation for kidney failure and epilepsy-like convulsions that fail to respond to antiepileptic drugs. Her most visible sign of illness, though, is a red rash extending over the bridge of her nose and onto her cheeks, in a shape resembling a butterfly.

A 63-year-old woman insists on hospitalization to determine why she is fatigued, her joints hurt, and breathing sometimes causes sharp pain. Ever since her teen years she has avoided the sun, which raises painful blistering rashes wherever her skin is unprotected.

A 20-year-old woman is surprised to learn from a routine health exam that her urine has an abnormally high protein level—a sign of disturbed kidney function. A renal biopsy reveals inflammation.

Although the symptoms vary, the underlying disease in all three patients is the same—systemic lupus erythematosus, which afflicts an estimated 1.4 million Americans, including one out of every 250 African-American women aged 18 to 65. It may disrupt almost any part of the body: skin, joints, kidneys, heart, lungs, blood vessels or brain. At times, it becomes life-threatening.

Scientists have long known that, fundamentally, lupus arises from an immunological malfunction involving antibody molecules. The healthy body produces antibodies in response to invaders, such as bacteria. These antibodies latch onto specific molecules that are sensed as foreign (antigens) on an invader and then damage the interloper directly or mark it for destruction by other parts of the immune system. In patients with lupus, however, the body produces antibodies that perceive its own molecules as foreign and then launch an attack targeted to those "self-antigens" on the body's own tissues.

Self-attack—otherwise known as autoimmunity—is thought to underpin many diseases, including type 1 diabetes, rheumatoid arthritis, multiple sclerosis and, possibly, psoriasis. Lupus, however, is at an extreme. The immune system reacts powerfully to a surprising variety of the patient's molecules, ranging from targets exposed at the surface of cells to some inside of cells to even some within a further sequestering chamber, the cell nucleus. In fact, lupus is notorious for the presence of antibodies that take aim at the patient's DNA. In the test tube, these anti-DNA "autoantibodies" can directly digest genetic material.

Until recently, researchers had little understanding of the causes of this multipronged assault. But clues from varied lines of research are beginning to clarify the underlying molecular events. The work is also probing the most basic, yet still enigmatic, facets of immune system function: the distinction of self from nonself; the maintenance of self-tolerance (nonaggression against native tissues); and the control over the intensity of every immune response. The discoveries suggest tantalizing new means of treating or even preventing not only lupus but also other autoimmune illnesses.

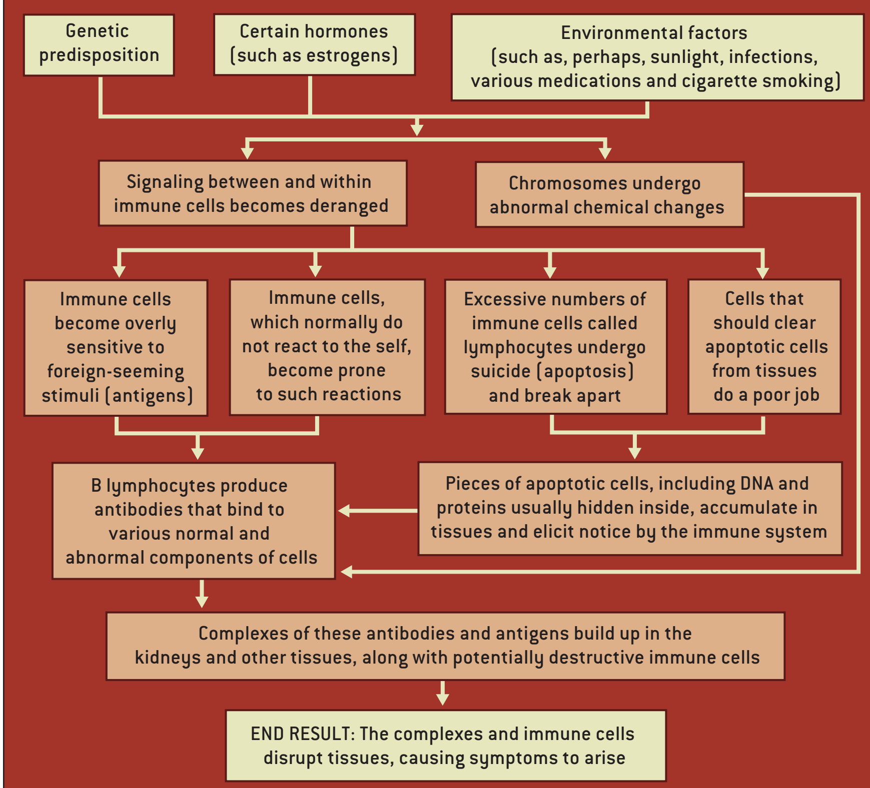
LUPUS, technically lupus erythematosus, means "the red wolf." It was so named because a face rash particular to the disorder often makes people look wolflike.

Some Givens

ONE THING ABOUT LUPUS has long been clear: the autoantibodies that are its hallmark contribute to tissue damage in more than one way. In the blood, an autoantibody that recognizes a particular self-antigen can bind to that antigen, forming a so-called immune complex, which can then deposit itself in any of various tissues. Autoantibodies can also recognize self-antigens already in tissues and generate immune complexes on-site. Regardless of how the complexes accumulate, they spell trouble.

PATHWAYS TO DISEASE

The processes underlying lupus are known in a general way (*flowchart*). But many of the details remain murky, such as how hormones and environmental triggers precipitate immune attacks on the body's tissues.



JEN CHRISTIANSEN

For one, they tend to recruit immune system entities known as complement molecules, which can directly harm tissue. The complexes, either by themselves or with the help of the complement molecules, also elicit an inflammatory response. This response involves an invasion by white blood cells that attempt to wall off and destroy any disease-causing agents. Inflammation is a protective mechanism, but if it arises in the absence of a true danger or goes on for too long, the inflammatory cells and their secretions can harm the tissues they are meant to protect. Inflammation can additionally involve the abnormal proliferation of cells native to an affected tissue, and this cellular excess can disrupt the normal functioning of the tissue. In the kidney, for instance, immune complexes can accumulate in glomeruli, the organ's blood-filtering knots of capillary loops. Excessive deposition then initiates glomerulonephritis, a local inflammatory reaction that can lead to kidney damage.

Beyond inciting inflammation, certain lupus autoantibodies do harm directly. In laboratory experiments, they have been shown to bind to and then penetrate cells. There they become potent inhibitors of cellular function.

The real mystery about lupus is what precedes such events. Genetic predisposition seems to be part of the answer, at least in some people. About 10 percent of patients have close blood relatives with the disease, a pattern that usually implies a genetic contribution. Moreover, investigators have found greater lupus concordance—either shared lupus or a shared absence of it—in sets of identical twins (who are genetically indistinguishable) than in sets of fraternal twins (whose genes generally are no more alike than those of other pairs of siblings).

Genetic Hints

SPURRED BY such findings, geneticists are hunting for the genes at fault, including those that confer enhanced susceptibility to the vast majority of patients who have no obvious family history of the disease. Knowledge of the genes, the proteins they encode and the normal roles of these proteins should one day help clarify how lupus develops and could point to ways to better control it.

In mice prone to lupus, the work has identified more than 30 fairly broad chromosomal regions associated to some extent either with lupus or with resistance to it. Some are tied to specific elements of the disease. One region, for example, apparently harbors genes that participate in producing autoantibodies that recognize components of the cell nucleus (although the region itself does not encode antibodies); another influences the severity of the kidney inflammation triggered by lupus-related immune complexes.

In human lupus, the genetic story may be even more mind-boggling. An informative approach scans DNA from families with multiple lupus patients to identify genetic features shared by the patients but not by the other family

Overview/*Lupus*

- Lupus arises when the immune system mistakenly produces antibodies that attack the body's own tissues, including the kidneys, skin and brain.
- The causes of this attack are complex, but a central component seems to be aberrant signaling within and between at least two types of immune cells: B lymphocytes (the antibody producers) and the T lymphocytes that help to activate the B cells.
- Several drugs under study aim to protect tissues by normalizing such signaling and quelling abnormal antibody production.

members. Such work has revealed a connection between lupus and 48 chromosomal regions. Six of those regions (on five different chromosomes) appear to influence susceptibility most. Now investigators have to identify the lupus-related genes within those locales.

Already it seems fair to conclude that multiple human genes can confer lupus susceptibility, although each gene makes only a hard-to-detect contribution on its own. And different combinations of genes might lay the groundwork for lupus in different people. But clearly, single genes are rarely, if ever, the primary driver; if they were, many more children born to a parent with lupus would be stricken. Lupus arises in just about 5 percent of such children, and it seldom strikes in multiple generations of a family.

Many Triggers

IF GENES ALONE rarely account for the disease, environmental contributors must play a role. Notorious among these is ultraviolet light. Some 40 to 60 percent of patients are photosensitive: exposure to sunlight, say for 10 minutes at midday in the summer, may suddenly cause a rash. Prolonged exposure may also cause flares, or increased symptoms. Precisely how it does so is still unclear. In one scenario, ultraviolet irradiation induces changes in the DNA of skin cells, rendering the DNA molecules alien (from the viewpoint of the body's immune defenses) and thus potentially antigenic. At the same time, the irradiation makes the cells prone to breakage, at which point they will release the antigens, which can then provoke an autoimmune response.

Environmental triggers of lupus also include certain medications, among them hydralazine (for controlling blood pressure) and procainamide (for irregular heartbeat). But symptoms usually fade when the drugs are discontinued. In other cases, an infection, mild or serious, may act as a lupus trigger or aggravator. One suspect is Epstein-Barr virus, perhaps best known for causing infectious mononucleosis, or "kissing disease." Even certain vaccines may provoke a lupus flare. Yet despite decades of research, no firm proof of a bacterium, virus or parasite that transmits lupus has been put forth. Other possible factors include diets high in saturated fat, pollutants, cigarette smoking, and perhaps extreme physical or psychological stress.

If genes alone rarely account for the disease, **environmental contributors must play a role.**

Perils of Cell Suicide

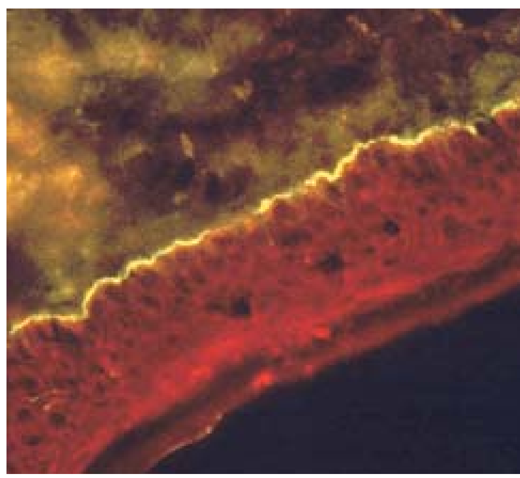
ANOTHER LINE of research has revealed cellular and molecular abnormalities that could well elicit or sustain autoimmune activity. Whether these abnormalities are usually caused more by genetic inheritance or by environmental factors remains unknown. People may be affected by various combinations of influences.

One impressive abnormality involves a process known as apoptosis, or cell suicide. For the body to function properly, it has to continually eliminate cells that have reached the end of their useful life or turned dangerous. It achieves this pruning by inducing the cells to make proteins that essentially destroy the cell from within—such as by hacking to pieces cellular proteins and the chromosomes in the nucleus. But the rate of apoptosis in certain cells—notably, the B and T lymphocytes of the immune system—is excessive in those who have lupus.

When cells die by apoptosis, the body usually disposes of the remains efficiently. But in those with lupus, the disposal system seems to be defective. This double whammy of increased apoptosis and decreased clearance can promote autoimmunity in a fairly straightforward way: if the material inside the apoptotic cells is abnormal, its ejection from the cells in quantity could well elicit the production of antibodies that mistakenly perceive the aberrant material as a sign of invasion by a disease-causing agent. And such antibody production is especially likely if the ejected material, rather than being removed, accumulates enough to call attention to itself.

Unfortunately, the material that spills from apoptotic cells of those with lupus, especially the chromosomal fragments, is often abnormal. In healthy cells, certain short sequences of DNA carry methyl groups that serve as tags controlling gene activity. The DNA in circulating immune complexes from lupus patients is undermethylated. Scientists have several reasons to suspect that this methylation pattern might contribute to autoimmunity. In the test tube, abnormally methylated DNA can stimulate a number of cell types involved in immunity, including B lymphocytes, which, when mature, become antibody-spewing factories. (Perhaps the body misinterprets these improperly methylated stretches as a sign that a disease-causing agent is present and must be eliminated.) Also, certain drugs known to cause lupus symptoms lead to undermethylation of DNA in T cells, which leads to T cell autoreactivity in mice.

All in all, the findings suggest that apoptotic cells are a potential reservoir of autoantigens that are quite capable of provoking an autoantibody response. In further support of this idea, intravenous

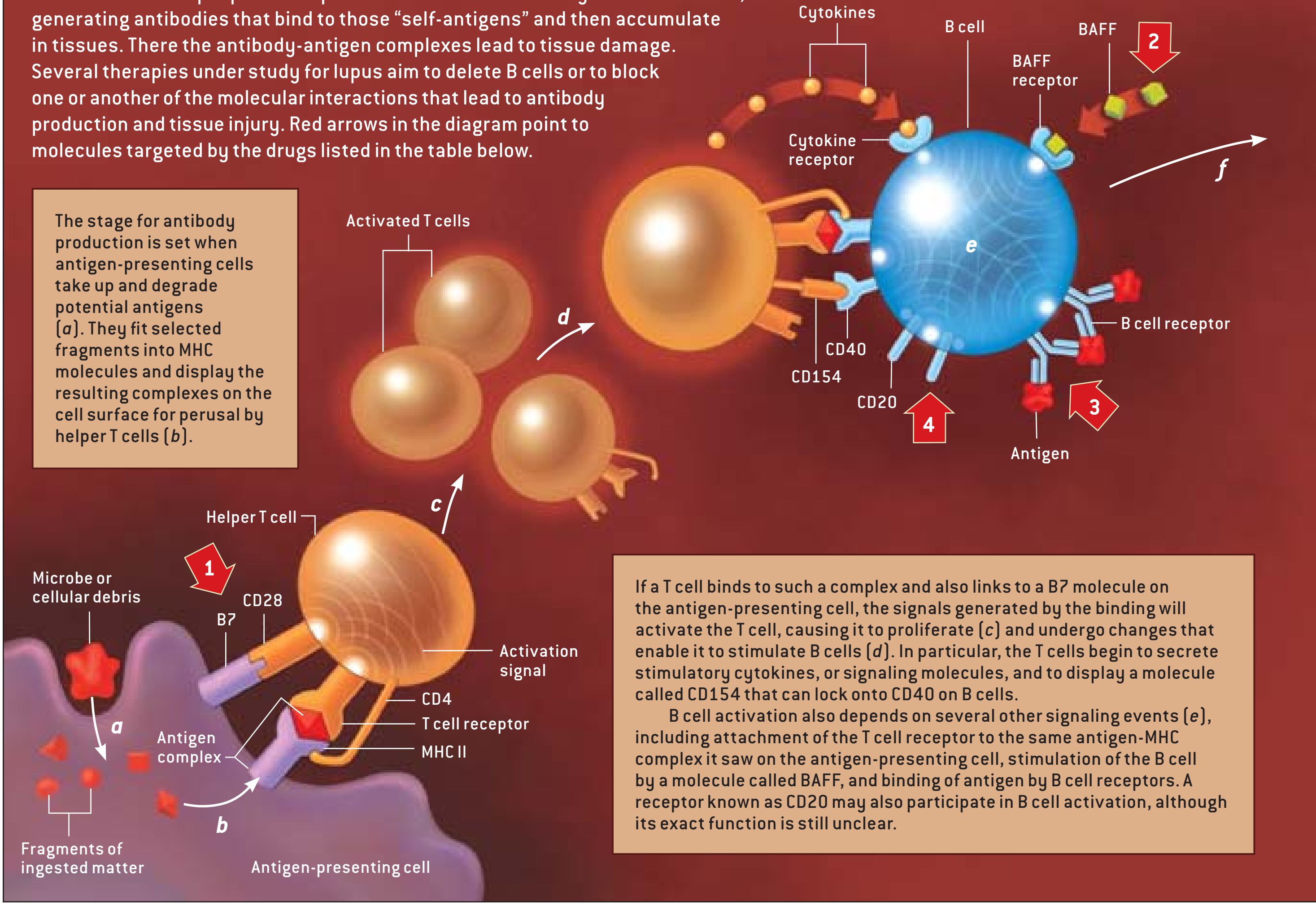


ANTIBODIES directed against tissue at the junction of the epidermis and dermis glow yellow in this micrograph of guinea pig skin exposed to blood serum from a patient with lupus. Such antibodies can trigger a damaging, inflammatory reaction.

ANDRÉ EYQUEM *Institut Pasteur, Paris*

B CELLS GONE WRONG

B lymphocytes normally respond only to foreign substances, or antigens, such as bacteria. But in people with lupus the cells react to the body's own molecules, generating antibodies that bind to those "self-antigens" and then accumulate in tissues. There the antibody-antigen complexes lead to tissue damage. Several therapies under study for lupus aim to delete B cells or to block one or another of the molecular interactions that lead to antibody production and tissue injury. Red arrows in the diagram point to molecules targeted by the drugs listed in the table below.



The stage for antibody production is set when antigen-presenting cells take up and degrade potential antigens (*a*). They fit selected fragments into MHC molecules and display the resulting complexes on the cell surface for perusal by helper T cells (*b*).

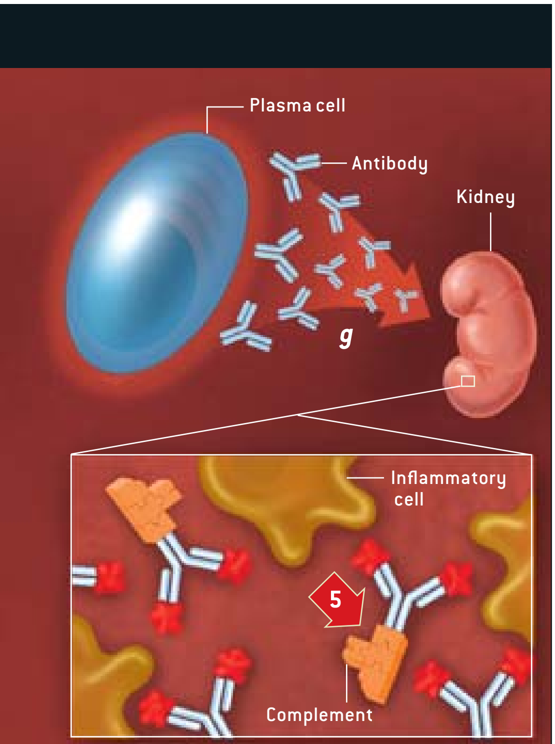
If a T cell binds to such a complex and also links to a B7 molecule on the antigen-presenting cell, the signals generated by the binding will activate the T cell, causing it to proliferate (*c*) and undergo changes that enable it to stimulate B cells (*d*). In particular, the T cells begin to secrete stimulatory cytokines, or signaling molecules, and to display a molecule called CD154 that can lock onto CD40 on B cells.

B cell activation also depends on several other signaling events (*e*), including attachment of the T cell receptor to the same antigen-MHC complex it saw on the antigen-presenting cell, stimulation of the B cell by a molecule called BAFF, and binding of antigen by B cell receptors. A receptor known as CD20 may also participate in B cell activation, although its exact function is still unclear.

Some Treatment Strategies under Study

	TYPE OF AGENT	STATUS
1	**Blocker of B7's interaction with CD28, to impede activation of helper T cells**	Immune Tolerance Network, a research consortium, and the National Institutes of Health are undertaking a small human trial of a blocker called RG2077
2	**Blocker of BAFF's interaction with its receptor, to keep BAFF (also called BLyS) from promoting B cell survival and antibody production**	Human Genome Sciences (Rockville, Md.) is evaluating one such drug, LymphoStat-B, in a multicenter trial; ZymoGenetics (Seattle) and Serono S.A. (Geneva, Switzerland) are conducting an early human trial of an agent named TACI-Ig
3	**Blocker of B cell receptors and of antibodies that recognize the body's own DNA, to inhibit the production and activity of antibodies that target such DNA**	La Jolla Pharmaceuticals (San Diego) is conducting a multicenter trial of abetimus sodium (Riquent) against lupus-related kidney disease
4	**Antibody to CD20, to deplete B cells**	Genentech (South San Francisco, Calif.) and Biogen Idec (Cambridge, Mass.) are conducting a multicenter lupus trial of rituximab (Rituxan), a drug already approved for B cell cancer
5	**Complement inhibitor, to prevent complement-mediated tissue damage**	Alexion Pharmaceuticals (Cheshire, Conn.) found evidence of disease amelioration in mice given an inhibitor of complement C5

JEN CHRISTIANSEN



Having received the needed stimulation, a B cell matures into an antibody-secreting plasma cell (*f*), and the antibodies go off to attack or mark for destruction any cells or tissues possessing the antigen recognized by the antibodies (*g*). For instance, antibodies attract complement molecules and inflammatory cells, both of which can be destructive (*inset*).

administration of large quantities of irradiated apoptotic cells is able to induce autoantibody synthesis in normal mice.

Hence, part of the underlying process leading to the formation of destructive immune complexes may involve the body's production of foreign-seeming antigens, which cause the body to behave as if tissues bearing those antigens were alien and threatening. But other work indicates that, in addition, the B lymphocytes of lupus patients are inherently deranged; they are predisposed to generate autoantibodies even when the self-molecules they encounter are perfectly normal. In other words, the mechanisms that should ensure self-tolerance go awry.

Deranged Cells

THE PROBLEM MOSTLY seems to stem from signaling imbalances within B cells. In the healthy body, a B cell matures into an antibody-secreting machine—known as a plasma cell—only after antibodylike projections on the B cell's surface (B cell receptors) bind to a foreign antigen. If a B cell instead attaches to a self-component, this binding normally induces the cell to kill itself, to retreat into a nonresponsive (anergic) state or to "edit" its receptors until they can no longer recognize the self-antigen.

Whether the cell responds appropriately depends in large measure on the proper activity of the internal signaling pathways that react to external inputs. Mouse studies show that even subtle signaling imbalances can predispose animals to produce antibodies against the self. And various lines of evidence indicate that certain signaling molecules (going by such names as Lyn, CD45 and SHP-1) on and in B cells of patients with lupus are present in abnormal amounts.

Other work suggests that it is not only the B cells that are deranged. For a B cell to become an antibody maker, it must do more than bind to an antigen. It must also receive certain stimulatory signals from immune system cells known as helper T lymphocytes. Helper cells of lupus patients are afflicted by signaling abnormalities reminiscent of those in the B cells. The T cell aberrations, though, may lead to autoantibody production indirectly—by causing the T cells to inappropriately stimulate self-reactive B cells.

All theorizing about the causes of lupus must account not only for the vast assortment of autoantibodies produced by patients but also for another striking aspect of the disease: the disorder is 10 times as common in women than in men. It also tends to develop earlier in women (during childbearing years). This female susceptibility—a pattern also seen in some other autoimmune diseases—may stem in part from greater immune reactivity in women. They tend to produce more antibodies and lymphocytes than males and, probably as a result, to be more resistant to infections. Among mice, moreover, females reject foreign grafts more rapidly than the males do. Perhaps not surprisingly, sex hormones seem to play a role in this increased reactivity, which could explain why, in laboratory animals, estrogens exacerbate lupus and androgens ameliorate it.

Estrogens could pump up immune reactivity in a few ways. They augment the secretion of prolactin and growth hormone, substances that contribute to the proliferation of lymphocytes, which bear receptor molecules sensitive to estrogens. Acting through such receptors, estrogens may modulate the body's immune responses and may even regulate lymphocyte development, perhaps in ways that impair tolerance of the self.

Toward New Therapies

THOSE OF US who study the causes of lupus are still pondering how the genetic, environmental and immunological features that have been uncovered so far collaborate to cause the disease. Which events come first, which are most important, and how much do the underlying processes differ from one person to another? Nevertheless, the available clues suggest at least a partial scenario for how the disease could typically develop.

The basic idea is that genetic susceptibilities and environmental influences may share responsibility for an impairment of immune system function—more specifically an impairment of the signaling within lymphocytes and possibly within other cells of the immune system, such as those charged with removing dead cells and debris. Faulty signaling, in turn, results in impaired self-tolerance, accelerated lymphocyte death, and defective disposal of apoptotic cells and

THE AUTHOR

MONCEF ZOUALI, an immunologist and molecular biologist, is a director of research at INSERM, the French national institute for medical research. He focuses on conducting basic research into the molecular causes of systemic autoimmune diseases and on translating scientific insights into useful approaches to disease management. Zouali has edited several books on autoimmunity and won research awards.

THE DIAGNOSTIC CHALLENGE

Physicians who suspect that a patient, whether female or male, has lupus continue to be hampered by the lack of a conclusive test. Because immunological self-attack may underlie many illnesses, even a classic sign of lupus—the presence of antinuclear autoantibodies—does not unmistakably diagnose this disorder.

In the absence of a sure test, doctors might gather information from a variety of sources, including not only laboratory tests but also the patient's description of current symptoms and medical history. To assist, the American College of Rheumatology has issued a list of 11 criteria that could indicate lupus. Seven concern symptoms, such as arthritis, sensitivity to sunlight or a butterfly facial rash. (The butterfly pattern is still unexplained.) The other four describe laboratory findings that include the presence of antinuclear autoantibodies or depressed concentrations of lymphocytes.

Researchers will consider a subject to have lupus if the person meets four of the criteria, but physicians might base a diagnosis on fewer cues, especially if a patient has strong indicators of the disorder, such as clinical evidence of abnormalities in several different organ systems combined with the presence of antinuclear autoantibodies. For more on common manifestations of lupus, visit the Lupus Foundation of America: www.lupus.org/ or the Lupus site: www.uklupus.co.uk/ —*M.Z.*

CLASSIC BUTTERFLY RASH was once thought to be the only effect of lupus.

Current Criteria

Malar rash (a rash, often butterfly-shaped, over the cheeks)
Discoid rash (a type involving red raised patches)
Photosensitivity (reaction to sunlight in which a skin rash arises or worsens)
Nose or mouth ulcers, typically painless
Nonerosive arthritis (which does not involve damage to the bones around the joints) in two or more joints
Inflammation of the lining in the lung or heart (also known as pleuritis or pericarditis)
Kidney disorder marked by high levels in the urine of protein or of abnormal substances derived from red or white blood cells or kidney tubule cells
Neurological disorder marked by seizures or psychosis not explained by drugs or metabolic disturbances (such as an electrolyte imbalance)
Blood disorder characterized by abnormally low concentrations of red or white blood cells or platelets (specifically, hemolytic anemia, leukopenia, lymphopenia or thrombocytopenia) and not caused by medications
Positive test for antinuclear antibodies (ANA) not explained by drugs known to trigger their appearance
Positive test for antibodies against double-stranded DNA or certain phospholipids or a false positive result on a syphilis test

the self-antigens they release. Abundantly available to the body's unbalanced immune surveillance, the antigens then misdirect the immune system, inducing it to attack the self.

Drugs do exist for lupus, but so far they focus on dampening the overall immune system. In other words, they are nonspecific: instead of targeting immunological events underlying lupus in particular, they dull the body's broad defenses against infectious diseases. Corticosteroids, for instance, reduce inflammation at the cost of heightening susceptibility to infections.

The challenge is to design new drugs that prevent autoimmune self-attacks without seriously hobbling the body's ability to defend itself against infection. To grasp the logic of the approaches being attempted, it helps to know a bit more about how helper T cells usually abet the transformation of B cells into vigorous antibody makers [*see box on pages 74 and 75*].

First, the helper cells themselves must be activated, which occurs through interactions with so-called professional antigen-presenting cells (such as macrophages and dendritic cells). These antigen presenters ingest bacteria, dead cells and cellular debris, chop them up, join the fragments to larger molecules (called MHC class II molecules) and display the resulting MHC-antigen complexes on the cell surface. If the receptor on a helper T cell recognizes a complex and binds to it, the binding conveys an antigen-specific signal into the T cell. If, at the same time, a certain T cell projection near the receptor links to a particular partner (known as a B7 molecule) on the antigen-presenting cell, this binding will convey an antigen-independent, or costimulatory, signal into the T cell. Having received both messages, the T cell will switch on; that is, it will produce or display molecules needed to activate B cells and will seek out those cells.

Like the professional antigen-presenting cells, B cells display fragments of ingested material—notably fragments of an antigen they have snared—on MHC class II molecules. If an activated helper T cell binds through its receptor to such a complex on a B cell, and if the T and B cells additionally signal each other through co-stimulatory surface molecules, the B cell will display receptors for small proteins called cytokines. These cytokines, which are secreted by activated helper T cells, induce the B cell to proliferate and mature into a plasma cell, which dispatches antibodies that specifically target the same antigen recognized by the coupled B and T cells.

Of course, any well-bred immune response shuts itself off when the danger has passed. Hence, after an antigen-presenting cell activates a helper T cell, the T cell also begins to display a "shutoff" switch known as CTLA-4. This molecule binds to B7 molecules on antigen-presenting cells so avidly that it links to most or even all of them, thereby putting a break on any evolving helper T and, consequently, B cell responses.

One experimental approach to treating lupus essentially mimics this shutoff step, dispatching CTLA-4 to cap over B7 molecules. In mice prone to lupus, this method prevents kidney disease from progressing and prolongs life. This substance is beginning to be tested in lupus patients; in those with psoriasis, initial clinical trials have shown that the treatment is safe.

A second approach would directly impede the signaling between helper T cells and B cells. The T cell molecule that has to "clasp hands" with a B cell molecule to send the needed co-stimulatory signal into B cells is called CD154. The helper cells of lupus patients show increased production of CD154, and in mice prone to the disease, antibodies engineered to bind to CD154 can block B cell activation, preserve kidney function and prolong life. So far early human tests of different versions of anti-CD154 antibodies have produced a mixture of good news and bad. One version significantly reduced autoantibodies in the blood, protein in the urine and certain symptoms, but it also elicited an unacceptable degree of blood-clot formation. A different version did not increase thrombosis but worked poorly. Hence, no one yet knows whether this approach to therapy will pan out.

The challenge is to prevent immune self-attacks without hobbling the body's ability to defend itself.

A third strategy would interfere with B cell activity in a different way. Certain factors secreted by immune system cells, such as the cytokine BAFF, promote cell survival after they bind to B cells. These molecules have been implicated in various autoimmune diseases, including lupus and its flares: mice genetically engineered to overproduce BAFF or one of its three receptors on B cells develop signs of autoimmune disease, and BAFF appears to be overabundant both in lupus-prone mice and in human patients. In theory, then, preventing BAFF from binding to its receptors should minimize antibody synthesis. Studies of animals and humans support this notion. In mice, a circulating decoy receptor, designed to mop up BAFF before it can find its true receptors, alleviates lupus and lengthens survival. Findings for a second decoy receptor are also encouraging. Human trials are in progress.

Targeting other cytokines might help as well. Elevated levels of interleukin-10 and depressed amounts of transforming growth factor beta are among the most prominent cytokine abnormalities reported in lupus, and lupus-prone mice appear to benefit from treatments that block the former or boost the latter. Taking a different tack, investigators studying various autoimmune conditions are working on therapies aimed specifically at reducing B cell numbers. An agent called rituximab, which removes B cells from circulation before they are able to secrete antibodies, has shown promise in early trials in patients with systemic lupus.

Some other therapies under investigation include molecules designed to block production of anti-DNA autoantibodies or to induce those antibodies to bind to decoy compounds that would trap them and provoke their degradation. An example of such a decoy is a complex consisting of four short DNA strands coupled to an inert backbone. Although the last idea is intriguing, I have to admit that the effects of introducing such decoys are apt to be complex.

Certain cytokines might be useful as therapies, but these and other protein drugs could be hampered by the body's readiness to degrade circulating proteins. To circumvent such problems, researchers are considering gene therapies, which would give cells the ability to produce useful proteins themselves. DNA encoding transforming growth factor beta has already been shown to treat lupus in mice, but too few tests have been done yet in humans to predict how useful the technique will be in people. Also, scientists are still struggling to perfect gene therapy techniques in general.

As treatment-oriented investigators pursue new leads for helping patients, others continue to probe the central enigmas of lupus. What causes the aberrant signaling in immune cells? And precisely how does such deranged signaling lead to autoimmunity? The answers may well be critical to finally disarming the body's mistaken attacks on itself. SA

MORE TO EXPLORE

Dubois' Lupus Erythematosus. Sixth edition. Daniel J. Wallace and Bevra H. Hahn. Lippincott Williams & Wilkins, 2001.

Immunobiology: The Immune System in Health and Disease. Sixth edition. Charles A. Janeway, Paul Travers, Mark Walport and Mark J. Shlomchik. Garland Science, 2004.

B Lymphocyte Signaling Pathways in Systemic Autoimmunity: Implications for Pathogenesis and Treatment. Moncef Zouali and Gabriella Sarmay in *Arthritis & Rheumatism,* Vol. 50, No. 9, pages 2730–2741; September 2004.

Molecular Autoimmunity. Edited by Moncef Zouali. Springer Science and Business Media (in press).

www.lupusresearch.org

NIKOLA TESLA sits before his large web coil in 1896. That year he wrote: "I do not think there is any thrill than can go through the human heart like that felt by the inventor as he sees some creation of the brain unfolding to success.... Such emotions make a man forget food, sleep, friends, love, everything."

Inventor of Dreams

By W. Bernard Carlson

Nikola Tesla,

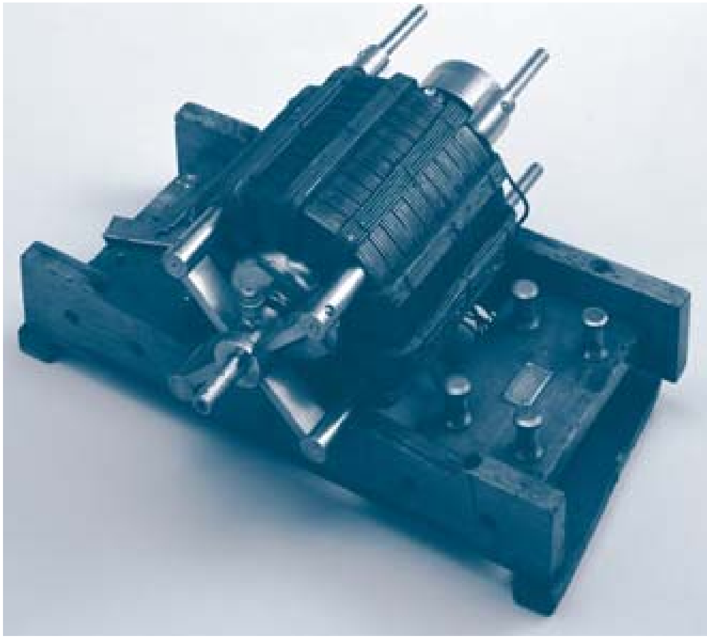
the father of today's AC electrical system and other key inventions, often failed to bring his visionary ideas to real-world fruition

When members of the Chicago Commercial Club arrived to hear a lecture by the famed electrical inventor Nikola Tesla on May 13, 1899, they were startled by the sight of an artificial lake sitting in the middle of the auditorium. Everyone knew that Tesla—the man who had devised the alternating-current (AC) system that brought electricity into people's homes and businesses—was a master showman. Six years earlier at Chicago's Columbian Exposition, for example, the dapper engineer had dazzled spectators by sending 250,000-volt shocks coursing through his body. Now the audience was abuzz, wondering what Tesla was going to do with his miniature lake and the six-foot boat that floated on its surface.

Abruptly, the craft began to motor around the pool on its own, with lights blinking. From the side, Tesla operated a remote-control unit that conveyed commands to the boat via invisible radio waves. The crowd was astonished. He then invited individuals to shout out commands: "Turn left! Flash the lights!" Using his wireless transmitter, Tesla signaled the boat, and it executed the requested maneuvers [*see illustration on page 83*]. With the Spanish-American War having just come to an end, the audience was impressed by Tesla's proposal to arm a larger vessel with dynamite and then steer it by remote control toward an enemy na-

TESLA WARDENCLYFFE PROJECT

As he admired the Budapest sunset, TESLA ENVISIONED the solution to his motor problem.



TWO-PHASE alternating-current (AC) induction motor was built by Tesla in 1887. By energizing pairs of induction coils on either side of the stator with two separate out-of-phase alternating currents, he created a rotating magnetic field that induced an opposing electric field in the rotor, causing it to turn.

SCIENCE MUSEUM/SCIENCE AND SOCIETY PICTURE LIBRARY

val ship. Here, more than a century ago, was a prototype for the guided missile.

Despite this spectacular demonstration, Tesla never converted his remote-control boat into a full-fledged weapon. His failure to do so is emblematic of a larger theme that permeated his life—a profound idealism that only occasionally reached practical reality. Throughout his career, Tesla strove to find the perfect principle on which to base a revolutionary invention. Having identified a grand concept, he was willing to patent and demonstrate it, but he often left it to others to carry out the down-and-dirty work of engineering a moneymaking product. Sadly, as his career progressed, the famous inventor found it increasingly difficult to convince prospective backers to help with the messy process of commercialization. As a result, he grew ever more disappointed with and disconnected from the world.

Motor Visionary

TESLA WAS BORN on July 10, 1856, to a Serbian family living on the frontier of the Austro-Hungarian Empire, in what is today Croatia. As a teenager, Tesla chose to study engineering at the Joanneum Polytechnic School in Graz, Austria. There the youthful scholar eagerly attended the physics lectures presented by Jacob Poeschl in 1876 and 1877.

During Poeschl's lectures, Tesla first started thinking about what would become his most important invention, an improved AC motor. One day he watched his professor attempt to control the troublesome sparking of a direct-current (DC) motor's brush commutator—copper-wire electrical contacts that reverse the current twice during each rotation so that the resulting opposing magnetic fields keep the rotor turning. Tesla suggested that it might be possible to design a motor without a commutator. Annoyed by the student's impudence, Poeschl lectured on the impossibility of creating such a motor, concluding: "Mr. Tesla may accomplish great things, but he certainly never will do this." The rebuke, however, merely stoked the fires of the youth's ambition. Tesla puzzled incessantly about how to make a spark-free motor as he pursued his studies in Graz and then in Prague.

In 1881 Tesla traveled to Budapest, hoping to work for family friends, Tivadar and Ferenc Puskas. An ambitious promoter, Tivadar had previously convinced Thomas A. Edison to give him the commercial rights to introduce inventions developed by the Wizard of Menlo Park in continental Europe. The Puskas brothers were planning to construct a telephone exchange in Budapest using Edison's improved telephone design. Unfortunately, they were unable to hire anyone immediately. While waiting, Tesla fell seriously ill. He only recovered with the help of a college friend, Anthony Szigeti, who encouraged the sick man to walk each evening to help regain his strength.

It was during one of these strolls with Szigeti that Tesla had an epiphany about motors. As they admired the sunset, Tesla suddenly envisioned using a rotating

Overview/*Nikola Tesla*

- Nikola Tesla (1856–1943) was a Serbian-American inventor and researcher who discovered the rotating magnetic field, the basis of most alternating-current (AC) machinery—dynamos, transformers and motors. He also invented the Tesla coil, a high-voltage induction coil used widely in radios, televisions and other electronic equipment.
- Tesla was a great showman and a favorite of newspaper reporters who sought sensational copy. His outrageous claims that he communicated with other planets and had developed a death ray led to considerable criticism, however.
- Despite devising many important fundamental technical concepts, Tesla rarely bothered to engineer them into usable products. Sadly, he was impractical about financial matters and ended up dying in poverty and obscurity.

"CITY OF LIGHT" at the Columbian Exposition at the 1893 Chicago World's Fair was powered by 12 1,000-horsepower AC generators of Tesla's design. The 27 million visitors came away from the fair knowing that AC power was the future of electricity.

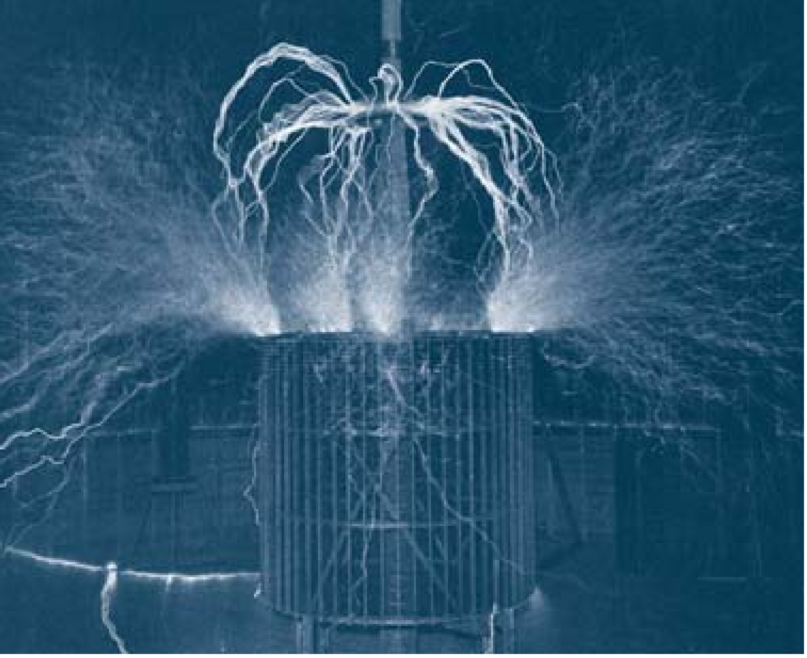
magnetic field in his motor—a major break with convention. The young Serb's insight was to invert the standard practice: rather than changing the magnetic poles in the rotor, he would alter the magnetic field in the stator. This configuration would eliminate the need for the sparking commutator. Tesla saw that if the magnetic field in the stator rotated, it would induce an opposing electric field in the rotor, thus causing the rotor to turn. He surmised that the rotating magnetic field could be created using AC instead of DC, but at the time he did not know how to achieve this feat.

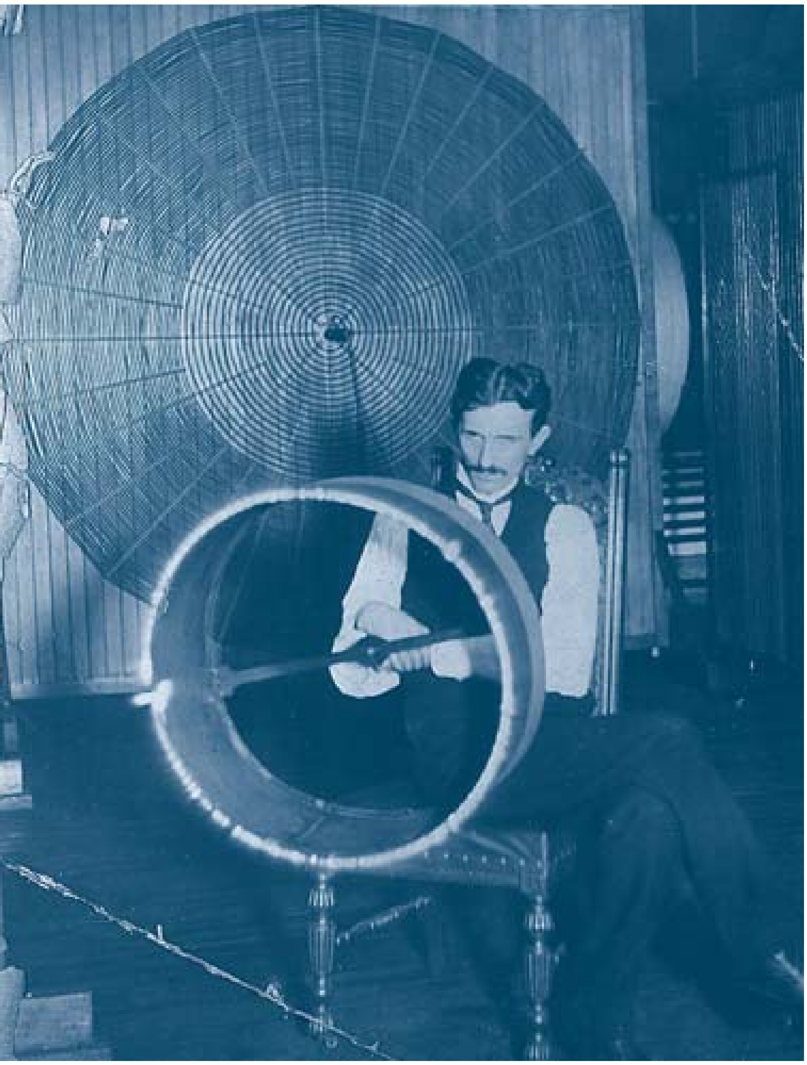
Rags to Riches

TESLA STRUGGLED for the next five years to acquire the practical knowledge he needed to realize his motor. After he had helped the Puskas brothers build their telephone exchange in Budapest, Tesla moved with Tivadar to Paris, where they both went to work for the Société Electrique Edison installing incandescent lighting systems. In 1884 Tesla transferred to the Edison Machine Works in New York City. Unfortunately, he had almost no personal contact with the renowned inventor. While there, the Serbian inventor nearly told Edison about his motor idea. "It was on Coney Island," he recalled, "and just as I was going to explain it to him, someone came and shook hands with Edison. That evening, when I came home, I had a fever and my resolve rose up again not to speak freely about [my motor] to other people." A few months later, after Tesla had completed the design of an improved arc lighting system (illumination based on electric sparks leaping the gap

HYDROELECTRIC GENERATORS producing three-phase AC power were installed by Westinghouse engineers in Niagara Falls, N.Y., in 1896. Initially, they transmitted electricity only the 25 miles to Buffalo, N.Y., but within a few years, power lines to New York City set Broadway ablaze with light.

TESLA WARDENCLYFFE PROJECT





ARTIFICIAL LIGHTNING erupts from a Tesla coil in the inventor's experimental station in Colorado Springs in 1899 or 1900 [*top*]. Tesla often employed large wire coils, some wound on a frame running around the lab, to achieve these spectacular effects. In the image at bottom (taken at his New York City lab in 1898), Tesla watches as powerful electromagnetic fields induce electrical streamers packing nearly half a million volts in the front coil.

TESLA WARDENCLYFFE PROJECT

between two electrodes), his managers reneged on a promised bonus, so the ambitious engineer quit in disgust.

Tesla was quickly hired by two business promoters from Rahway, N.J., Benjamin A. Vail and Robert Lane, who encouraged him to patent his arc lighting system so they could commercialize it. Tesla unwisely assigned the patents to the shifty pair, trusting that they intended to manufacture equipment and compete with Edison. Vail and Lane, however, decided that the real financial opportunity lay in operating an electric lighting utility. So once Tesla had his arc lighting system running in Rahway, his backers fired him and reorganized the firm. Utterly destitute after being abandoned, Tesla was forced to dig ditches.

Despite enduring a year of backbreaking hardship, Tesla mustered the energy in March 1886 to file a patent application for a thermomagnetic motor—a novel device powered by heating and cooling magnets. Discussions about his invention with the foreman at his ditchdigging job led to an introduction to Charles Peck, a clever attorney. Intrigued by the thermomagnetic motor concept, Peck offered to underwrite Tesla's research. Because Peck was not a technical expert, he invited Alfred S. Brown, a superintendent at Western Union, to join him in supporting Tesla.

Peck and Brown rented a laboratory for Tesla in lower Manhattan, where the immigrant inventor devoted himself initially to developing the thermomagnetic motor. When that concept proved unworkable, Peck pushed Tesla to work on perfecting AC motors. Building on his Budapest vision, Tesla began experimenting with multiple alternating currents in a motor. This approach was unconventional because most contemporary experimenters employed a single alternating current in their systems. By September 1887 Tesla discovered that he could produce a rotating magnetic field by feeding two separate alternating currents into pairs of coils set on opposite sides of the stator [*see illustration on page 80*]. In modern parlance, the two currents are 90 degrees out of phase, and the motor runs on two-phase current. Elated, Tesla submitted several patent applications that broadly covered the principle of a rotating magnetic field. In these filings, he introduced the idea that multiphase AC could transmit power over substantial distances, a notion that was to become important later.

When it became clear that Tesla's AC motor had real promise, his backers began pondering how to promote it. Peck and Brown planned to sell Tesla's patents to the highest bidder, rather than to manufacture motors. Toward that end, they arranged for Tesla to lecture before the American Institute of Electrical Engineers in May 1888. The talk received extensive coverage in electrical journals and soon attracted the interest of George Westinghouse, who had made a fortune manufacturing air brakes and signal systems for railroads. At this time, electric lighting

Tesla believed that his SIGNALS REACHED MARS and that he had received a return message from Martians.

companies were considering shifting from DC to AC, because AC could be transmitted over longer distances and thus reach more customers. Whereas Edison focused on DC technology, Westinghouse had bet on AC, and so Peck and Brown were able to convince him to pay handsomely for Tesla's patents. In July 1888 Westinghouse offered the group $25,000 in cash, plus $50,000 in notes and a royalty of $2.50 per horsepower for each motor manufactured. Tesla generously gave five ninths of the proceeds to his two supporters while retaining the rest for himself.

Westinghouse hoped Tesla's motor could be used to drive streetcars, so Tesla went to Pittsburgh to adapt his design to this application. The inventor and the Westinghouse engineers were, however, stymied by technical difficulties. Because his motor required two alternating currents and four wires, it could not be merely dropped into existing single-phase AC systems; one would need to install additional wires to the network. Although Tesla developed several two-wire motors, these so-called split-phase designs ran best on currents of 50 cycles per second or less. At that time, Westinghouse single-phase systems employed 133-cycle current so customers would not see their incandescent lamps flickering.

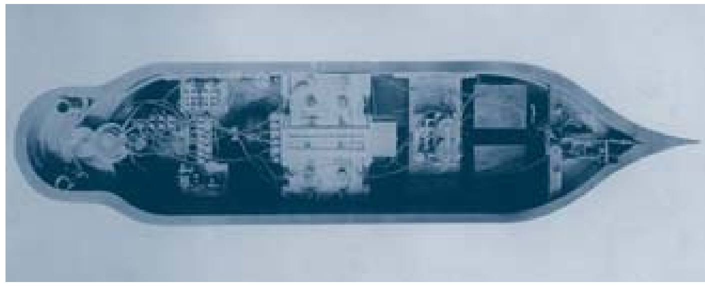
Westinghouse engineers eventually solved these problems by modifying Tesla's motor and developing a new AC system using three-phase, 60-cycle current. Westinghouse demonstrated this new technology in dramatic fashion in 1895 by building a hydroelectric station at Niagara Falls, a plant that subsequently transmitted power across the 25 miles to factories in Buffalo, N.Y. Thus, Tesla's AC motor and multiphase AC system formed the basis for today's North American power-distribution system [*see bottom illustration on page 81*].

Resonating with Energy

LONG BEFORE the Niagara station came on line, however, Tesla grew restless and left Westinghouse. He had come up with the ideal AC motor but wasn't interested in working out the details.

Drawing on his royalties, in 1889 Tesla established a new laboratory in New York City. To attract public attention and new investors, he now cultivated the image of an eccentric genius. Just as reporters had publicized Edison's exploits at Menlo Park in the 1870s, so they flocked to Tesla's laboratory in the 1890s to cover his sensational discoveries and dramatic pronouncements [*see bottom illustration on opposite page*].

Searching for a way to create an arc light for use on AC networks, Tesla now found a new fundamental ideal on which to focus: high-frequency electrical phenomena.



RADIO-CONTROLLED BOAT was unveiled by Tesla in 1898. The next year he demonstrated to the Chicago Commercial Club that he could run a boat (*view from above*) without touching it, making it turn, accelerate and flash its lights whenever he sent signals to it. Some experts regard the boat's circuitry as a progenitor of the basic AND logic used in modern computers.

TESLA WARDENCLYFFE PROJECT

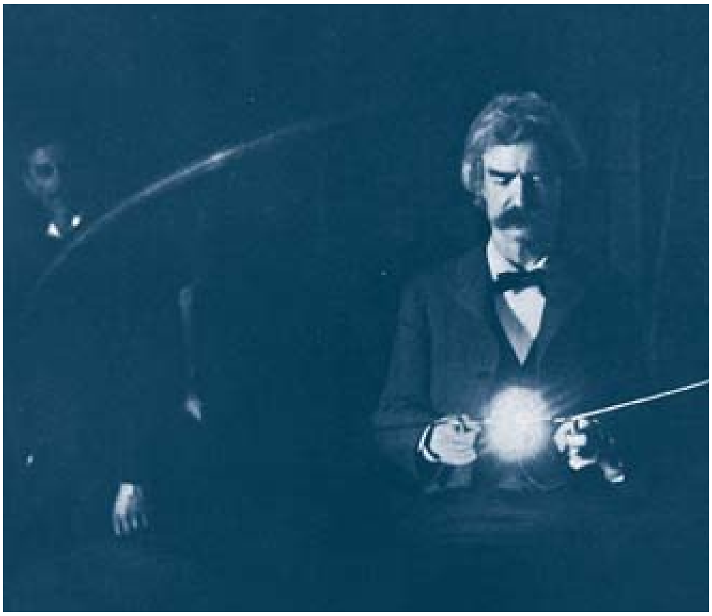
If one could build a practical motor using 60-cycle AC, he wondered, what could be made of current with a frequency of 10,000 cycles per second? Whereas Tesla had combined magnetic induction coils, resistors and capacitors to fashion his split-phase motors, he now connected induction coils and capacitors in new configurations to produce high-frequency currents.

The inventor investigated this grand concept for the next 15 years. By likening a capacitor to a storage tank and an induction coil to a coil spring, Tesla realized that a properly configured circuit could amplify electrical signals and raise them to ever higher frequencies and voltages. Exploiting this insight, he constructed huge "magnifying transmitters"—today called Tesla coils—that generated sparks more than 135 feet long [*see top illustration on opposite page*]. Tesla further appreciated that resonance opened the way to tuning radio signals. Giving a transmitter a particular capacitance and inductance would generate signals at a desired frequency; likewise, endowing a receiving circuit with the same capacitance and inductance would allow it to respond to signals transmitted at that original frequency.

Drawing on the fundamental idea of electrical resonance, Tesla simultaneously pursued inventions in light-

THE AUTHOR

W. BERNARD CARLSON is associate professor of science, technology and society in the School of Engineering and Applied Science at the University of Virginia. He received his doctorate in the history of science and sociology from the University of Pennsylvania in 1984, and he studied business history as a postdoctoral fellow at the Harvard Business School from 1988 to 1989. He recently finished the seven-volume *Technology in World History*, which will be published in 2005 by Oxford University Press. With support from the Alfred P. Sloan Foundation, Carlson is currently completing a biography of Tesla to be published by Princeton University Press.



MARK TWAIN (Samuel Clemens) demonstrates the wireless transmission of power. A large resonating coil (*not visible*) has induced a high-voltage current in the wire loop he holds. The current passed harmlessly through Twain's body yet caused the incandescent bulbs to glow. Tesla is seen (*obscured at far left*) operating the apparatus's controls.

ing, wireless communications and the wireless distribution of power. Hoping to develop a high-efficiency lamp to replace Edison's incandescent bulb, the brilliant inventor not only created early fluorescent lamps but also observed that a vacuum tube could detect radio waves. Tesla did not follow up on this observation, however, and J. A. Fleming and Lee De Forest subsequently developed their own radio tubes.

TESLA IS SEEN IN HIS NEW YORK City office in 1916. The inventor often crossed the street to Bryant Park to feed the pigeons there. The drawings behind Tesla depict his steam engine design.

Having perfected the circuits needed to transmit and receive radio waves, Tesla tested them using antennas suspended from balloons floating over his downtown laboratory and his uptown Manhattan hotel. But just as he began to get promising results, his lab was destroyed by fire in March 1895, and all his research apparatus and notes were lost.

Broadcasting Power Globally

IN THE SPRING OF 1899 Tesla closed his rebuilt New York laboratory and constructed a facility at the foot of Pikes Peak in Colorado Springs, Colo. There the inventor tackled what he believed would be the most important application for electromagnetic waves: the wireless transmission of power around the world. During that period, it seemed as if all of America was being wired. The demand for electricity appeared to be insatiable, so he dreamed of trumping the burgeoning landline networks by distributing both power and messages without wires.

Tesla's newest dream was based on electrical resonance. Like other early wireless researchers, he viewed the relation between transmitter and receiver as twofold. First, the transmitter sent radio waves through the air to the receiver. Then, because both devices were grounded to the earth, a return current passed through the ground from the receiver to the transmitter. Unlike everyone else, who focused on transmitting radio waves through the atmosphere, however, Tesla decided to concentrate on the earth-borne current. Why not, he thought, have the transmitter send waves through the earth to the receiver and then use the atmosphere for the return circuit? Tesla imagined that it should be possible for a transmitting station to pump electromagnetic energy into the earth's crust until the planet's electrical resonant frequency was reached; then, with the whole globe pulsing with energy, it could be tapped by receiving stations all over the world. Tesla assembled several large magnifying transmitters at Colorado Springs to test this theory and convinced himself that they had successfully broadcast power around the world. (Tesla also believed that his signals had reached Mars and that he had received a return message from Martians!)

Satisfied that power could be transmitted around the globe underground, he returned to New York City in 1900. So certain of success was he that he took rooms in the luxurious Waldorf-Astoria Hotel. Tesla then wrote a 60-page treatise for *Century* magazine entitled "The Problem of Increasing Human Energy." His promotional efforts paid off, and in 1901 tycoon J. Pierpont Morgan invested $150,000 in Tesla's wireless-power scheme. Tesla rapidly spent this advance, sparing no expense in outfitting a new laboratory in Wardenclyffe, on the north shore of Long Island, N.Y. Despite Morgan's refusal to provide more cash and Tesla's failure to produce positive technical results, the inventor nonetheless built a 187-

TESLA WARDENCLYFFE PROJECT (*top*); BETTMANN/CORBIS (*bottom*) foot antenna tower in Wardenclyffe [*see illustration at right*]. Even with his connections to New York's moneyed elite, however, Tesla could not secure the funds he needed to complete his project and thereupon suffered a nervous breakdown.

Later Life and Legacy

FOLLOWING HIS PARTIAL RECOVERY, Tesla hoped to raise money to resume work at Wardenclyffe by shifting his creative efforts from electrical to mechanical engineering. Aware that power plants were replacing piston-based reciprocating steam engines with more efficient rotary steam turbines, he began investigating a radical bladeless turbine design. Like his other inventions, the bladeless turbine was based on a grand idea. Just as a rotating magnetic field "dragged" the rotor along in his AC motor, so Tesla thought it possible to have steam drag around a series of thin, closely spaced disks fastened to a turbine's shaft via viscous forces—shearing stresses that depend on a fluid's flow velocity. Tesla's turbine had to operate at speeds exceeding 10,000 revolutions per minute—unfortunately, much too fast for any thin steel disks to withstand.

Although Tesla was unable to convince anyone to manufacture his bladeless turbine, he was able to patent an automotive speedometer based on the same principle: the use of viscous forces that cause closely placed disks to spin. During the next two decades, he lived off the royalties from his speedometer. Tesla meanwhile wrote articles for popular magazines in which he speculated on the future of electricity and radio. Gradually, however, he grew depressed and finally became an itinerant recluse, moving from hotel to hotel as the bills came due.

To mark Tesla's 75th birthday, in 1931, *Time* magazine ran a cover story in which the inventor held forth on signaling the stars with his "Teslascope"—a giant radio transmitter. Enjoying his regained celebrity, he held annual press conferences on his birthday. During these events, Tesla warned about the dangers of global war and argued that disaster could be avoided only by developing a super weapon that could maintain a balance of terror. The ultimate deterrent, he claimed, was a ray gun or particle-beam device that could direct immense amounts of energy at enemy airplanes, ships and armies. In 1937, while Tesla was taking his daily stroll around the city, he was struck by a taxi. The eminent inventor never fully recovered, and he died on January 8, 1943.

Tesla left a mixed legacy. On the one hand, he is acknowledged as the father of the AC motor, and in 1956 the "tesla" was adopted as the international unit of measure for the flux density of magnetic fields. On the other hand, his many colorful predictions led him to become a patron saint for groups who hold nonmainstream spiritual beliefs. Fascinated by Tesla's claims of uncovering the mystical secrets of the universe, these fans contend that powerful individuals such as Edison and Morgan had conspired to keep Tesla from perfecting his inventions and revolutionizing the world.

Exaggerated claims and conspiracy theories notwithstanding, Tesla made enormous contributions to engineering. His ability to focus on fundamental principles was his greatest strength, but it was also his biggest weakness. All too often, Tesla became intoxicated by the beauty of his basic concepts, so much so that he was unwilling to work out the practical details of his inventions. SA

TESLA WARDENCLYFFE PROJECT

WARDENCLYFFE TOWER, at 187 feet tall, stood near the lab Tesla constructed in 1901 in what is now Shoreham, Long Island. The facility was intended both for transatlantic wireless communications and radio broadcasting, as well as for global transmission of electric power.

MORE TO EXPLORE

My Inventions: The Autobiography of Nikola Tesla. Edited by Ben Johnston. (Originally published in *Electrical Experimenter* in 1919.) Reprinted by Hart Brothers, Williston, Vt., 1982.

The Inventions, Researches, and Writings of Nikola Tesla. Thomas Commerford Martin. (Originally published in 1893.) Reprinted by Barnes & Noble, 1995.

Prodigal Genius: The Life of Nikola Tesla. John J. O'Neill. (Originally published by Ives Washburn, New York, 1944.) Reprinted by Kessinger Publishing Company, 1996.

Wizard: The Life and Times of Nikola Tesla. Marc J. Seifer. Birch Lane Press, 1996.

The Tesla Collection, Vols. 1–23. Full-text periodical/newspaper bibliography. Edited by Iwona Vujovic. The Tesla Project, 1998.

Tesla: Master of Lightning. Margaret Cheney and Robert Uth. Barnes & Noble, 1999.

Empires of Light: Edison, Tesla, Westinghouse, and the Race to Electrify the World. Jill Jonnes. Random House, 2003.

Nikola Tesla Museum, Belgrade, Serbia: **www.tesla-museum.org**

Tesla Wardenclyffe Project: **www.teslascience.org/**

Wild zebra, asses and horses are being killed for meat, medicine and money. Combined with vanishing habitats and naturally slow reproduction, such predation threatens remaining populations

By Patricia D. Moehlman

Endangered

AFRICAN WILD ASSES pause on a rocky slope in Eritrea. These young males display the unique pattern of leg stripes that allows researchers to identify individuals.

Wild Equids

FROM THE TIME OUR ANCESTORS FIRST PAINTED ON CAVE WALLS, the beauty and speed of horses have captured our imagination. During this period, some 20,000 to 25,000 years ago, equids were among the most abundant and ecologically important herbivores on the grasslands of Africa, Asia and the Americas. Today only seven species of wild equids remain—three asses, three zebra and one wild horse—and IUCN-The World Conservation Union now lists most of these as endangered [*see box on opposite page*].

Wildlife biologists, including the Equid Specialist Group of the IUCN, which I chair, study the dwindling populations to learn as much as possible about these historically important animals while they still roam free. We also search for ways to stem their disappearance and have recently developed a plan that prioritizes the actions that should be taken.

Two Styles of Life

OUR WORK, which builds on that of an early researcher, Hans Klingel of the University of Braunschweig in Germany, distinguishes two distinct patterns of social organization in wild equids. All the animals live in open lands, but their habitats can range from arid desert to grassy plains favored by moderate rainfall. It is the ease of obtaining food and water that determines how these potentially gregarious animals organize themselves for foraging and for mating and rearing their foals.

In the grasslands, such as the Serengeti Plain of Tanzania, abundant forage and water allow females to feed together and thus to form stable groups. A male that can block other males from access to this group gains exclusive mating rights with all the females, and thus this system is referred to as a "harem" or "family." In dry environments, such as the Danakil Desert of Ethiopia and Eritrea, the scattered supply of food and limited water usually do not permit females to forage close to one another or to form consistent groups. Each adult is on its own to find nourishment, and a male will establish a territory near a critical source of water or food; he then controls mating rights with all females that come onto the territory to drink or feed.

In the harem type of organization, groups usually consist of one adult male and one or more females and their offspring. Other males live in "bachelor" groups. The adult females often remain together throughout their lives, but the harem stallion may be displaced by another male, depending on his age and fighting ability and the number of competitors he has to contend with. Foals born into a group stay with it for two to three years before they disperse. Young females usually leave during their first estrus and join other families. Young males tend to stay on for several more years before they depart to find bachelor groups.

The harem strategy, generally followed by plains and mountain zebra as well as by feral horses, often provides a relatively safe environment in which mothers and their foals can thrive. The presence of the dominant stallion markedly reduces harassment from bachelor males, which might otherwise chase and attempt to copulate with the females. Such harassment can be deadly: it hinders the females' ability to feed and can end in abortion or even infanticide. Stable groups and the presence of the stallion also help to fend off predators such as wolves, lions and hyenas.

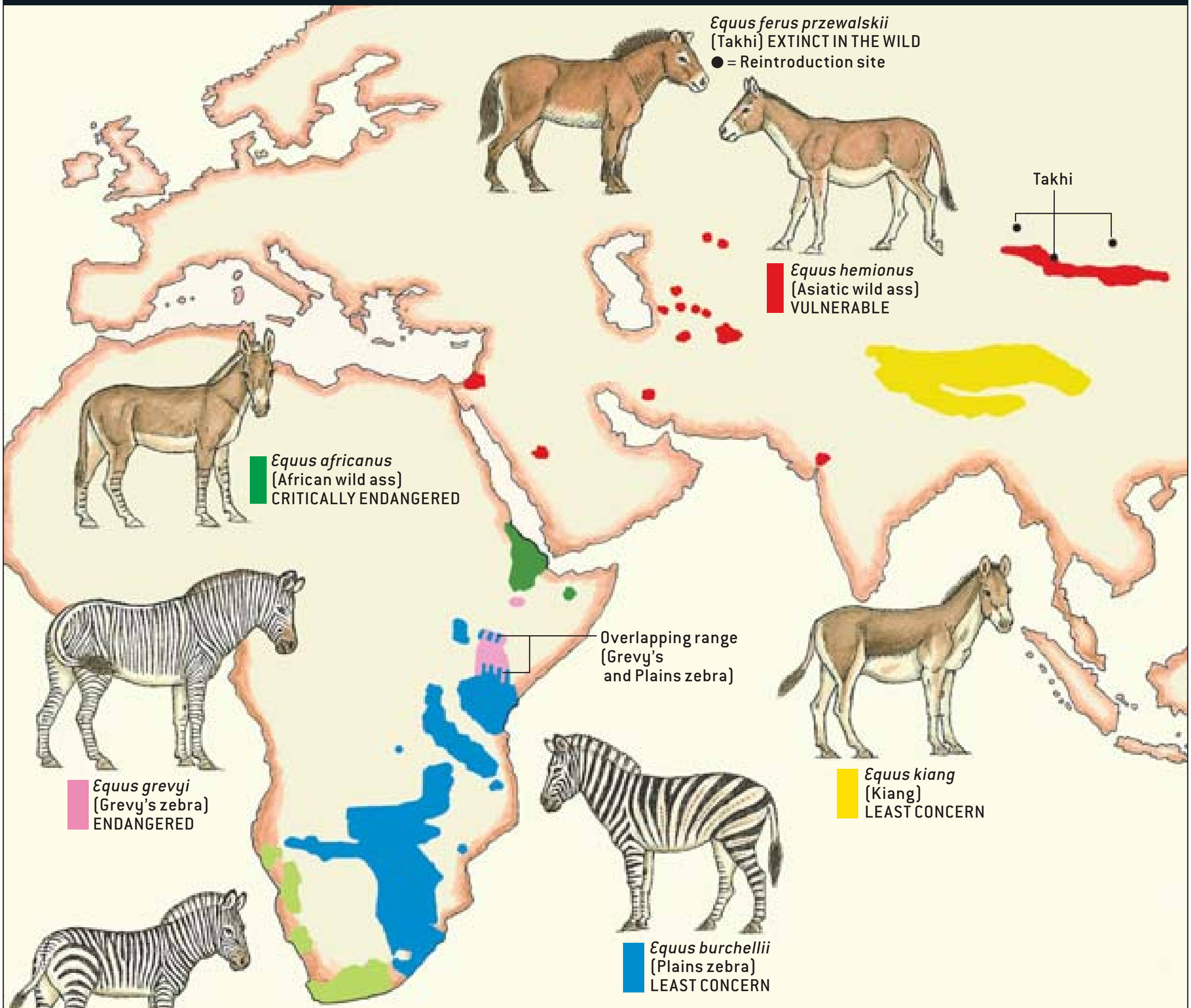
By contrast, in dry environments, the only long-term assemblages are a female and her offspring, sometimes just a foal, sometimes a foal and a yearling. No permanent bonds persist between adults, although they sometimes form temporary groups. African wild and feral asses, Grevy's zebra and Asiatic wild asses organize themselves in this more socially ephemeral way, with a dominant male controlling a territory near a critical resource. The territorial stallion can dominate his area for years. He tolerates both males and females on his land, but he alone can mate with any female that ventures into his realm.

Controlling access to water is critical. Lactating females need to drink at least once a day, and so they will stay as close to a pond or stream as possible. A female comes into estrus a week or two after giving birth and, if she is not fertilized then, again about a month later. Thus, the territorial male has several

Overview/*Equid Conservation*

- Wild horses, asses and zebra were once one of the most abundant herbivores in Africa and Asia. Now only seven species remain, and most of these are endangered.
- Human populations, themselves struggling to survive, can be their greatest threat, killing them outright and encroaching on their habitat.
- Extinction is a real possibility for these endangered animals because wild equids reproduce slowly.
- Researchers are stepping up efforts to learn about the animals' way of life and are seeking ways to conserve them in their natural habitats.

THE LAST WILD EQUIDS



ONLY SIX SPECIES of equids remain in the wild: three asses and three zebra. A seventh species—Przewalski's horse, or takhi—is extinct in the wild, but programs are well under way to reintroduce these animals, which have been preserved in zoos and parks, to their native habitat in Mongolia. Colored areas indicate present ranges.

chances to father a new foal. The females, in turn, gain not only access to water, they may also benefit from reduced harassment from bachelor males and better protection from predators.

Whichever mating system they follow, the territorial or the harem, all wild equids tend to have their first offspring only after reaching four or five years of age; subsequently, they then reproduce only every other year until the end of their lives at about 16 years of age. Although they have the biological potential to produce a foal every year, they seldom do so in the wild, where the struggle to find food and water restricts reproduction. They nurture their relatively rare offspring with a large investment of parental care—milk, shared food and water, and protection from predators. This kind of trade-off can be a good reproductive strategy, and it worked well for equids for millennia. But the strategy fails the animals when conditions lead to high death rates—such as those that hunters currently levy on equids in their pursuit of food, medicine and the commercial sale of hides.

Death rates are also affected today by loss of habitat and reduced access to forage and water. Females with young foals often have to live farther away from water now, which means that fewer of the foals survive to replenish the population. A small population is more vulnerable than a larger one, because an episode of severe weather or disease can wipe out a geographically isolated group.

Those of us who try to monitor these population trends face a complicated task. Not only do the frequently low numbers of equids in an area make normal sampling techniques

PATRICIA J. WYNNE

AFRICAN WILD ASS population, which is critically endangered, is beginning to increase in Eritrea because of government support and the conservation ethic of the local Afar people, who share their resources with wildlife.

less effective, but many species live in difficult terrain, which makes finding them a challenge. My own research on the African wild ass (*Equus africanus*) offers a case in point.

The World's Most Endangered Equid

THE DANAKIL DESERT in the Horn of Africa presents an austere and daunting landscape. Even by desert standards, it is extremely dry; rainfall measures only four inches in a good year. Mountains and ridges of rough lava are furrowed with narrow valleys of alkaline soil sheltering a few grasses and shrubs.

When I set out to search for the African wild ass in the Danakil in 1994, no sightings had been documented for 20 years. Ever since my early research in California during the 1970s on the feral ass in Death Valley, I had been interested in their ancestors in the desert mountains of Africa. At last I was setting out to find them or, more accurately, to find out whether they still existed.

DIFFERENT WILD ASS species, the Kiang, lives on the steppes of the Tibetan Plateau, at a higher altitude than any other equid.

I worked with local conservationists—Fanuel Kebede of the Ethiopian Wildlife Conservation Organization and Hagos Yohannes of the Eritrean Wildlife Conservation Unit. It soon became clear to us that although very few wild asses remained, the local Afar pastoralists knew where we could find these elusive animals. In Eritrea, accompanied by an Afar guide, Omar, we trekked for days, and many hot, dry miles, through the volcanic landscape. Finally, one morning Omar led us up through the basalt ridges of the Messir Plateau. There we found a female, her foal and a male grazing near Afar shepherds tending their sheep and goats.

Since that exciting day, my colleagues and I have identified at least 45 asses that inhabit the plateau. They owe their continued existence and relatively high density in great part to the Afar pastoralists of Eritrea. These people traditionally share their lands and resources with the wildlife and do them no harm. Once they understood the work my colleagues and I were doing, they set out to help. Now when we arrive at their village for a research trip, they round up three camels to carry our camping equipment, food and water, and we all walk to the top of the plateau and set up camp. Thereafter, every other day a man and camel bring us four plastic jerricans with 160 liters of water. This assistance allows us to do our fieldwork on foot in the midst of the best area for the African wild ass.

Just to find this rare and elusive animal ranked as an accomplishment. In the 20 years since wild ass populations were documented in the Danakil, our surveys revealed that their numbers had dropped by more than 90 percent, and the IUCN has designated them as critically endangered; probably fewer than 1,000 (including our 45) remain in the wild. We can tell that the 45 we have located are different individuals, because each animal has a unique pattern of stripes on its legs. Thus, we have been able to follow their movements, social interactions and survival. We can also track a female's reproductive

GREVY'S ZEBRA mother and foal constitute the only stable social unit among these endangered equids that live in the arid habitat of northern Kenya and Ethiopia.

status, how often she gives birth, and the fate of her foals.

What we have uncovered so far tells us that their behavior is typical for equids living in arid habitats: the dominant males maintain mating territories, and the only socially stable group is a mother and her offspring. Occasionally they form small temporary groups made up of fewer than five adults. The composition of these groups varies widely—from single-sex adult groups to mixed groups of males and females of all ages. Females in the same reproductive stage—lactating mothers with foals, for example—may temporarily move and forage together. But competition among females for the sparse forage probably limits their ability to form long-term associations.

Once the male foals reach two to three years of age, we do not see them again in the study area. Presumably they disperse to other areas, suggesting that inbreeding is unlikely. Female foals, in contrast, usually remain with their mother until they produce their own foals.

Our findings about reproductive biology are still limited, but they indicate that females have their first foal at five or six years of age, rather than the more common four or five years, and then may give birth every other year. During prolonged periods of drought, the age at which a female first gives birth may be delayed. Similarly for mature females, a year in which forage is scarce will see few births and few of the foals that do make it into the world will survive. If adult mortality was also high for any reason—because of inadequate nutrition, lack of water or overhunting—the population could decline to such a degree that recovery would be difficult or even impossible.

The years of 1997 and 1998 provided a vivid illustration of how closely reproduction is linked to rainfall. A severe drought on the Messir Plateau in 1997 meant that none of the females had foals. The following year an El Niño brought abundant rainfall to this parched area. All the females had foals, and at least 80 percent of them survived. The potential for such high birth rates and survivorship in good years indicates that the Messir Plateau may be a critical habitat for reproduction. And in fact this area has the highest population density of this species ever recorded—approximately 50 asses per 100 square kilometers. But the highly sporadic rainfall means that the continued existence of the population is precarious.

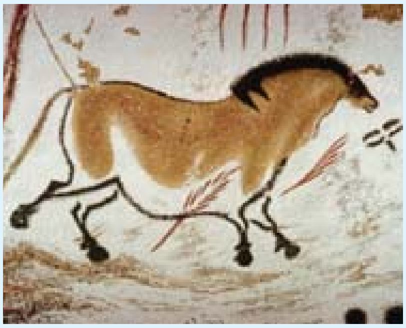
A Plan for Survival

IN CONTRAST TO the African wild ass searching for food in their arid habitat, the plains zebra (*E. burchellii*) roam the productive grasslands of Kenya and Tanzania and south to the tip of Africa. They are the most widespread and abundant equid in the world today, although their welfare depends on conservation programs aimed at maintaining their habitat and preventing overhunting. As one would expect, their social organization follows the harem model rather than the territorial. Another species of these striped equids, the Grevy's zebra (*E. grevyi*), lives in a more arid habitat and has the territorial social organization and mating system typical of such land-

THE AUTHOR

PATRICIA D. MOEHLMAN received her Ph.D. from the University of Wisconsin–Madison. She has studied the behavioral ecology and the evolution of mating systems in equids and canids for the past 35 years. Since 1989 she has worked with wildlife department personnel and local pastoralists in Somalia, Ethiopia and Eritrea to find and conserve the critically endangered African wild ass. A significant part of her work has involved securing training and postgraduate education for her Ethiopian and Eritrean colleagues. A member of the Wildlife Trust Alliance, she has served as chair of the IUCN-The World Conservation Union/Species Survival Commission Equid Specialist Group since 1997.
Mary Pearl and the Wildlife Trust have provided critical support for the conservation of wild equids. The Whitley Laing Foundation, Saint Louis Zoological Park, Wildlife Conservation Society and African Wildlife Foundation have also provided important funding for the protection of these endangered species.

The Return of the Takhi



PAINTING of early horse from Lascaux Cave in France.

TAKHI STALLION rounds up mares in his group.

Once thousands of wild horses ranged from Europe through central Asia and China to Mongolia. Today only a scattering of one species exists—the takhi, or Przewalski's horse (*Equus ferus przewalskii*), as it is known in the West. And this species is actually extinct in the wild; the last confirmed sighting was in the Gobi Desert of southwestern Mongolia in 1969. The takhi that survive—numbering about 1,500 in zoos and private parks throughout the world—have been bred in captivity and descend from 12 ancestors captured early in the 20th century. Now, however, efforts are under way to reintroduce these magnificent horses to the wild.

In 1992 captive takhi chosen to represent as much genetic diversity as possible (to avoid the hazards of inbreeding) were flown by transport plane from Europe to two sites in Mongolia: Takhin Tal and Hustain Nuruu. Initially placed in fenced enclosures so that they could adapt to "semiwild" conditions, the horses are now foraging and mating on their native turf. Subsequent transports and births, plus an additional reintroduction site established at Khomin Tal in 2004, have brought the total number of takhi in Mongolia to roughly 250. Since the time of Genghis Khan, the horse has played an integral role the country's culture, and today's Mongolians have welcomed these living symbols of their heritage and have been instrumental in the success of the programs.

Although the takhi is similar to the wild horses that people began to tame some 6,000 years ago, recent DNA research has shown that it is not ancestral to the modern domestic horse. Przewalksi's horse has two more chromosomes than occur in modern domestic horses. The two can interbreed, however, and produce fertile offspring, so the reintroduction programs need to guard against this possibility.

The reintroductions have taught us the critical importance of teaching once confined animals how to avoid predators, such as wolves. And they have alerted us to unexpected problems such as exposure to tick-borne diseases. Even more sobering, we have learned how much it costs to transport and reestablish populations. Saving a species before it goes extinct in the wild would make much better sense. *—P.D.M.*

TAKHI MOTHERS and foals graze at Takhin Tal, Mongolia, one of the sites where these horses have been brought back to their native land. Many foals have been born, but severe winters, exposure to tick-borne diseases, and predatory wolves challenge their survival.

BETTMANN/CORBIS (*top left*); © ROLEX AWARDS/HEINE PEDERSEN (*top right*); © 2004 PATRICIA D. MOEHLMAN (*bottom*)

PLAINS ZEBRA live in stable family groups composed of a male and several females with their offspring. The African savannas where they live provide abundant forage, which allows the long-term groups to form.

scapes; these creatures are endangered—only 2,500 to 3,000 remain in northern Kenya and Ethiopia.

Can we then conclude that one system of social organization is more likely to benefit survival than the other? Not necessarily. The Przewalski's horse, or takhi (*E. ferus przewalskii*), shared the harem social system of the plains zebra. Yet these horses are now extinct in the wild [*see box on opposite page*].

Habitat degradation and hunting pressure turn out to present far higher barriers to survival. In its plan for actions to counter these problems, the Equid Specialist Group of the IUCN gives top priority to finding out more about the animals themselves—basic biology, seasonal movements, interactions with livestock, and the dynamics of the arid ecosystems in which they live. Also important are the protection of water supplies, the control of poaching, and improved monitoring of equid populations.

And the Afar pastoralists of Eritrea, with their long-standing practice of sharing resources with wildlife, offer a model for an additional—and essential—component. No attempt to conserve wildlife will succeed without the involvement of the local people. If they have a vital stake in protecting and benefiting from their resources—land, water, vegetation as well as wildlife—then they will have a rationale for investing in the long-term management of this habitat. The income from tourists who come to view the animals in their natural setting may turn out to offer the greatest financial incentive for conserving the environment, but each locale will need to figure out the best strategy for its own constellation of resources and needs. Any revenue from such programs can then be invested in schools, health and veterinary care.

The challenges are formidable, but these steps offer the best chance for the survival of these wonderful animals that have struck awe in the hearts of our own species for thousands of years. SA

MORE TO EXPLORE

Horses, Asses, and Zebras in the Wild. C. P. Groves. R. Curtis Books, Hollywood, Fla., 1974.

The African Wild Ass (*Equus africanus*): Conservation Status in the Horn of Africa. P. D. Moehlman, F. Kebede and H. Yohannes in *Applied Animal Behavior Science,* Vol. 60, Nos. 2–3, pages 115–124; November 15, 1998.

Feral Asses (*Equus africanus*): Intraspecific Variation in Social Organization in Arid and Mesic Habitats. P. D. Moehlman in *Applied Animal Behavior Science,* Vol. 60, Nos. 2–3, pages 171–195; November 15, 1998.

Equids: Zebras, Asses and Horses: Status Survey and Conservation Action Plan. Edited by P. D. Moehlman. IUCN-The World Conservation Union, Gland, Switzerland, 2002.

Natural and Sexual Selection and the Evolution of Multi-level Societies: Insights from Zebras with Comparisons to Primates. D. I. Rubenstein and M. Hack in *Sexual Selection in Primates: New and Comparative Perspectives.* Edited by P. M. Kappeler and C. P. van Schaik. Cambridge University Press, 2004.

Equid Specialist Group at the IUCN:
www.iucn.org/themes/ssc/sgs/equid/

DIGITAL PHOTOGRAPHY

Take My Pixel

Digital cameras come with lots of bells and whistles. But what matters most is picture quality, and it has improved significantly in the newest pixel takers.

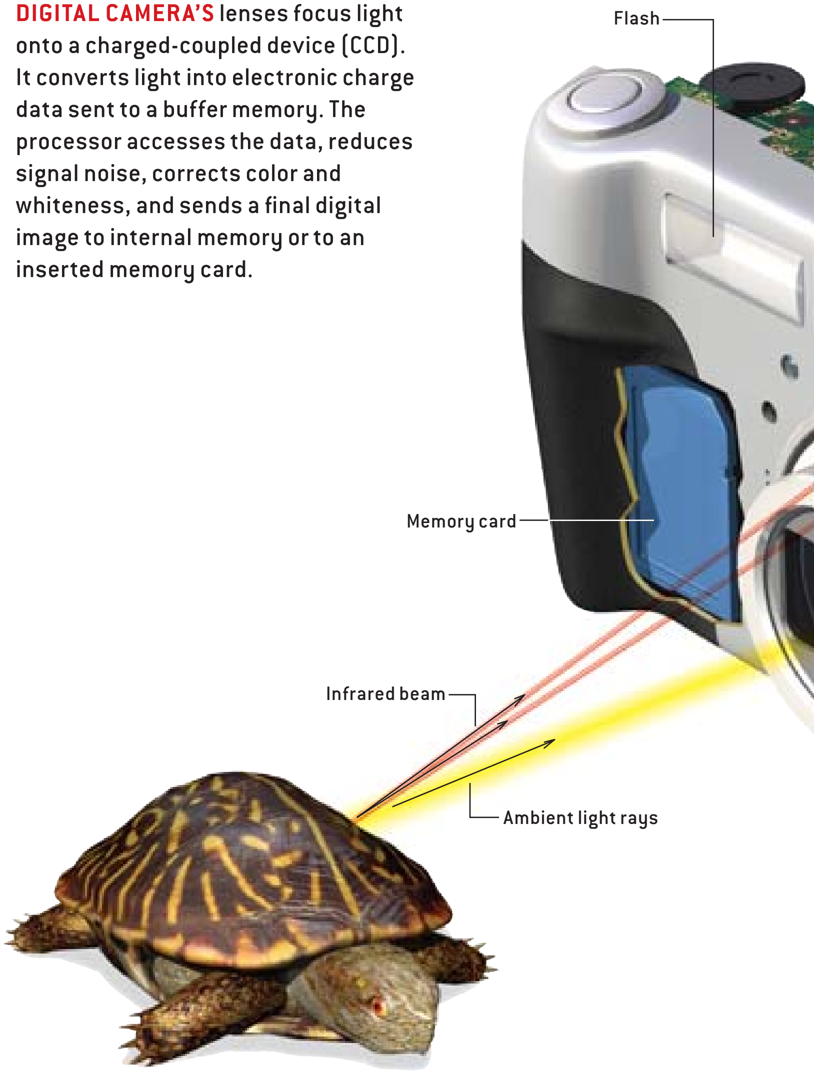
Instead of striking unexposed film, light entering a typical digital camera is focused onto a charge-coupled device, or CCD. This semiconductor array, consisting of many tiny picture elements (pixels), converts light energy into electron charge. A microprocessor reads the charge in each pixel as a digital signal and constructs an image of the scene.

CCDs and the human eye do not "see" light the same way, however. Creating authentic images depends on coherent focusing, color correction and proper whiteness. Aspherical lenses, which have nonspherical curvature, are inserted between the usual spherical lenses so light is focused uniformly on all pixels, improving sharpness. Filters in front of pixels ensure that color-processing algorithms can generate lifelike and bright colors. Other algorithms check for biases in the wavelengths of incoming light; these indicate the presence of fluorescent lighting, which gives a green cast, or tungsten (incandescent) lighting, which gives a yellow cast. The algorithms eliminate the tint, which the human brain does automatically, so a scene's true color and whiteness appear the way we expect them to appear.

The latest digicams also minimize practical problems of early models. Optical zooming, achieved by moving the lenses, was limited in order to keep cameras compact; so-called digital zoom extends the range using software processing. And faster digital-image-processing chips have sped up click-to-click time—how quickly the camera can take pictures in succession—to 1.5 seconds or less.

Click-to-capture time—the delay between the moment the shutter button is pushed and the moment the shutter actually opens—has also been reduced to half a second or less, primarily by speeding up autofocus. "In the early days a lot of people took pictures of their shoes," says Gary Hallenbeck, new-business development manager at Eastman Kodak Company; they had pushed the shutter button, figured the shot was taken and lowered the camera before the shutter opened. —*Mark Fischetti*

DIGITAL CAMERA'S lenses focus light onto a charged-coupled device (CCD). It converts light into electronic charge data sent to a buffer memory. The processor accesses the data, reduces signal noise, corrects color and whiteness, and sends a final digital image to internal memory or to an inserted memory card.



SOURCE: EASTMAN KODAK COMPANY; GEORGE RETSECK (*illustrations*)

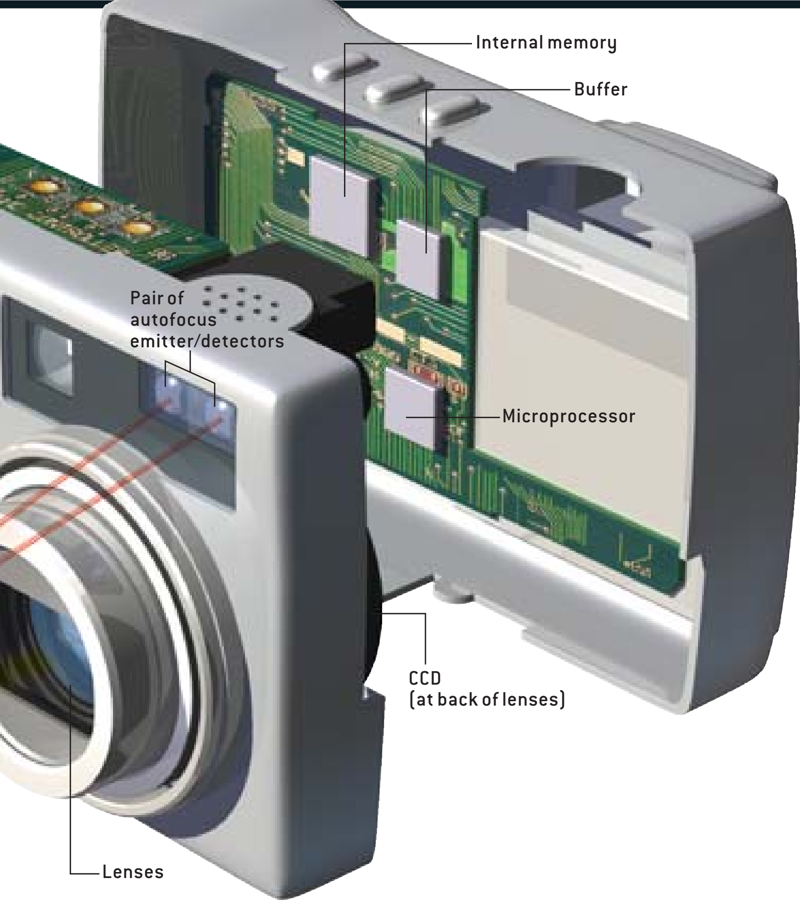
ASPHERICAL LENS ELEMENTS (*right*) are inserted among spherical lenses to correct distortion. Spherical lenses have difficulty focusing incoming parallel light rays that strike the lens's outer edges and center into a single convergence point, causing fuzzy edges in a picture (*diagrams*). In this case, the first group of glass elements funnels rays onto the second group, which moves forward and backward as focusing or zoom requires. The second group narrows light onto the fixed, third group, which directs beams onto the CCD.

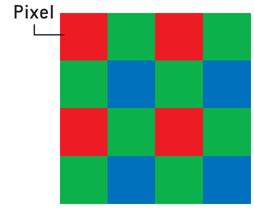
DID YOU KNOW...

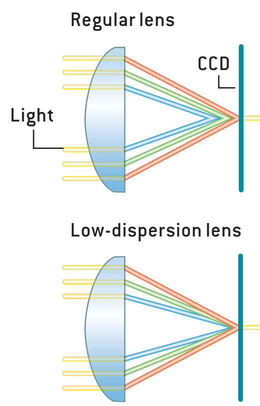
➤ MEGAPIXEL MAX: A so-called four-megapixel camera has a CCD with four million pixels. The higher this resolution, the sharper the photograph. But affordable lens systems cannot resolve light into more than six or eight megapixels, Kodak's Gary Hallenbeck says. So consumer cameras touting 10 or 12 megapixel sensors will not create an overall sharper image. The higher count does help make images clearer when using digital zoom, however.

➤ THUMBNAIL: The "photograph" in most digital cameras is created in jpeg (Joint Photographic Experts Group) format, a graphic standard used widely on computers and the Internet. What you see on the camera's little liquid-crystal display screen is a "thumbnail" version of that image. The thumbnail typically contains about 150,000 bytes of data, commonly known as a 150K file.

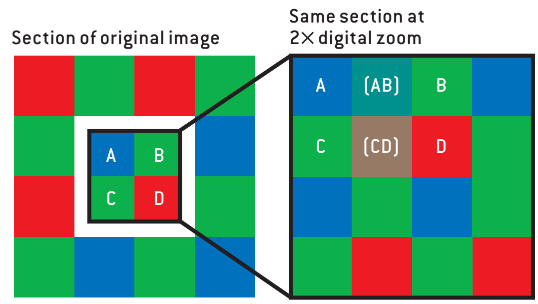
➤ FAST FOCUS: To autofocus, many cameras use external CCDs to sense ambient light. The processor first evaluates the charge on the CCDs and triangulates to gauge distance. Then it moves the lenses and repeats the process until the peak charge is found and bypassed (envision the top of a sine curve). The lenses are set at the peak position, the shutter opens, and the processor fine-tunes the focus by sampling the main, imaging-recording CCD. By establishing a rough focus, this approach requires fewer cycles than older models that just used the main CCD, speeding up autofocus.



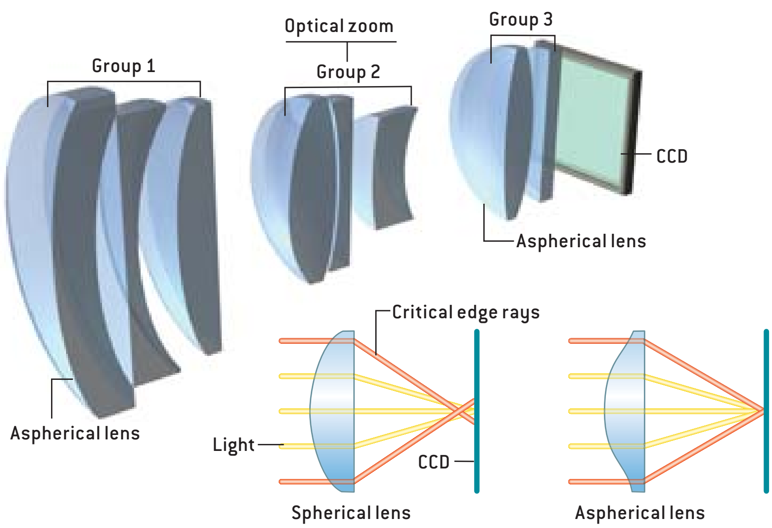




COLOR FILTER covers each pixel on a CCD so it registers only one color. Most cameras use a Bayer filter pattern, as shown; green is favored because the eye is more sensitive to that wavelength. The processor combines the red-green-blue signals into a full-color image. New, low-dispersion lenses (*diagrams*) help to reduce color inaccuracies caused by different wavelengths that naturally focus at slightly different points.



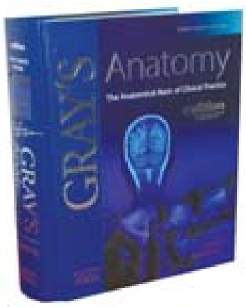
DIGITAL ZOOM begins once lenses are fully deployed, which maxes out optical zoom. For 2× digital zoom, the processor crops in to 50 percent of the original image; for 4× zoom, to 25 percent. It then positions known pixels (*A, B*) in a grid that fills the full frame and interpolates their values to determine colors for intermediate pixels (*AB*). This estimation decreases image sharpness.



Topic suggested by Yang Zhou and Kurt Becker. Send ideas to workingknowledge@sciam.com

An Institution between Covers

THE 39TH EDITION EXPANDS GRAY'S ORIGINAL TASK **BY SHERWIN B. NULAND**



GRAY'S ANATOMY: THE ANATOMICAL BASIS OF CLINICAL PRACTICE,
39th edition
Edited by Susan Standring and others
Elsevier Churchill Livingstone, 2005
($169)

The eminent mid-20th century British historian of medicine F.N.L. Poynter once said of *Gray's Anatomy* that "what began as a book has become an institution."

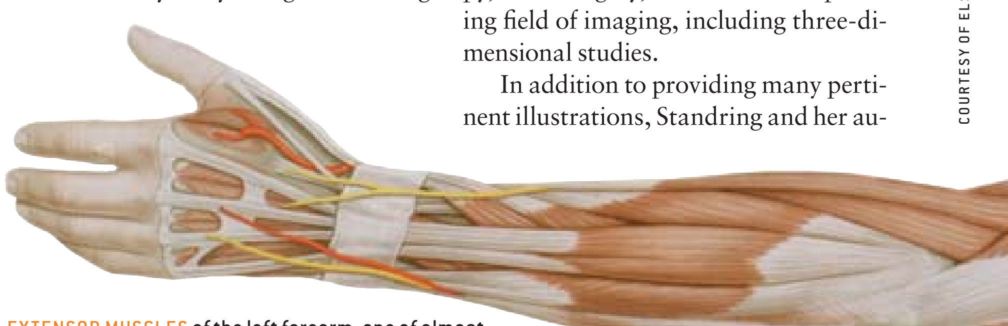
Like all progressive institutions, this one periodically looks itself over, evaluates its development and takes measures to be sure that it has kept up with the times. Keeping up has occasionally required increasing the complexity of its operations, necessarily expanding its bureaucracy, and seeking new and forward-looking leadership. As *the* institution among medical books, *Gray's Anatomy* has throughout its history continued to do all these things, with the result that it has only improved with age; it is venerable but not hoary.

With this prologue as background, I am pleased to report that the all-important tradition of improvement with age is most emphatically maintained by the newest edition of *Gray's Anatomy,* the 39th. The new leadership comes in the accomplished person of Susan Standring, professor of experimental neurobiology at King's College London and incidentally the first female editor in chief. The necessary bureaucracy has been once more expanded to an assemblage of what is by my count a total of almost a score of editors and more than three times that many specialist contributors and reviewers, some of whom are respected holdovers from the excellent 38th edition of 1995. The volume resulting from everyone's labors is, at 11 pounds, now heavy enough for use as a gym weight to build the skeletal muscles it so elegantly describes, from their myoblastic genesis and cellular physiology to their good old-fashioned origins and insertions.

Anyone perusing the last 10 incarnations of this vigorous old warhorse of medical literature will note that a significant change came about with the 35th in 1973, when the visual character of the book began a veritable transformation. Since that time, each edition has incrementally added material covering advances in such fields as molecular biology, imaging, computer-assisted and electron microscopy, embryology and immunohistology to encompass new knowledge and provide didactic clarifications. Henry Gray's original offering of 1858 has taken on the task of providing an overview of the science on which comprehensive understanding of gross anatomy is based in today's biomedical and clinical worlds.

After the publication of the 37th edition in 1989, a formal editorial board was created to provide a supervisory framework for the additions being made by the specialist authors whose contributions were increasing the value of *Gray's Anatomy* as a source for basic science and clinical applications. When the next edition appeared in 1995, the main changes to be found in it—other than new sections on surface and neonatal anatomy—were organizational, consisting primarily of rearranging the material to make it more accessible and useful. But with the present volume, new and important ground has been broken—or at least more fully and effectively tilled. The authors have increasingly taken on the task of accommodating the new uses to which anatomy is being put in clinical situations, such as minimally invasive surgery, endoscopy, arthroscopy, microsurgery, and the entire expanding field of imaging, including three-dimensional studies.

In addition to providing many pertinent illustrations, Standring and her au-



EXTENSOR MUSCLES of the left forearm, one of almost 2,000 illustrations from the latest edition of *Gray's Anatomy.*

COURTESY OF ELSEVIER CHURCHILL LIVINGSTONE thoritative team have taken the major and very practical step of presenting their material by regions rather than by the old method of systems such as the reproductive, the gastrointestinal and the muscular. This is a tremendous advantage for clinicians, because it reflects the way in which they need to see anatomy. And it has at least as worthy a benefit for students, because it will correlate even their earliest first-year learning directly to the real world of bedside medicine. Not only that, but brief comments about common diseases are interspersed in the text as their respective anatomical locations are being discussed. All of this is reflected in a change in the book's subtitle, which on first glance would seem insignificant but actually says a great deal. It has gone from *The Anatomical Basis of Medicine and Surgery* to *The Anatomical Basis of Clinical Practice.*

Quite obviously, no single reviewer is competent to judge the reliability of every bit of material to be found in this encyclopedic book. As a general surgeon selectively studying sections with which I have a career's worth of experience and only perusing others, I am much taken with their usefulness and lucid readability, which says a great deal for an anatomy text. At the astonishingly low price of $169 for the print edition and only an extra $30 to have it on CD-ROM and online as well, this may be the best value seen in medical publishing since 1819, when René Laennec's two-volume treatise on auscultation was put on sale at a price of 13 francs, with a stethoscope thrown in for a small additional cost.

One final word. It is customary when reviewing a book that is in all ways as outstanding as this one to introduce a quibble or two, if for no other reason than to show that the volume has been carefully and completely eval-

REVIEWS

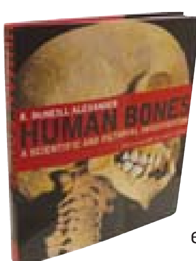
uated with a critical eye. Being a surgeon and not an anatomist (who therefore does not know a *fissura antitragohelicina* from a *sulcus antihelicis transversus*), I have been able to find only one item about which to grouse: One looks in vain for the "Surface Anatomy of the Lower Limb" to be found on page 1339, as the table of contents claims. It is to be located 60 pages further on, where the topic is just as clearly presented as is every other facet of this beautifully produced and medically invaluable book. SA

Sherwin B. Nuland, clinical professor of surgery at the Yale University School of Medicine, is the author of How We Die, *which won the National Book Award in 1994. His most recent book is* Lost in America: A Journey with My Father *(Alfred A. Knopf, 2003).*

THE EDITORS **RECOMMEND**

HUMAN BONES: A SCIENTIFIC AND PICTORIAL INVESTIGATION

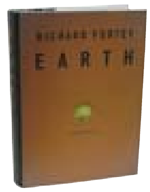
by R. McNeill Alexander. Photography by Aaron Diskin. Pi Press, 2005 ($37.50)



If you are not up for something as weighty as *Gray's Anatomy*, this might well be the book for you. True, it covers only bones, not all the other essential tissues and organs. But its coverage of bones is exquisite—thanks in equal part to the gorgeous photographs and the erudition and charm of the author. Alexander, emeritus professor of zoology at the University of Leeds in England and author of many books and articles on locomotion (including *Dynamics of Dinosaurs*), takes us from the living cells scattered throughout bone to the linked assemblages that form a human skeleton. Stops along the way examine specimens of the human skull (an astonishing number damaged by ax blows and other trauma) and offer enlightening comparisons—child to adult, abnormal to normal, diseased to healthy.

EARTH: AN INTIMATE HISTORY

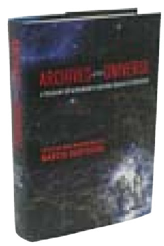
by Richard Fortey. Alfred A. Knopf, 2004 ($30)



"Geology underlies everything: it founds the landscape, dictates the agriculture, determines the character of villages." Fortey, senior paleontologist at the Natural History Museum in London, set out to explore those connections. "My solution has been to visit particular places, to explore their natural and human history in an intimate way, thence to move to the deeper motor of the earth—to show how the lie of the land responds to a deeper beat, a slow and fundamental pulse." His stops as he takes the reader on a journey around the world include Mount Vesuvius, the Alps, Newfoundland, Los Angeles and the Deccan Traps in India. He is an eloquent guide.

ARCHIVES OF THE UNIVERSE: A TREASURY OF ASTRONOMY'S HISTORIC WORKS OF DISCOVERY

Edited and with introductions by Marcia Bartusiak. Pantheon Books, 2004 ($35)



Here the reader gets not only a clear and concise history of astronomy but also excerpts from many of the memorable papers written by the scientists who made the pivotal astronomical discoveries. The history comes in Bartusiak's fine introductions to the eight periods she describes and to the individual papers. The authors include such eminent figures as Ptolemy, Copernicus, Albert Einstein and Alan H. Guth. Bartusiak, a science writer who teaches at the Massachusetts Institute of Technology, set as her focus "the discoveries that came to define the universe as we now know it: its composition, its various members, its structure, its evolution."

The books reviewed are available for purchase through www.sciam.com

Meteorwrongs

SOME PEOPLE ARE STUCK BETWEEN A ROCK AND A HARD TRUTH BY STEVE MIRSKY

Trains are better than planes, if you have the time and dry land. I was reminded how much I prefer trains as I waited for one on a frigid December day in Waterbury, Vt.—a window of the tiny station featured a quaint and charming photo exhibit of great local train crashes. I haven't checked every square foot of LaGuardia Airport, but I bet there isn't a single display of entertaining and nostalgic photos of great aviation disasters.

Crashes were all over the news around the time of my train trip, because a hunk of matter some 400 meters across had suddenly become a solar system media star: the likelihood that an asteroid dubbed 2004 MN4 would cause a really bad day in the year 2029 was briefly rated an unprecedented 4 (out of 10) on the Torino scale. Contrary to popular opinion, the Torino scale is not used to weigh muscle cars coming off the Ford assembly line. The scale in fact describes the level of threat from space stuff smashing into Earth. (Imagine the current and confusing color-coded terror alert system, only with numbers and for the most part based on the best available data.)

A Torino 4 translates to "a 1 percent or greater chance of collision leading to regional devastation." A 4 also means that astronomers are confident that more data will show a lesser threat. And when more data were evaluated a few days later, the consensus was that 2004 MN4 would miss us altogether, leaving us to find our own techniques for regional devastation.

Just a few months before 2004 MN4 had everyone figuring out how old they'd be in 2029, I had visited with the inventor of the Torino scale. Richard P. Binzel, a planetary scientist at the Massachusetts Institute of Technology, has a strong affection for Pluto, amateur astronomers and the Italian city of Torino, where he first proposed the impact scale at a conference in 1999. ("A 4 on the Binzel" sounds too much like a craps-table side bet, so they went with "Torino scale.")

Binzel revealed that he regularly entertains visitors convinced that they own a piece of outer space. "The basic story is that you get a phone call where someone says that they have found a meteorite or they have just inherited this meteorite that has been in the family for generations," Binzel said. "It's a family heirloom. But to their knowledge, it's never been reported to any scientific authority. And they would like it checked out, because if it's scientifically interesting they want the scientists to know about it, and maybe it's an important case."

An alleged meteorite may have been *displayed* in an important case. For example, the most memorable sample that showed up in Binzel's office was incorporated into a redesigned bowling trophy. "Instead of the guy in the trophy holding a bowling ball," Binzel recalled, "he was holding this rock. Like Atlas. Mounted and on the mantle for generations."

But despite the hopes and expectations of their owners, the 50 or so rocks Binzel has examined for civilians have turned out to have earthy origins. "In 15 years, no one has ever had [an] actual meteorite," he said. "So I'm careful to warn people that it's very likely they're going to walk out knowing it's not a meteorite." (A guest may still leave clutching something extraterrestrial, however—Binzel has on occasion rewarded the star-unstruck visitor with a tiny shard of an actual meteorite for his or her trouble.) And, Binzel noted, "to the credit of these people, they say, 'That's okay, all I want to know is the truth.' I've always been impressed by that."

Imagine millions of people letting go of a cherished belief simply because they're confronted with indisputable facts to the contrary. Well, before I go all John Lennon, I must say that even only 50 people able to incorporate reality into their worldview isn't bad. In fact, it fills me with a kind of hope for the future I haven't felt since the 2029 flyby of MN4 was downgraded to a 0 on the Torino scale. SA

ILLUSTRATION BY MATT COLLINS; PHOTOGRAPH BY FRANK VERONSKY

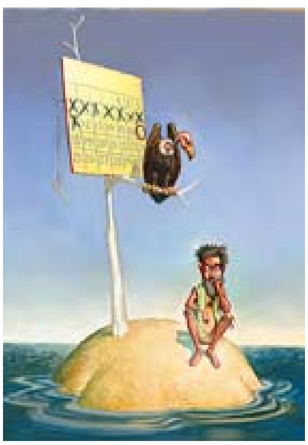
Q How long can a person survive without food?

—Carlos Santiago, Dominican Republic

Alan D. Lieberson, an M.D., attorney and the author of *Treatment of Pain and Suffering in the Terminally Ill and Advance Medical Directives*, explains:

The duration of survival without food is greatly influenced by body weight, genetic variation, other health considerations and, most important, the presence or absence of dehydration.

Without liquids or food, people typically perish after 10 to 14 days. (Depending on whether the individual is dehydrated or overhydrated at the outset, the time may range from approximately one to three weeks.) This situation comes up frequently in two medical groups—the incompetent, terminally ill patients for whom artificial maintenance of life is no longer desired and the individuals who, though not necessarily terminally ill or incompetent, decide to refuse food and hydration to end their own lives.



MATT COLLINS

In cases where healthy individuals are receiving adequate hydration but no food, reliable data on survival are hard to obtain. Mahatma Gandhi, the famous nonviolent petitioner for India's independence, survived 21 days of complete fasting while allowing himself only sips of water. A 1997 article in the *British Medical Journal* by Michael Peel, senior medical examiner at the Medical Foundation for the Care of Victims of Torture, cites well-documented studies reporting survivals of other hunger strikers for 28, 36, 38 and 40 days. But most such reports have been poorly substantiated.

Unlike total starvation, near-total starvation with continued hydration has happened frequently. Survival for many months to years is common in concentration camps and during famines. The body can moderate metabolism to conserve energy. The alteration of metabolism is not well understood, but it occurs at least in part because of changes in thyroid function. This ability may help explain the evolutionary persistence of genes causing diabetes, which in the past could have enabled survival during famine by fostering more economical use of energy.

Medical practitioners encounter cases of near-total starvation in patients suffering from, among other conditions, anorexia nervosa and end-stage malignancies, as well as in those adhering to "starvation" diets. Death may result from organ failure or heart attack when a person's weight corresponds to a body mass index (BMI) of approximately half of what is normal, or about 12 to 12.5. Normal BMI is 18.5 to 24.9, and many fashion models have a BMI of around 17.

Q How do scientists detect new elements that last only milliseconds?

—J. Adams, Jesup, Ga.

Todd M. Hamilton, associate professor and chair of the department of chemistry at Adrian College, provides an answer:

Even elements that exist only briefly before decaying leave behind a calling card, in the form of an energy signature. The challenge for researchers is detecting that fleeting signal.

When a heavy element disintegrates, or decays, it gives off a unique radiation signature. Alpha-particle (essentially a helium nucleus) emission is the type most commonly used, because it gives off distinct energies.

Scientists make heavy elements by smashing together two elements that add up to the mass of the desired new element. One element, the projectile, is sped up in a cyclotron or other particle accelerator and shot at the second, the stationary target. Sometimes it takes millions of collisions and several weeks of bombardment to generate one atom of the new element.

In addition to using the unique energies of emitted alpha particles to identify new elements, heavy-element hunters turn to a cascade of alpha emissions to confirm their existence. Assembling all of this information is tricky business, but it can serve as convincing evidence that a new element was, in fact, created. SA

For a complete text of these and other answers from scientists in diverse fields, visit www.sciam.com/askexpert