NATURAL HISTORY

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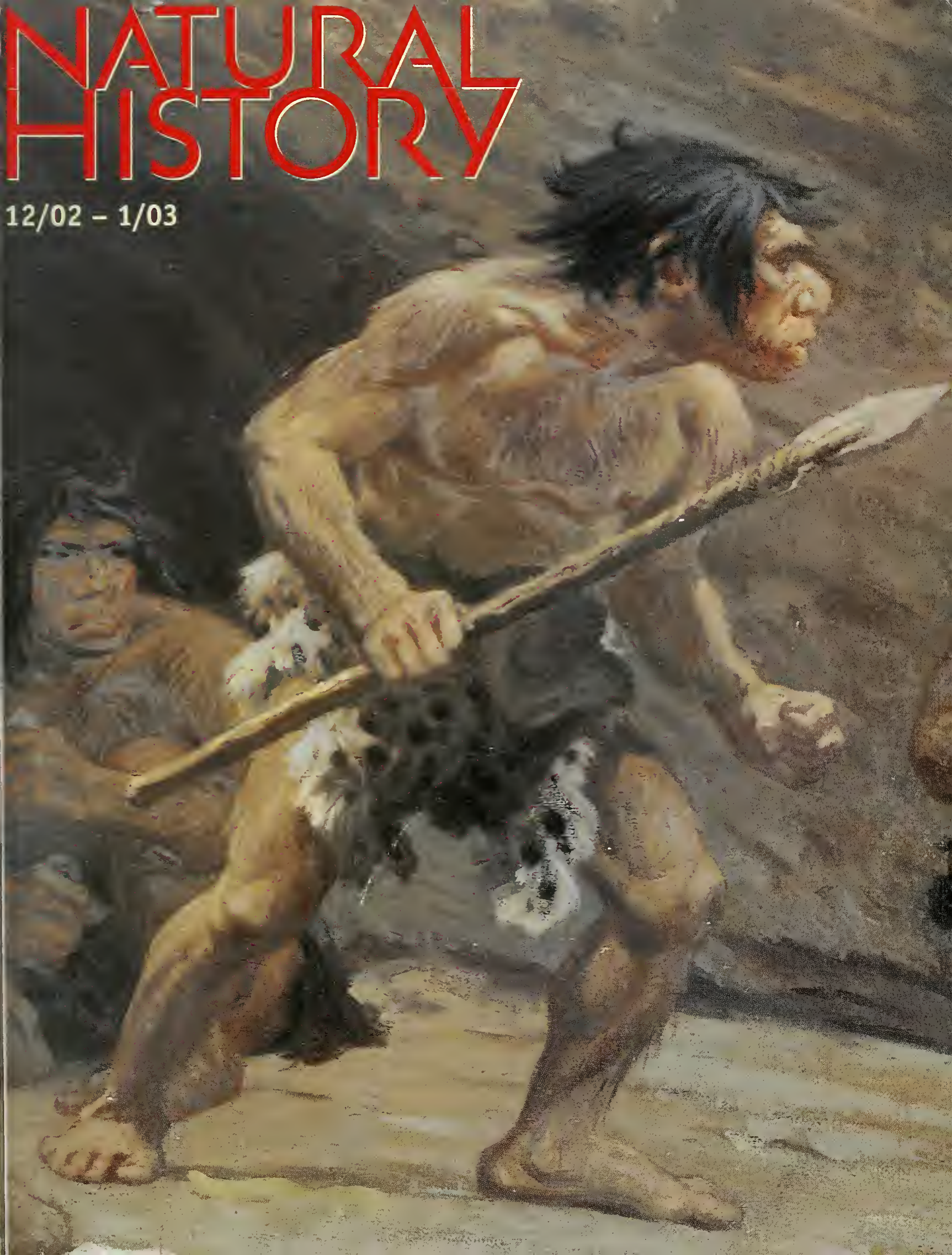

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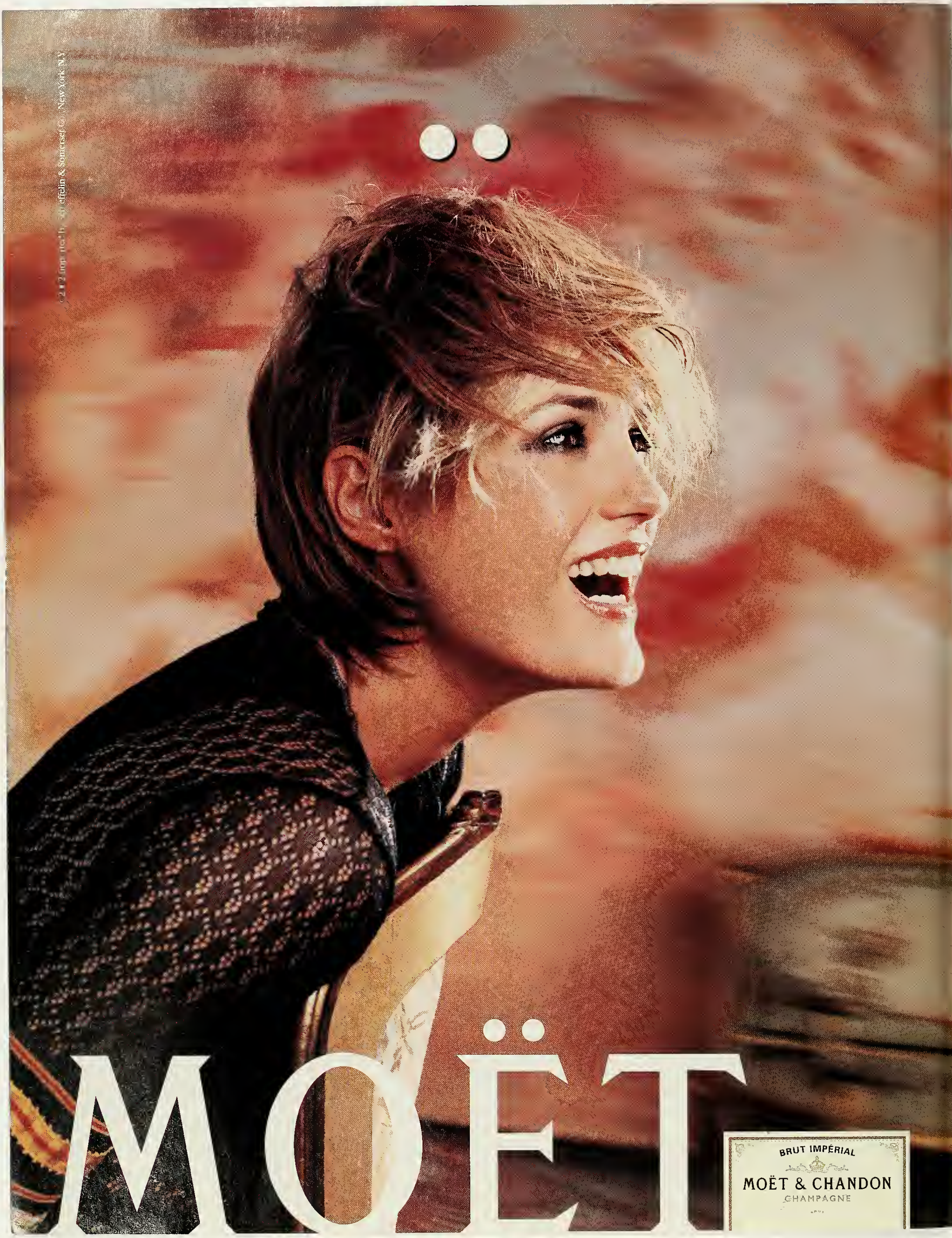
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NATURAL HISTORY

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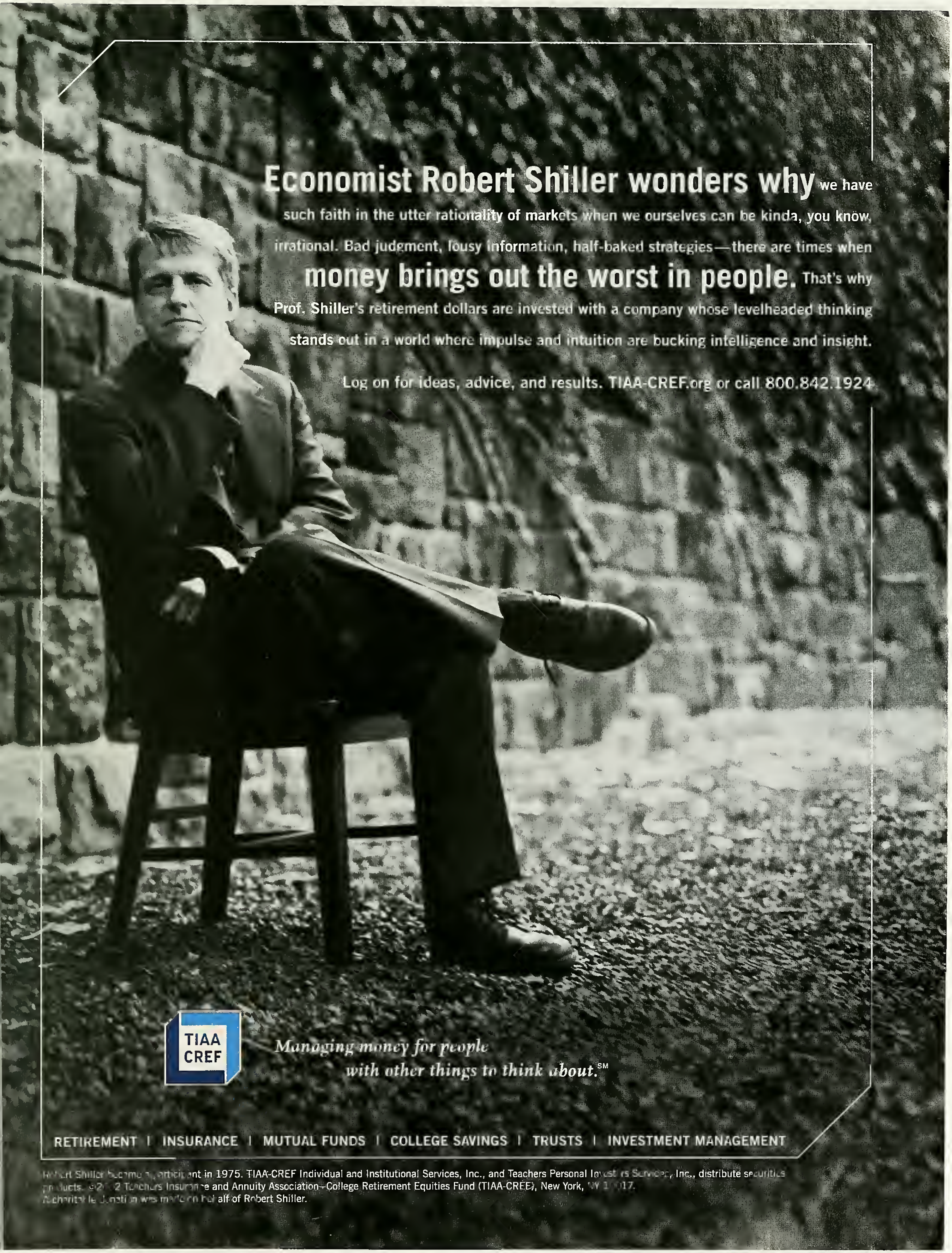

Economist Robert Shiller wonders why we have such faith in the utter rationality of markets when we ourselves can be kinda, you know, irrational. Bad judgment, lousy information, half-baked strategies—there are times when
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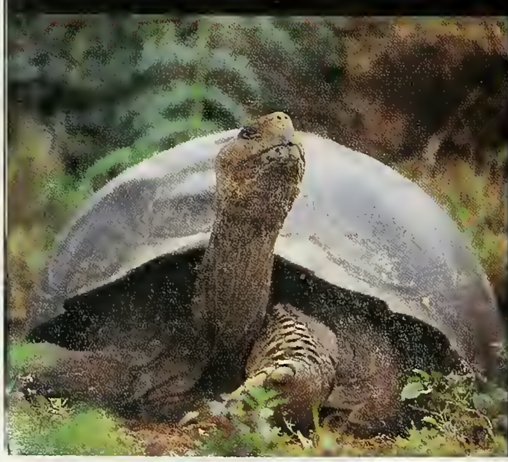

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UPFRONT

Who Is the Center of the Universe?

It takes work, as the shrinks put it, to "de-center." While I'm burrowing through, say, the fascinating details of Neil deGrasse Tyson's column about the history of the Copernican principle in astronomy (see "Delusions of Centrality," page 28), it's hard to remember that the Copernican principle applies to me, too. Only after I come up for air, after too many nights preoccupied with the minutiae of *Natural History*, do my family remind me that there is a world beyond the office. (To the tune of the *Sesame Street* song "People in Your Neighborhood," they chant, "Oh, who is the center of the universe?")

There's a lot to be said, of course, for focus and undivided attention—the upside of thinking that whatever you're doing at the moment is the most important thing in the world. It's just that the downside is self-absorption. Equally so, there's plenty to be said for the human propensity to assume that we live on a remarkable planet, at an extraordinary time in evolutionary history. We're special. But what the Copernican principle says, fundamentally, is: Not so fast. Where we live and when we live are not remarkable, from any physical point of view. We're not so special, after all. That's a hard one to swallow; at bottom, I think, it's a big part of what a lot of people don't like about science.

But the Copernican principle has also been immensely fruitful for a band of smart apes confined by a brief lifetime and a vast universe to an infinitesimally small patch of space-time. And it's the Copernican principle that will enable you to take the armchair voyages we have in store for you in this issue. With Juan Luis Arsuaga ("Requiem for a Heavyweight," page 42), you'll visit a band of proto-Neanderthals who found shelter in a Spanish cave 400,000 years ago—thanks to the fact that rates of radioactive decay at that time were much the same as they are today. (If Arsuaga's story whets your appetite, be sure to visit "The First Europeans: Treasures from the Hills of Atapuerca," a new exhibition that opens at the American Museum of Natural History on January 11, 2003.)

With Kenneth A. Nagy, you'll explore the insides of a tortoise's burrow in the desert Southwest—in fact, the insides of the tortoise itself—courtesy of the laws governing the chemistry of minerals dissolved in water (see "Dry, Dry Again," page 50). You'll go back in time 370 million years, to a coral reef preserved in what is now an Australian cliffside (see "Dodging Mass Extinction," by Rachel Wood, page 58)—thanks to experiments with what happens to rocks and shells under extreme heat and pressure. You'll even take a journey back 12 billion years, to the most distant known galaxies (see "Universe by Number," by Charles Liu, page 74), thanks to spectroscopists who have matched the spectral lines in hot gases on Earth with the spectral lines emitted by those incredibly faraway objects in space.

Deny the Copernican principle, and miss such a show? You might as well commit the ultimate solipsism and reject the Golden Rule.

—Peter Brown

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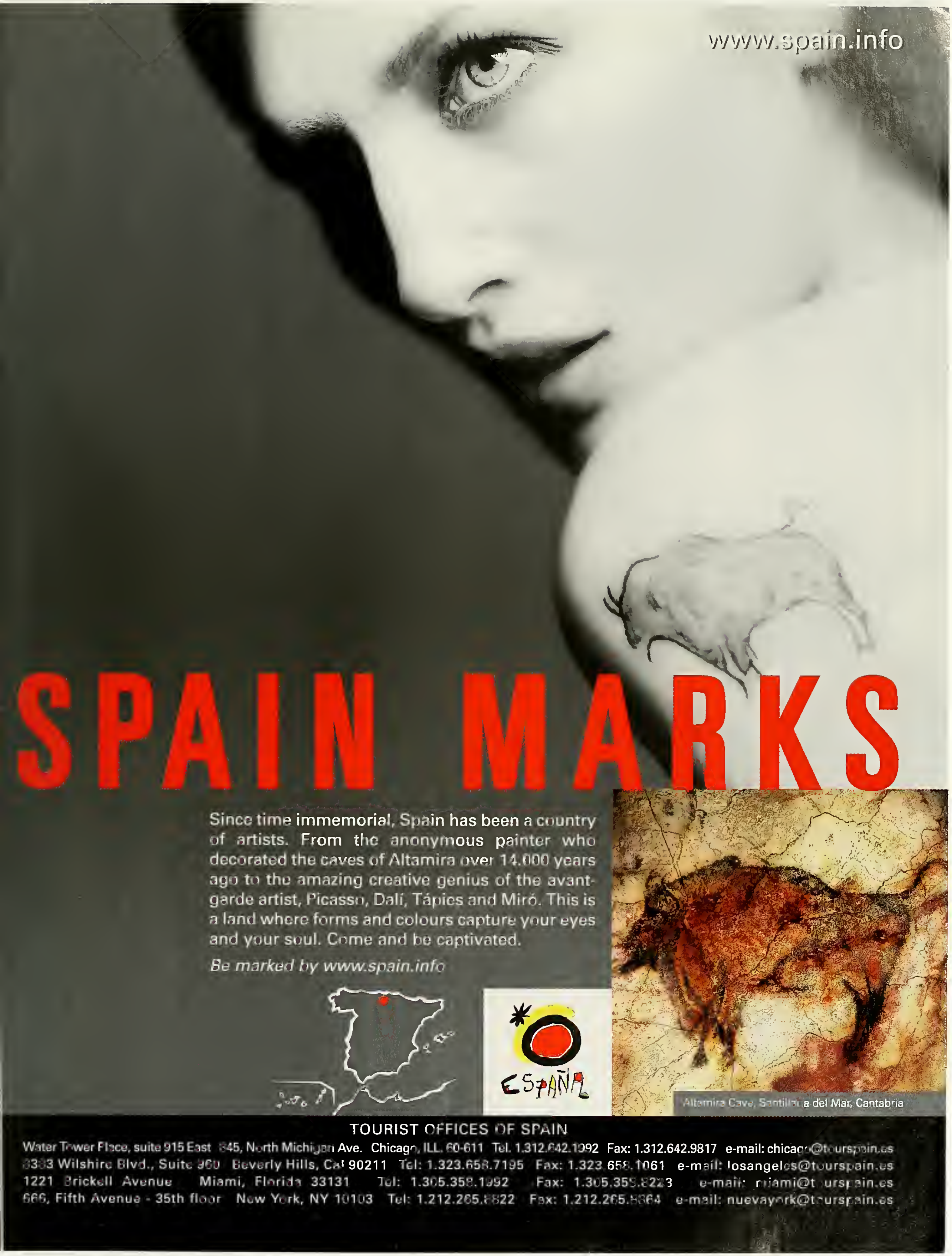
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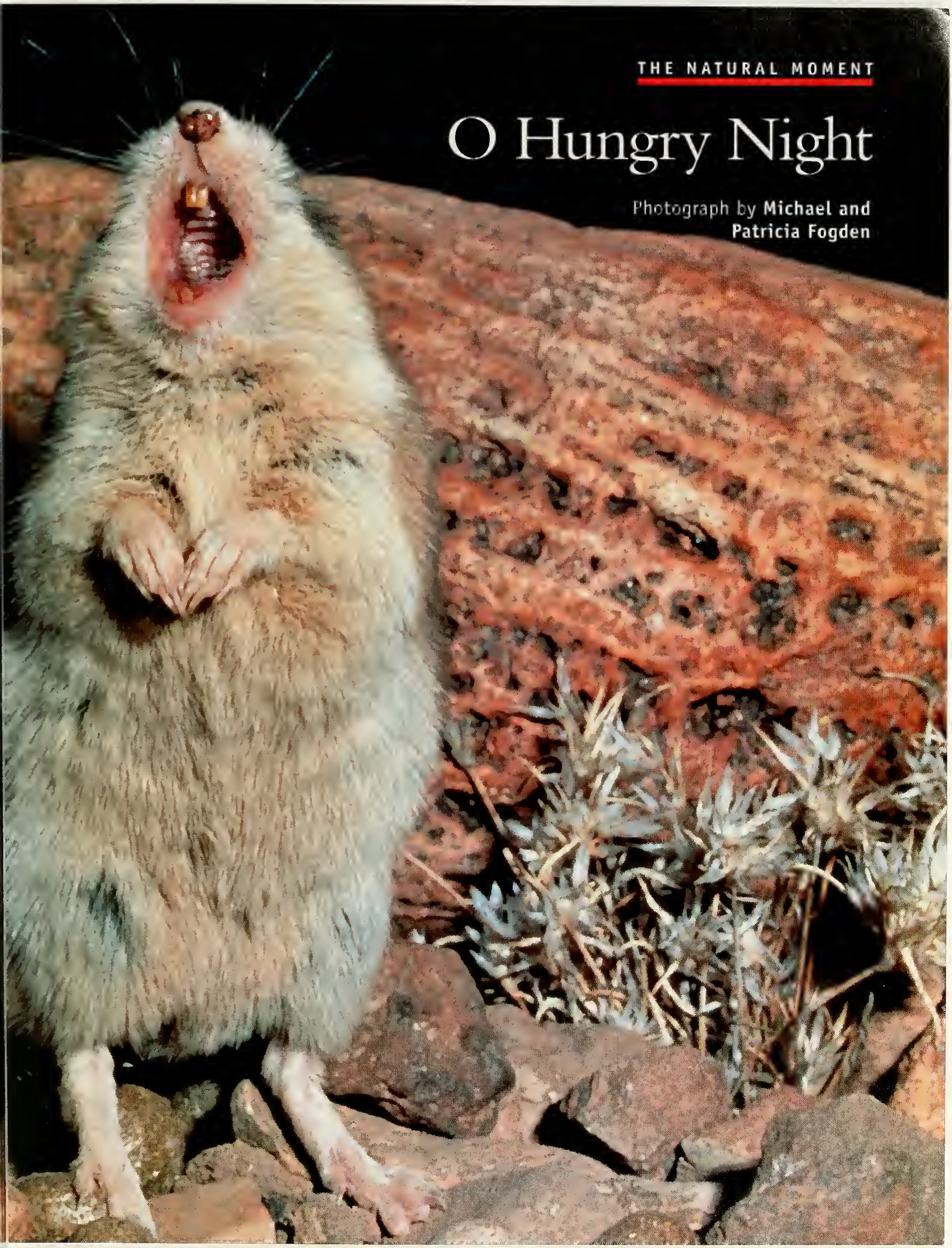
On a winter's night in the deserts of northern Mexico one might expect to hear the chilling cries of coyotes or a solitary wolf baying at the moon. But another animal is often stirring: the grasshopper mouse. A high-pitched whistle led photographers Michael and Patricia Fogden to the seemingly cherubic caroler pictured here: *Onychomys arenicola*, one of three species of grasshopper mice inhabiting the deserts. The singing, performed by both males and females, is thought to announce territorial boundaries, attract a mate, or even herald a birth. The mouse captured on film by the Fogdens was most likely a male, with seasonally thick fur, bulky hind legs, protruding olfactory bulbs, and two elongated front teeth. Grasshopper mice, not unlike their howling canine neighbors, are built to hunt. Carnivores to the core, *O. arenicola* have been known to tear off the tails of scorpions, jam the noxious butts of stinkbugs into the ground, and even bite into the skulls of other mice in order to get at the juicy flesh of their nocturnal catch.

—*Erin Espelie*

O Hungry Night

Photograph by **Michael and Patricia Fogden**



Handy Antidote

The bala ants of Costa Rica, described in "Bites of Passage" ["Endpaper," by Nathan Welton, October 2002], sound like Venezuela's *veinticuatro* (meaning "twenty-four") ants, so called because most people spend twenty-four hours in bed after being bitten by one.

In more than thirty years of jungle adventures, I've suffered numerous stings by many kinds of insects. I was once on a mining dredge out on the Caroní River in eastern Venezuela and was picking up a diamond-sieving screen when my finger trapped an unseen *veinticuatro* under the screen rim. The sting caused an immediate searing pain. The instant I removed the big stinger, along with the attached ant, the pain lessened. But within fifteen minutes my armpit started aching and I was getting nauseous. And I didn't have the one item I almost never fail to carry when I'm out in the jungle: an onion.

Luckily the camp boat came by fifteen minutes later, and I jumped in while it was still a few feet from the dredge. The driver didn't hesitate when I shouted "Camp!" My appearance showed something was very wrong. The second I saw our cook, I gasped, *"Veinticuatro,"* and she knew what to do.

The cook made a poultice of crushed onion and, without doing any suction or cutting, bound it over the site of the sting. For good measure, she also gave me some peeled sugarcane, another local remedy, to chew on. Within half an hour I was mostly free of the effects of the ant venom.

Jack Johnson
San Rafael, California

Dark Skies over Brooklyn

Like Neil deGrasse Tyson, I was born in New York City, but somewhat earlier—1918 to be exact. And I can attest firsthand that the light pollution he deplores in his "Universe" column ["Let There Be Dark," October 2002] is a fairly recent phenomenon. I remember distinctly that the Milky Way was easily observed until I was well into my teens.

Brooklyn had few electric streetlights before the late 1920s. And in September 1941 there was an amazing display of the northern lights: green flashes filling the sky for hours.

Stanley B. Dickes
Sun City West, Arizona

On Comets and Canids

I thoroughly enjoyed the excerpt from Dale F. Lott's book on the American bison ["Plains Song," October 2002]. But it is clear that the author did not send his manuscript to your resident astrophysicist, Neil deGrasse Tyson. Had Mr. Lott done so, Tyson would surely have caught the error in the statement "A running cow attracts bulls, and a string of them are soon following her, just as a tail follows its comet."

Comet tails are pushed away from the head of a comet by the solar wind. As a comet moves about the Sun on the inbound segment of its orbit, the tail does indeed appear to follow the comet. But on the outbound segment the tail actually precedes the comet.

Darrel Hoff
Calmar, Iowa

In writing about the bison's "neighborhood," Dale Lott compares the hierarchy of the wolf pack to human despotism. As a wild-canid research behaviorist, I find that comparison laughable. When have human despots provided for, defended, or nurtured the young of their species?

Most packs I have studied are made up of the parent wolves and their yearlings or two-year-old offspring, as well as subordinate wolves. Unattached strangers seeking the security of pack life may be driven off and in some cases killed, but sometimes the pack assimilates them, albeit in a minor role. Yes, the alpha pair—male *and* female—eat the prey first: they are the ones that do the arduous and dangerous work of initiating the hunt and tackling the prey. And they are the first of the pack to provide protection and chase off any intruding mammals (such as bears) that would usurp the kill.

Skirmishes among wolves are rarely fatal, because the animals have evolved a complex set of facial expressions and body postures that make many domestic dogs look like dullards. By contrast, many breeds of the latter—whose appearance and behavioral characteristics have been genetically modified for hundreds of years to suit the whims and urges of humans—often continue to fight to the death, even when the losing dog surrenders.

Marvin J. Sheffield, D.V.M.
Pacific Grove, California

DALE F. LOTT REPLIES: Mr. Sheffield, pointing out that wolves nurture and protect their offspring, asks a question that is apparently intended to be rhetorical: "When have human despots provided for, defended, or nurtured the young of their species?"

My answer is that human despots almost always provide for, defend, and nurture their own offspring and close relatives, just as wolves do. Like most social systems, despotism is at bottom a reproductive strategy. At the same time, human despots, again like wolves, do not foster anything resembling social or political equality.

In spite of those similarities, as I note in the book from which the excerpt is drawn, judging wolves or any other animal by human standards of conduct is as wrongheaded as judging ourselves by their standards. They live as they must and can.

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["Samplings," September 2002], Stéphan Reebs reports that the reason for the order in which various species of birds begin to sing their dawn chorus is how well they see in low light. No argument there. But I think it is important to distinguish between the reason different species take up the order they do and the reason that an order exists at all.

Order benefits all species of birds, because each one is thereby assured a turn to compete for mates, with a minimum of interspecies conflict. Given the selective pressure favoring order of some kind, disparate sensitivity to low light can then serve as the rule leading to the particular order that all the species follow.
George Cammarota
San Jose, California

Ingredients of Life

Oliver Sacks ["Anybody Out There?" November 2002] notes that amino acids could have been synthesized at high temperatures early in the Earth's history, as Stanley L. Miller showed experimentally in the early 1950s. Mr. Sacks might also have mentioned that not long afterward Leslie Orgel conducted experiments at the other end of the temperature scale. Orgel dissolved several of the primordial ingredients of our universe in water, then found that slowly freezing the water would create organic compounds, including adenine, one of the bases that make up DNA.

It may well be that comets, as they trace their varied orbits, pick up small amounts of various chemical compounds in space. When the comets approach the Sun, the Sun's heat partly vaporizes them, and the compounds concentrated in the vapor might then condense into complex organic molecular chains, in much the same way that compounds were formed in Orgel's experiments. As the Earth and other planets pass through the cloud of molecular debris, they might acquire those materials as well. Hence vaporized comets might be the source of the compounds that can eventually form life—not only on Earth but also on other planets where water occurs.
Melvyn J. Oremland
Pace University
New York, New York

Stalinist Biology

In her article "The Interpretation of Genes" [October 2002], Jennie Dusheck maintains that the Soviet biologist Trofim Lysenko was discredited because he overemphasized the influence of environment on phenotype. But that influence, after all, was then and still is obvious. Lysenko's error was in positing that the influence of the environment could be genetically transmitted. Thus, for example, wheat normally grown in the warm Ukraine could be acclimatized to survive in the cold climes of northern Russia. Lysenko believed this was the result of a change in genotype; eventually it was shown to be caused by nothing more than the Darwinian survival of the fittest wheat strains already present.
Myron R. Schoenfeld, M.D.
Scarsdale, New York

JENNIE DUSHECK REPLIES: Lysenko was discredited not for positing that environmental influences could be genetically transmitted, but for denying the existence of genes at all. He held that the hereditary material lay in every particle of the body rather than in some special information-carrying, self-reproducing substance (such as DNA). In his writings Lysenko even placed the word *genes* in quotation marks. His fanaticism on this point compelled mainstream biologists to distance themselves from any ideas about environmental influences on development, lest they be mistaken for adherents of Lysenkoism. Their retreat was a loss to biology.

Natural History*'s e-mail address is nhmag@amnh.org.*

CONTRIBUTORS

Since 1978 **Michael** and **Patricia Fogden** ("The Natural Moment," page 12) have spent most of their time in the rainforests of Central America, working as freelance writer-photographers specializing in natural history subjects. The couple (pictured here in the Monteverde Cloud Forest Reserve in Costa Rica) enjoy collaborating in the field with scientists—having once been working zoologists themselves—and are fascinated by the relationships that have evolved between plants and animals. Their picture of the grasshopper mouse was taken in the northernmost part of the Chihuahuan desert in Mexico.

"When I was a child," says **Juan Luis Arsuaga** ("Requiem for a Heavyweight," page 42), "what I really wanted to be was a hunter-gatherer. Maybe that is why I became a paleontologist. Somewhere within us all hides a prehistoric human who still responds to the call of the wild." Codirector of excavations at Sierra de Atapuerca, in Spain, Arsuaga (foreground) has had ample opportunity to delve into the lifeways of the Neanderthals and their ancestors, and to reflect on why they eventually disappeared. When not hunting and gathering fossils, he teaches human paleontology at the University of Madrid and, as a visiting professor, at University College London. Arsuaga is also a co-curator of a new exhibition at the American Museum of Natural History, "The First Europeans: Treasures from the Hills of Atapuerca," opening January 11, 2003.

Growing up in southern California, **Kenneth A. Nagy** ("Dry, Dry Again" page 50) frequented two spots that resonate in his life to this day. One was the ocean off Venice beach, where he learned to bodysurf. The other was a salt marsh near Santa Monica, where he became fascinated with the resident lizards and snakes. Today Nagy is a professor in UCLA's department of organismic biology, ecology, and evolution. For the past thirty-five years he has studied the physiological ecology of desert animals, particularly reptiles, and has traveled to arid regions worldwide, most recently the Atacama Desert of northern Chile. Much of Nagy's work, however, takes place closer to home, where he began his studies: the Mojave Desert of southern California. And he still takes time off to bodysurf in the Pacific two or three times a week.

Rachel Wood ("Dodging Mass Extinction," page 58) traces her fascination with paleontology to her childhood, when she played in a gravel bed while waiting for the school bus and found out that the stones were full of fossils. From that first gravel field, her passion for the past has taken her across the globe, in particular to central Asia and to the United States. But the special place that led to the article in this month's issue is northwestern Australia, where the fossil reefs are "truly spectacular." Her doctoral thesis, written at the department of earth sciences of the Open University, in Milton Keynes, England, was on Mesozoic reef-building stromatoporoid sponges—relatives of the animals that figure prominently in her article. Wood is a paleontologist on the staff of Schlumberger Cambridge Research, in England, and a researcher in the department of earth sciences of the University of Cambridge. When she isn't digging, Wood enjoys taking walks.

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AMERICAN MUSEUM ō NATURAL HISTORY

THE FIRST EUROPEANS: Treasures from the Hills of Atapuerca

Who were the earliest humans in Western Europe? How long ago did they live and what were their lives like?

A partial composite skeleton assembled from the remains of several separate *Homo antecessor* individuals from the Gran Dolina site

Opening January 11, 2003, at the American Museum of Natural History, *The First Europeans: Treasures from the Hills of Atapuerca* is an unparalleled exhibition that addresses these questions and reveals the mysteries of ancient humans. The exhibition features exquisitely preserved ancient hominid and animal fossils—some dating as far back as one million years—and stone tools found at two extremely rich archaeological sites in the Atapuerca Hills in the region of Castilla y León in northern Spain. *The First Europeans* is co-organized by the American Museum of Natural History and Consejería de Educación y Cultura de Castilla y León.

On view through April 13, 2003, will be more than 70 fossils and artifacts excavated from these two remarkably evocative sites, providing Americans their first-ever glimpse of these early hominids and exploring their lives and practices. Perhaps most importantly, the exhibition will consider what their existence teaches us about what it means to be human today.

The first site, called Gran Dolina, provides a revealing record of the flora and fauna of 1,100,000 to 350,000 years ago, and contained the oldest hominid fossil remains found in Western Europe—a new species named *Homo antecessor,* dating to about 800,000 years ago. Primitive stone tools and hundreds of animal fossils have also been found there. A particularly intriguing aspect of this site is evidence of what may be the first case of cannibalism documented in human evolution.

The second site, Sima de los Huesos, holds the largest and most complete accumulation of hominid bones ever recovered, which archaeologists have assigned to *Homo heidelbergensis.* These remains, dating to between 350,000 and 300,000 years ago, were found mixed with fossil remains of wolves, lions, red foxes, wild cats, weasels, and bears—literally a "pit of bones," which may have been intentionally assembled by the hominids.

The First Europeans will exhibit some of the most beautifully preserved hominid fossils ever found, including a partial composite skeleton of *Homo antecessor* as well as skulls and jaws. Also on display will be ancient artifacts and fossils of Ice Age fauna that recall the climatic conditions under which our ancestors lived. In addition, dramatic photographs and models of the Atapuerca archaeological sites will be on view.

Perhaps most intriguing of all is what secrets these ancient specimens might reveal about where we came from and who we are. "These fossils are aesthetically beautiful and scientifically important," said Ian Tattersall, Curator in the Museum's Division of Anthropology, co-curator of *The First Europeans,* and a world-renowned authority on human evolution. "They cannot help but stimulate reflection in the viewer about what it means to be truly 'human.'" •

The First Europeans: Treasures from the Hills of Atapuerca is co-curated by Ian Tattersall, Curator, Division of Anthropology, American Museum of Natural History; Jose Maria Bermudez de Castro, Research Professor at Centro Superior de Investigaciones Científicas of Spain; Juan Luis Arsuaga, Professor of Paleontology at Complutense University in Madrid; and Eduard Carbonell, Professor of Prehistory at the Rovira and Virgill University of Tarragona.

AN INTERVIEW

WITH THE CURATOR OF *EINSTEIN*, MICHAEL M. SHARA

D. FINNIN; AMNH

***Michael M. Shara** is Curator-in-Charge of Astrophysics in the Division of Physical Sciences at the American Museum of Natural History. He spoke with us about relativity and Einstein's celebrity.*

Q: How can someone who's not a scientist understand relativity? Didn't Einstein say something about a young girl and a hot cinder?

He said that very tongue-in-cheek. That quote, as near as I can remember it, is: "When you have a pretty girl sitting on your lap, an hour seems like a second; when you're sitting on a hot stove, a second seems like an hour." And the fact that he used both heat and a pretty girl tells you something about Einstein.

What he was trying to get across was that time is relative in different frames of reference. That is, time does not tick by at the same rate for observers who are moving relative to each other.

And then in General Relativity, what Einstein finds is the following: matter tells space-time how to curve, and curved space-time tells matter how to move. And that pair of statements explains how gravity works.

The reason that the Earth goes around the Sun is that the Sun *bends* the space-time around itself, just like a heavy weight placed in the middle of a trampoline warps the surface of the trampoline. A marble rolled across the surface of a trampoline with a heavy weight in it follows a curved path. And if you roll that marble just right it will follow an orbit around that heavy weight. That's why the Earth goes around the Sun. That's the essence of General Relativity.

Q: How did Einstein come to be a celebrity? Was it due to his personality?

Once General Relativity had been demonstrated in 1919, he became . . . *the* pop star of the world.

The public persona was largely humble. He certainly never put on airs. He was truly disinterested in money. The search for knowledge, the search for a fundamental understanding of the universe is what drove him. That was his *raison d'être.*

That having been said, he spent a significant fraction of the second half of his life in the public eye doing very public things. And he was willing to use his celebrity status to advance causes that he felt were important.

Q: Einstein was an extraordinary man living in extraordinary times. Was his impact as a scientist amplified by his public role?

Well, Einstein considered himself to be a citizen of the world. And he was willing to espouse causes that were very unpopular at the time. It's not an accident that the FBI had a 1,400-page file on him. He found McCarthyism utterly repulsive. He hated nuclear weapons. He espoused a world government.

He did take American citizenship, and as a loyal American he felt it was his obligation to speak out against fascism, against nuclear arms, against militarism of all sorts. So that's the kind of person that he was.

Q: Time *magazine chose Einstein as "Person of the Century." Do you agree with that assessment?*

Absolutely. To my mind it was a no-brainer. The fact of the matter is that, yes, he was the most influential scientist of the century, probably of all time.

Take a look at the Earth in 1900 and the Earth in 2000. There were more changes in that century than in the previous 2,000 years in terms of technological advances...and practically every one of those is traceable back to Einstein, including the biological revolution. Crick and Watson could not have done what they did vis-à-vis DNA had we not known of the existence of molecules. Einstein's work on Brownian motion is fundamental to our knowledge of molecules.

The entire computer revolution can be traced to the photoelectric effect. Much of our economy today, and our ability to communicate information is entirely due to Einstein as well as, of course, nuclear weapons and our understanding of how the stars shine, the distances to the galaxies, and the creation of the universe. We are a different race of people than we were a century ago, utterly and completely different, because of Einstein.

EINSTEIN

Through August 10, 2003

This unprecedented exhibition profiles this extraordinary scientific genius, whose achievements were so substantial and groundbreaking that his name is virtually synonymous with science in the public mind. On display are letters and personal effects; documents including several rare manuscripts; and eye-opening explanations of Einstein's theories.

Organized by the American Museum of Natural History, New York; The Hebrew University of Jerusalem; and the Skirball Cultural Center, Los Angeles. Einstein *is made possible through the generous support of Jack and Susan Rudin and the Skirball Foundation, and of the Corporate Tour Sponsor, TIAA-CREF.*

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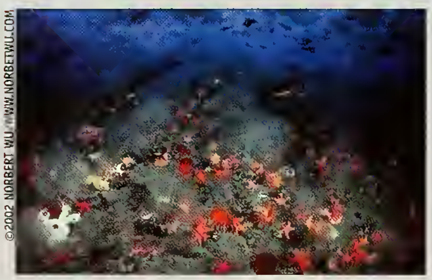
MUSEUM EVENTS

EXHIBITIONS

The Butterfly Conservatory: Tropical Butterflies Alive in Winter
Through May 26, 2003
The butterflies are back! This popular exhibition includes more than 500 live, free-flying tropical butterflies in an enclosed tropical habitat where visitors can mingle with them.

The Butterfly Conservatory *is made possible through the generous support of Bernard and Anne Spitzer and Con Edison.*



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Under Antarctic Ice
Through March 2, 2003
Spectacular large-format photographs by one of the world's leading underwater photographers, Norbert Wu.

This exhibition is made possible by the generosity of the Arthur Ross Foundation. Developed by Norbert Wu Productions and produced by the Pacific Grove Museum of Natural History.

DAVID LITTSCHWAGER AND SUSAN MIDDLETON

Kokia drynarioides

Remains of a Rainbow: Rare Plants and Animals of Hawaii
December 7, 2002–March 2, 2003
Color and black-and-white photographs of Hawaii's endangered species.

Organized by Umbrage Editions, New York, in association with Environmental Defense.

LECTURES

Einstein: A Curator's Lecture
Thursday, 12/5, 7:30–9:00 p.m.
Michael M. Shara discusses Einstein the physicist, Einstein the man, and the profound and world-changing synergy between the two.

Atapuerca: A New View of Evolution
Monday, 1/13, 7:00–8:30 p.m.
With Juan Luis Arsuaga, Professor of Human Paleontology at Complutense University in Madrid and co-director at the Atapuerca sites.

City of Stars
Tuesday, 1/14, 7:00 p.m.
Join Neil deGrasse Tyson, AMNH, for a tour of the "cosmic" in New York City.

JERRY BAUER

Howard Gardner on Genius
Wednesday, 1/15, 7:00–9:00 p.m.
Noted psychologist Howard Gardner, author of *Frames of Mind: The Theory of Multiple Intelligences,* will discuss the genius of Einstein while exploring the very notion of creative genius.

Einstein's Dreams
Thursday, 1/23, 7:00–9:00 p.m.
A concert performance of *Einstein's Dreams,* a new musical about the nature of time.

LECTURE SERIES

Hot Topics in Science and Culture: Einstein

Einstein and the FBI
Thursday, 12/12, 7:00–8:30 p.m.
Fred Jerome, author of *The Einstein File,* will weave the true story of the FBI's 23-year campaign to undermine Albert Einstein's reputation.

Time Travel: Fantasy or Reality?
Wednesday, 12/18, 7:00–9:00 p.m.
With clips from sci-fi films, J. Richard Gott of Princeton University will clarify how Einstein's work suggests the possibility of time travel.

Einstein: Patents and Inventions
Wednesday, 1/22, 7:00–8:30 p.m.
Join Linda S. Therkorn, U.S. Patent and Trademark Office, to learn how Einstein's theories may be at play right now in your home or office.

CHILDREN'S PROGRAMS

Fly Me to the Moon
Saturday, 12/7, 10:30 a.m.–12:00 noon (Ages 4–6, each child with one adult)

I Want to Be an Astronaut
Saturday, 12/7, 1:30–3:00 p.m. (Ages 4–6, each child with one adult)

Space Camp
Sunday, 12/8, 10:30 a.m.–12:00 noon (Ages 7–9)

Space Explorers

Myths and Constellations of the Night Sky
Tuesday, 12/10, 4:30–5:45 p.m.

Voyages into the 3-D Universe
Tuesday, 1/14, 4:30–5:45 p.m. (Ages 12 and up)

Courses

Humans in Space
Three Tuesdays, 1/14–28, 4:15–5:45 p.m. (Ages 10–12)
Students learn about the space environment and a day in the life of an astronaut.

Einstein's Universe

Three Wednesdays, 1/15–29, 4:15–5:45 p.m. (Ages 12 and up)
This course will examine the fundamental concepts of light, time, energy, and gravity.

Einstein for Everyone: Workshops

An Expedition into Space-Time
Saturday, 12/14, 10:30 a.m.–12:00 noon (Ages 7–9)

Adventures in Light!
Saturday, 12/14, 1:30–3:00 p.m. (Ages 4–6, each child with one adult)

The Sun and Its Energy
Sunday, 12/15, 1:30–3:00 p.m. (Ages 7–9)

GLOBAL WEEKENDS

Mediterranean Festival
Saturday and Sunday, 12/14 and 12/15. The diverse artistic heritage of the Mediterranean is highlighted in lectures, workshops, and performances.

Kwanzaa 2002: A Soulful Celebration
Saturday, 12/28, 1:00–6:00 p.m.
A day-long celebration of family and community.

Living in America: The Mexican Community
Three weekends of celebrating the artistic contributions that Mexican immigrants are making to New York City.

JOHN SANN

Mariachi Real

The Mexican Immigrant Experience in New York
Saturday and Sunday, 1/11 and 1/12

The "Great Manhattilan": Mixteca-Mexican Culture in New York
Saturday and Sunday, 1/18 and 1/19

Mexican Family Day/*Día Familiar Mexicano*
Saturday and Sunday, 1/25 and 1/26

HAYDEN PLANETARIUM PROGRAMS

The Extravagant Universe
Monday, 12/2, 7:30 p.m.
With Robert Kirshner, Harvard University

Black Holes Illuminated: A Quasar's Perspective
Monday, 12/9, 7:30 p.m.
With Joanne Attridge, Haystack Observatory, MIT

Celestial Highlights
Monday, 12/30; Tuesday, January 28, 6:30–7:30 p.m. This monthly tour of the heavens offers a view of the constantly changing night sky.

Frontiers of Matter, Motion, and Energy
14 Wednesdays, 1/29–5/14

Stars, Constellations, and Legends
Four Wednesdays, 1/22–2/12

Choosing a Telescope
Three Mondays, 1/13–27

Astrophotography
Five Tuesdays, 1/14–2/11

Life after Death: The Great Cosmic Recycler
Six Thursdays, 1/16–2/20

Special Relativity
Six Thursdays, 1/23–2/27

SPACE SHOWS

The Search for Life: Are We Alone?
Narrated by Harrison Ford. Every half hour Sunday–Thursday and Saturday, 10:30 a.m.–4:30 p.m.; Friday, 10:30 a.m.–7:30 p.m.

Look Up!
Saturday and Sunday, 10:15 a.m. (Recommended for children ages 6 and under)

LARGE-FORMAT FILMS

Pulse: A STOMP Odyssey
Take a rhythmic voyage of discovery around the world of percussion.

Kilimanjaro: To the Roof of Africa
Follow a team of hikers up Africa's highest mountain.

GENERAL INFORMATION

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LOTS OF FOAM, PLEASE The chocoholics among us won't be surprised to learn that people were sipping decoctions of cacao a millennium earlier than archaeologists had previously thought. All too often when ancient ceramics are found, their well-meaning finders give them a good wash—one of the worst things that can happen to a piece of archaeological evidence. But the spouts of some of the ceramic vessels unearthed at a Preclassic (600 B.C.–A.D. 250) Maya site in northern Belize are long and narrow—a shape that generally defies efforts at cleaning—and so food and beverage residues from the insides of those spouts remained intact. There, W. Jeffrey Hurst of the Hershey Foods Technical Center in Pennsylvania and his colleagues from the University of Texas at Austin found traces of theobromine, a relative of caffeine and a smoking gun for an extract of the tree *Theobroma cacao*—the source of all things chocolate. Before Hurst's discovery, the oldest known cacao residue had come from artifacts at an Early Classic (A.D. 460–480) Maya site in northeastern Guatemala.

Maya king with a chocolate brew, Late Classic period (A.D. 600–800)

According to documents from the time of the Spanish Conquest, the Maya and Aztecs loved chocolate froth even more than chocolate liquid, and they created the prized foam by pouring the liquid back and forth from one container to another. The same froth, suggest the researchers, could have been made in the earlier vessels by blowing air through the spouts—a bit like the way cappuccino is made today. ("Cacao usage by the earliest Maya civilization," *Nature* **418:**289–90, July 18, 2002)

EXPERIMENT OF THE MONTH "Opportunistic" is a good description for animal behavior, whether the animals be birds or biologists. On Middleton Island in the Gulf of Alaska stands an abandoned U.S. Air Force radar tower. Years ago, high winds blew off its exterior siding, and the exposed beams became favored nesting sites for a colony of black-legged kittiwakes. But that serendipitous development has also made it possible for biologists to monitor the seabirds, which normally nest on nearly inaccessible cliff ledges.

The biologists' opportunism comes not a moment too soon. In Alaska at least, some kittiwake colonies have drastically declined over the past quarter century. To test their hunch that food shortage—and not, say, predation—was the primary problem, two biologists from the U.S. Geological Survey began feeding the birds and monitoring their activities through one-way mirrors. The biologists, Verena A. Gill and Scott A. Hatch, regularly served breakfast, lunch, and dinner to breeding kittiwakes by pushing chopped herring through openings in the walls behind the nests. In two years of study, Gill and Hatch found that the longer the kittiwake parents were fed, the more fledglings they produced. In fact, the breeding rates of the food-aided birds became comparable to rates in Atlantic colonies, which seem so far to have avoided the troubles that plague some of the Pacific populations. ("Components of productivity in black-legged kittiwakes *Rissa tridactyla:* response to supplemental feeding," *Journal of Avian Biology* **33:**113–26, 2002)

SHARK SEX Sharks do things differently from most other fishes, and sex is no exception. Marine biologists have known for some time about the peculiarities of shark reproductive anatomy and physiology: sharks have specialized copulatory organs, practice internal fertilization (almost all bony fishes practice external fertilization), can store sperm for months, and produce relatively few, well-provisioned young. Now a study by Kevin A. Feldheim, Samuel H. Gruber, and Mary V. Ashley of the University of Illinois at Chicago has helped fill in our picture of the behavioral side of sex among sharks.

The investigators studied a population of lemon sharks (*Negaprion brevirostris,* a species that gives birth to live young) that inhabit the waters around a small chain of mangrove-fringed islands in the Bahamas. A large lagoon, protected from the open sea by the surrounding islands, serves as a natural nursery for the population. By tagging individual sharks, analyzing their DNA, and capturing them repeatedly over a six-year period, Feldheim and his colleagues determined that females of the species normally mate with more than one male per breeding cycle—a behavior called polyandry, which has never before been observed in any fish species that practices internal fertilization. Because the male bites and bloodies the female at each mating, the investigators were surprised that female sharks put themselves through the ordeal more than once a season.

The study also showed that even though females breed only once every two years, they always come back to the same lagoon to give birth. To conserve threatened species of coastal sharks, biologists may have to identify and protect traditional nursery grounds as well as the sharks themselves. ("The breeding biology of lemon sharks at a tropical nursery lagoon," *Proceedings of the Royal Society of London* B **269:**1655–61, July 22, 2002)

HOT PLANTS If you've ever visited Yellowstone National Park, you can probably still picture the sulfurous landscape: broad, crusty, white rock terraces with their patches of ocher and canary yellow; bubbling pools of gray mud; steaming basins of jade-green and pale turquoise water. But you might not remember the scattering of plants at the water's edge. These organisms are as remarkable, in their own way, as the otherworldly landscape: the steaming soil they thrive in is hot enough to kill most other members of the plant kingdom.

For six summers and two winters Richard G. Stout and Thamir S. Al-Niemi, both biologists at Montana State University in Bozeman, have documented the distribution and microenvironment of this unusual flora. For example, the soil temperature around the roots of *Dichanthelium lanuginosum,* known locally as hot springs panic grass—the most common species in Yellowstone's hottest soils—is often as high as 122 degrees Fahrenheit in summer and, at some sites, seldom falls below 95 degrees even in winter.

Searing temperatures can kill organisms by unfolding their proteins, a change in shape that renders them biologically useless. Some plants counter the effect by making so-called heat-shock proteins, which probably stabilize the other proteins. Stout and Al-Niemi identified a class of small heat-shock proteins (sHSPs) whose concentration in the roots of hot springs panic grass increases as the soil temperature rises. Those proteins usually do not occur in the leaves, which are always cooler than the roots. Other kinds of heat-shock proteins are known to help plants tolerate heat for brief periods, but the work on panic grass suggests that sHSPs are important for long-term resistance. ("Heat-tolerant flowering plants of active geothermal areas in Yellowstone National Park," *Annals of Botany* **90:**259–67, August 2002)

Stéphan Reebs is a professor of biology at the University of Moncton in New Brunswick, Canada, and the author of Fish Behavior in the Aquarium and in the Wild *(Cornell University Press).*

Hope springs eternal: Arctic foxes anticipate a polar bear's table scraps.

SURF AND TURF Maybe you can't tell a book by its cover, but it turns out you can sometimes tell what was once in an animal's stomach by analyzing its hair. Take the arctic fox, whose diet is a mix of the marine (seal carrion and seal pups) and the terrestrial (lemmings, bird eggs, caribou carrion). The ratio of the two stable isotopes of carbon—carbon-12 and carbon-13—in the fox's newly grown coat can show how much of its recent diet was marine, because marine fare is the richer in carbon-13.

The bad news is that because of global warming, the marine part of that diet may soon start drying up. James D. Roth, an ecologist at the University of Central Florida in Orlando, recently studied the hair of arctic foxes near Cape Churchill, Manitoba, on the west coast of Hudson Bay. In four years of observation Roth found that the animals' winter diet was higher in marine nutrients than their summer diet, particularly in years when lemmings (the foxes' year-round favorite menu item) were scarce. It seems that in winter the foxes follow polar bears out onto the sea ice to grab the spoils of the bears' seal hunts. But if sea ice in the Arctic continues to decline, as it has in recent years, arctic foxes (as well as polar bears) will lose access to an important part of their diet. ("Temporal variability in arctic fox diet as reflected in stable-carbon isotopes; the importance of sea ice," *Oecologia* **133:** 70–77, August 10, 2002)

ABANDONED IN THE GARDEN Many orchids have flower parts that mimic the shape and scent of female wasps. Male wasps, beguiled and bamboozled by the impersonators, land on the flowers, unwittingly pick up pollen, and carry it to the next floral mimic—a classic example of how natural selection can make stooges of its protagonists, to the general amusement of biology students everywhere. But new research shows that the orchids' trick may not be so harmless as a simple practical joke, and that it is mostly the imitated females who pay the price.

Bob B.M. Wong of the Australian National University in Canberra and Florian P. Schiestl of the Swiss Federal Institute of Technology in Zürich measured how often male thynnine wasps visited patches of wasp-mimicking *Chiloglottis* orchids, compared with how often males visited genuine female thynnines, both inside and outside the orchid patches. The biologists observed that the males' visits to orchid sites decreased with time, suggesting that unrewarded males learned to avoid areas where the flowers proved deceptive.

But for the females—which are wingless and cannot readily change location—the stakes were much higher. As the males learned to avoid the orchids, female wasps outside the flower patches soon had many suitors approaching them. Females within the suddenly unpopular patches, however, had few or no visits; in their case, a gorgeous surrounding was no thing of beauty. ("How an orchid harms its pollinator," *Proceedings of the Royal Society of London* B **269:**1529–32, July 3, 2002)

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Delusions of Centrality

Even astronomers have had a hard time accepting that humanity does not inhabit a special part of the universe.

By Neil deGrasse Tyson

So much of the universe appears to be one way but is really another that I wonder, at times, whether there's an ongoing conspiracy designed to embarrass astrophysicists.

Examples of such cosmic tomfoolery abound.

In modern times it's taken for granted that we live on a spherical planet. But the evidence for a flat Earth seemed clear for thousands of years. Just look around. Without satellite imagery, it's hard to convince yourself that the Earth is anything but flat, even when you look out of an airplane window. What's true on Earth is true on all smooth surfaces in non-Euclidean geometry: a sufficiently small region of any curved surface is indistinguishable from a plane. Long ago, when people did not travel far from their birthplace, a flat Earth promoted the ego-stroking view that you occupied its exact center, and that all points along the horizon (the edge of your world) were equally distant from you. As one might expect, nearly every map of a flat Earth depicts the map-drawing civilization at its center.

A flat Earth promoted the ego-stroking view that you occupied the exact center of the cosmos.

Now look up. Without a telescope, you can't tell how far away the stars are. They keep their places, rising and setting as if they were glued to the inside surface of a dark, inverted bowl. So why not assume they're all the same distance from Earth, whatever that might be?

But they're not all equally far away. And of course there is no bowl.

Let's grant that the stars are scattered through space, hither and yon. But how hither, and how yon? To the unaided eye the brightest stars are more than a hundred times brighter than the dimmest. So the dim ones are obviously a hundred times farther away from Earth, aren't they?

Nope.

That simple argument boldly assumes that all stars are intrinsically equally luminous, automatically making the near ones brighter than the far ones. Stars, however, come in a staggering range of luminosities, spanning ten orders of magnitude—ten powers of ten. So the brightest stars are not necessarily the ones closest to Earth. In fact, most of the stars you see in the night sky are of the highly luminous variety, and they lie extraordinarily far away.

If most of the stars we see are highly luminous, then surely those stars are common throughout the galaxy.

Nope again.

High-luminosity stars are the rarest. In any given volume of space, they're outnumbered by the low-luminosity stars a thousand to one. It's the prodigious energy output of high-luminosity stars that enables you to see them across such large volumes of space.

Suppose two stars emit light at the same rate (meaning that they have the same luminosity), but one is a hundred times farther from us than the other. We might expect it to be a hundredth as bright. No. That would be too easy. Fact is, the intensity of light dims in proportion to the square of the distance. So in this case, the faraway star looks 10,000 (100^2) times dimmer than the one nearby. The effect of this "inverse-square law" is purely geometric. When starlight spreads in all directions, it becomes diluted by the growing spherical shell of space through which it moves. The surface area of this sphere increases in proportion to the square of its radius (you may remember the formula: $Area = 4\pi r^2$), forcing the light's intensity to diminish by the same proportion.

All right: the stars don't all lie the same distance from us; they aren't all equally luminous; the sample we see is highly unrepresentative. But surely they are stationary in space. For millennia, people understandably thought of stars as "fixed," a concept evident in such influential sources as the Bible ("And God set them in the firmament of the heaven," Genesis 1:17) and Ptolemy's *Almagest,* published circa A.D. 150, wherein he argues strongly and persuasively for no motion:

> To sum up, if one assumes any motion whatever, except spherical, for the heavenly bodies, it necessarily follows that their distances, measured from the earth upwards, must vary, wherever and however one supposes the earth itself to be situated. Hence the sizes and mutual distance of the stars must appear to vary for the same observers during the course of each revolution, since at one time they must be at a greater distance, and another at a lesser. Yet we see that no such variation occurs.

Edmond Halley (of comet fame) was the first to measure the movement of stars across the sky. In 1718 he compared "modern" star positions with the ones mapped by the second century B.C. Greek astronomer Hipparchus. Halley trusted the accuracy of Hipparchus's maps, but he also benefited from a baseline of more than eighteen centuries from which to compare the ancient and modern positions. He promptly noticed that the star Arcturus was not where it once was. The star had indeed moved, but not enough within a single human lifetime to be noticed without the aid of a telescope.

Seven "stars" made no pretense of being fixed; they appeared to wander against the "fixed" starry background and so were called *planetes,* or "wanderers," by the Greeks. You know all seven (our names for the days of the week are traceable to them): Mercury, Venus, Mars, Jupiter, Saturn, the Sun, and the Moon. Since ancient times, each planet was correctly thought to be closer to Earth than was the rest of the starry sky.

Aristarchus of Samos first proposed a Sun-centered universe in the third century B.C. But back then it was obvious to anybody who paid attention that irrespective of the planets' complicated motions, they and all the background stars revolved around the Earth. If the Earth moved we would surely feel it. Common arguments of the day included:

- If Earth rotated on an axis or moved through space, wouldn't clouds in the sky and birds in flight get left far behind? (They aren't.)
- If you jumped vertically, wouldn't you land in a very different spot as Earth traveled swiftly beneath your feet? (You don't.)
- And if the Earth moved around the Sun, wouldn't the angle at which we view the stars change continuously, creating a visible shift in the stars' positions on the sky? (It doesn't—at least not visibly.)

John Thompson, *Universe,* 2001

The naysayers' evidence was compelling.

For the first two cases, the work of Galileo would later demonstrate that while you are airborne, you, the atmosphere, and everything else around you are carried forward with the rotating, orbiting Earth. For the same reason, if you stand in the aisle of a cruising airplane and jump up, you do not catapult backward past the rear seats and get pinned against the lavatory doors. In the third case, there's nothing wrong with the reasoning—except that the stars are so far away you need a powerful telescope to see the seasonal shifts. That effect would not be measured until 1838 by the German astronomer Friedrich Wilhelm Bessel.

The geocentric universe was a pillar of Ptolemy's *Almagest,* and it preoccupied scientific, cultural, and religious consciousness until 1543, when Copernicus placed the Sun instead of the Earth at the center of the known universe. Fearful that this heretical work would freak out the establishment, Andreas Osiander, a Protestant theologian who oversaw the late stages of the printing of Copernicus's *De Revolutionibus,* supplied an unauthorized and unsigned preface to the work. In it he pleads:

I have no doubt that certain learned men, now that the novelty of the hypothesis in this work has been widely reported—for it establishes that the Earth moves and indeed that the Sun is motionless in the middle of the universe—are extremely shocked. . . . [But it is not] necessary that these hypotheses should be true, nor even probable, but it is sufficient if they merely produce calculations which agree with the observations.

Copernicus himself was not unmindful of the trouble he was about to cause. In the book's dedication, addressed to Pope Paul III, Copernicus notes:

I can well appreciate, Holy Father, that as soon as certain people realize that in these books which I have written about the Revolutions of the spheres of the universe I attribute certain motions to the globe of the Earth, they will at once clamor for me to be hooted off the stage with such an opinion.

But soon after the Dutch spectacle maker Hans Lippershey had invented the telescope in 1608, Galileo was able to observe such cosmic phenomena as Venus going through phases and four moons in orbit around Jupiter rather than Earth. These and other observations were nails in the geocentric coffin, making Copernicus's heliocentric universe an increasingly persuasive concept. Once the Earth no longer occupied a unique place in the cosmos, the Copernican revolution, based on the principle that we are not special, was officially under way.

Now that Earth was in solar orbit, just like its planetary brethren, where did that place the Sun? At the center of the universe? No way. Nobody was going to fall for that one again; it would violate the freshly minted Copernican principle. But let's investigate to make sure.

If the solar system were in the center of the universe, then no matter where we looked on the sky we would see approximately the same number of stars. But if the solar system were off to the side somewhere, we would presumably see a great concentration of stars in one direction—the direction of the center of the universe.

Vivian Torrence, *Catoptrics*, 1979

In 1785, having tallied stars everywhere on the sky and crudely estimated their distances, the English astronomer Sir William Herschel concluded that the solar system did indeed lie at the center of the cosmos. Slightly more than a century later the Dutch astronomer Jacobus Cornelius Kapteyn—using the best available methods for calculating distance—set out to verify once and for all the position of the solar system.

When seen through a telescope, the band of light called the Milky Way resolves into dense concentrations of stars. Careful tallies of their positions and distances yield similar numbers of stars in every direction along the band itself. Above and below it, the concentration of stars drops symmetrically. No matter which way you look on the sky, the tally comes out about the same as it does in the opposite direction, 180 degrees away. Kapteyn devoted some twenty years to preparing his sky map, which, sure enough, showed the solar system lying within the central one percent of the universe. We weren't in the exact center, but we were close enough to reclaim our rightful place in space.

But the cosmic cruelty continued.

Little did anybody know at the time, especially not Kapteyn, that most sight lines to the Milky Way do not pass all the way through to the end of the universe. The Milky Way is rich in large clouds of gas and dust that absorb the light emitted by objects behind them. More than 99 percent of all the stars that should be visible to us when we look in the direction of the Milky Way are blocked from view by the Milky Way itself. To presume that the Earth was near the center of the Milky Way was almost like walking into a large, dense forest and, after a few dozen steps, asserting that you've reached the center simply because you see the same number of trees in every direction.

By 1920—but before the light-absorption problem was well understood—Harlow Shapley, who was to become director of the Harvard College Observatory, studied the spatial distribution of globular clusters in the Milky Way. Globular clusters are tight concentrations of as many as a million stars and are seen easily in regions above and below the Milky Way, where the least amount of light is absorbed. Shapley reasoned that these titanic clusters should enable him to pinpoint the center of the universe—a spot that, after all, would surely have the highest concentration of mass and the strongest gravity. Shapley's data showed that the solar system is nowhere close to the center of the globular clusters' distribution, and so is nowhere close to the center of the known universe. Where was this special place he found? Sixty thousand light-years away, in roughly the same direction as—but far beyond—the stars that trace the constellation Sagittarius.

Shapley's distances were too large by more than a factor of two, but he was right about the center of the system of globular clusters. It coincides with what was later found to be the most powerful source of radio waves in the night sky (radio waves are unattenuated by intervening gas and dust). Astrophysicists eventually identified the site of peak radio emissions as the exact center of the Milky Way, but not until one or two more episodes of seeing-isn't-believing had taken place.

Once again the Copernican principle had triumphed. The solar system was not in the center of the known universe but far out in the suburbs. For sensitive egos, that could still be okay. Surely the vast system of stars and nebulae to which we belong comprised the entire universe. Surely we were where the action was.

Nope.

Most of the nebulae in the night sky are like island universes, as presciently proposed in the eighteenth century by several people, including the Swedish philosopher Emanuel Swedenborg, the English astronomer Thomas Wright, and the German philosopher Immanuel Kant. In *An Original Theory or New Hypothesis of the Universe* (1750), for instance, Wright speculates on the infinity of space, filled with stellar systems akin to our own Milky Way:

> We may conclude . . . that as the visible Creation is supposed to be full of sidereal Systems and planetary Worlds, . . . the endless Immensity is an unlimited Plenum of Creations not unlike the known Universe. . . . That this in all Probability may be the real Case, is in some Degree made evident by the many cloudy Spots, just perceivable by us, as far without our starry Regions, in which tho' visibly luminous Spaces, no one Star or particular constituent Body can possibly be distinguished; those in all likelyhood may be external Creation, bordering upon the known one, too remote for even our Telescopes to reach.

Wright's "cloudy Spots" are in fact collections of hundreds of billions of stars, situated far away in space and visible primarily above and below the Milky Way. The rest of the nebulae turn out to be relatively small, nearby clouds of gas, found mostly within the Milky Way band.

That the Milky Way is just one of the multitudes of galaxies that comprise the universe was among the most important discoveries in the history of science, even if it made us feel small again. The offending astronomer was Edwin Hubble, after whom the Hubble Space Telescope is named. The offending evidence culminated in a photographic plate made on the night of October 5, 1923. The offending instrument was the Mount Wilson Observatory's 100-inch telescope, at at the time the most powerful in the world. The offending cosmic object was the Andromeda nebula, one of the largest on the night sky.

Within Andromeda, Hubble discovered a highly luminous kind of star that was already familiar to astronomers from surveys of stars much closer to home. The distances to the nearby stars were known, and their apparent brightness varies only with their distance. By applying the inverse-square law for the brightness of starlight, Hubble derived the distance to the star in Andromeda, placing the nebula far beyond any known star within our own stellar system. Andromeda was actually an entire galaxy, whose fuzz could be resolved into billions of stars, all situated more than two million light-years away. Not only were we not in the center of things, but *overnight* our entire Milky Way galaxy, the last measure of our self-worth, shrank to an insignificant smudge in a multibillion-smudge universe that was vastly larger than anyone had previously imagined.

Although the Milky Way turned out to be only one of countless galaxies, couldn't we still be at the center of the universe? Just six years after Hubble demoted our galaxy, he pooled all the available data on the motions of galaxies. Nearly all of them recede from the Milky Way at velocities directly proportional to their distances from us.

Finally we were in the middle of something big: the universe was expanding, and we were at the center of its time and space.

We might occupy just one universe in a "metaverse" of countless other universes.

No, we weren't going to be fooled again. Just because it looks as if we're in the center of the cosmos doesn't mean we are. As a matter of fact, a theory of the universe had been waiting in the wings since 1916, when Einstein published his paper on general relativity—the modern theory of gravity. In Einstein's universe, the fabric of space and time warps in the presence of mass. This warping, and the movement of objects in response to it, is what we interpret as the force of gravity. When applied to the cosmos, general relativity allows the space of the universe to expand, carrying its constituent galaxies along for the ride. A remarkable consequence of this new reality is that the universe looks to all observers in every galaxy as though it expands around them. It's the ultimate illusion of self-importance, where nature fools not only sentient human beings but also all life-forms that have ever lived in all of space and time.

But surely there is only one cosmos—the one where we live in happy delusion.

At the moment, cosmologists have no evidence for more than one universe. But if you extend several well-tested laws of physics to their extremes (or beyond), you can describe the small, dense, hot birth of the universe as a seething foam of tangled space-time that is prone to quantum fluctuations, any one of which could spawn an entire universe of its own. In this gnarly cosmos we might occupy just one universe in a "metaverse" that encompasses countless other universes popping in and out of existence. The idea relegates us to an embarrassingly smaller part of the whole than we ever imagined.

Our plight persists, but on ever larger scales. Hubble's summary of the matter, written in 1936, could apply at all stages of our endarkenment:

> Thus the explorations of space end on a note of uncertainty. . . . We know our immediate neighborhood rather intimately. With increasing distance our knowledge fades, and fades rapidly. Eventually, we reach the dim boundary—the utmost limits of our telescopes. There, we measure shadows, and we search among ghostly errors of measurement for landmarks that are scarcely more substantial.

What are the lessons to be learned from this journey of the mind? That humans are emotionally fragile, perennially gullible, hopelessly ignorant masters of an insignificantly small speck in the cosmos. Have a nice day.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of the Hayden Planetarium in New York City and a visiting research scientist at Princeton University.

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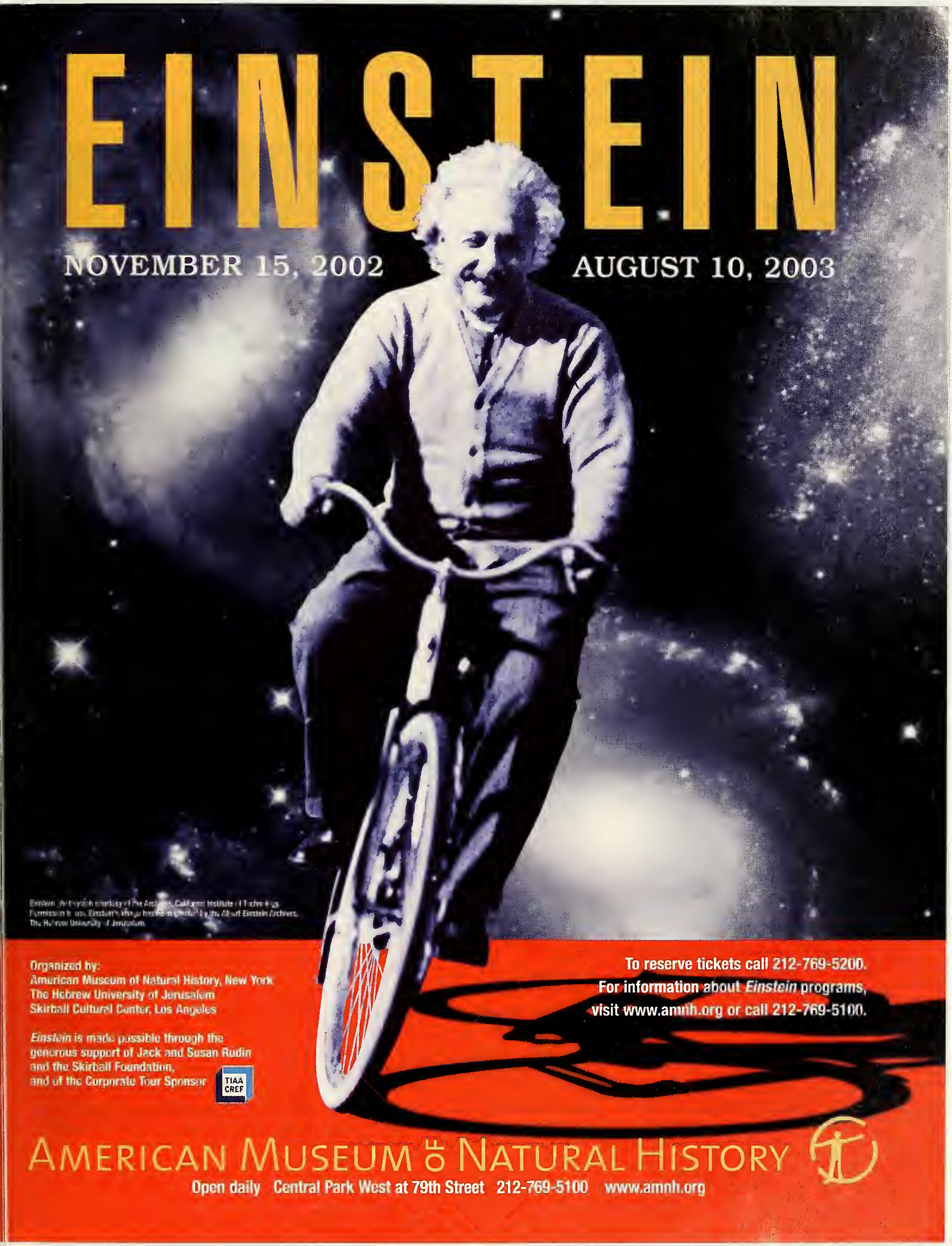
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Caught in Traffic

A synaptic detour from the boardwalk to the Great White Way

By Alan Burdick

Living in a city is an ongoing act of adaptation: to the cramped caves that pass for apartments, to the beehive pace of human contact, to the astonishing olfactory varieties of filth and decay. Most of all, one must find a way to sleep through the honking, bleating, wailing, and screeching of nighttime traffic.

My bedtime solution was to pretend that the traffic noise was the sound of the ocean, and I taught myself to fall asleep to it. Fortunately I didn't have to contend with loud car horns or trucks slamming across potholes, just the steady murmur of Broadway at night—taxicabs on the prowl, night owls flying home—muffled by an interceding block of buildings. I told myself that from a distance it sounded like waves rolling against the shore. I slept like a submerged rock.

Sounds that soothe and sounds that bother can get cross-wired in the memory networks of the cerebral cortex.

All fine and well, until I packed up and rented a summer house within earshot of the sea—the real sea. Thereupon every night for the first month, sometime in the wee hours, I was jolted awake by the thundering sound of what I thought was traffic—though the nearest major road was miles away. Somehow the boxes in my brain marked "traffic sounds" and "ocean sounds" must have gotten mixed up, to my detriment. I got to wondering: How is it that I can call traffic "ocean" and be soothed by it? And if my brain accepted these mislabeled "ocean" sounds in Manhattan, why, upon falling asleep by the seashore, did it reject the real thing? Who the heck was in charge in there?

I called my friend Robert Sapolsky, a neuroscientist at Stanford University, for some insight. First of all, he said, I should forget about "boxes" of sound—that's not the way the brain handles chunks of information. After its journey through the ear's anatomical resonators and amplifiers, sound gets processed by a small number of successive layers of neurons in the auditory cortex, a half-dollar-size segment of the cerebral cortex. The initial layer of neurons responds to specific frequencies of sound—a single musical note, perhaps—whereas successive layers respond to arrays of frequencies—a chord, perhaps—and then more complex arrays. The visual cortex works much the same way: individual neurons (in the first layer of processing) recognize dots of light, whereas successive layers register lines, then moving lines.

For a long time, brain scientists assumed this layering went on indefinitely. Somewhere, they figured, many layers along, they'd find what Sapolsky calls the "grandmother neuron," the neuron that would respond specifically to a photograph of your grandmother (or a recording of her voice).

But they never found it, because it doesn't exist. "By the time you're getting that high up in brain processing, information is not confined within a single neuron," Sapolsky told me. "A neuron does not contain one fact and one fact only."

Instead, after registering with the auditory cortex, a sound passes into the associational cortex—which constitutes 90 percent of the cerebral cortex. There it enters a still-mysterious filing system, a crowded metropolis of overlapping memory networks. The sound of rolling ocean waves, for instance, probably lies at the intersection of numerous generic networks, such as Sounds That Ebb and Flow, Low-Amplitude Sounds, Water-Related Sounds, and dozens if not thousands of others. Retrieving a memory—registering a familiar sound and thinking, "Hey, that's the ocean!"—is basically a matter of driving around in the right neural neighborhoods long enough to find the right street corner. "You're working the net," Sapolsky says. "You're trying to access as many networks as possible."

That's the key to my Manhattan trick. As I'm falling asleep to the din of traffic, I'm cruising the neural networks, hunting for the familiar overlap of neighborhoods. Sounds That Ebb and Flow: I'm getting closer. Low-Amplitude Sounds: I'm zeroing in. Upon reaching Sounds That Bug Me (known to my waking mind as Manhattan traffic), however, I intentionally veer away, toward Sounds That Soothe Me. Hey, I hear the ocean! Broadway traffic and the oceanfront are pretty close to each other, it turns out, just a couple of carefully chosen wrong exits apart.

(By the way, there is no scientific evidence that the sound of the ocean is inherently more relaxing than, say, the thrum of a lawnmower. Some people are soothed by water sounds, but according to Mark Tramo, director of the Institute for Music and Brain Science at Harvard University, your response depends both on context and on your own personal psychodynamics. "If you lost a parent in a situation like the one in the movie *Jaws*," he says, "you might not like the sound of waves splashing.")

The dupe here, as Sapolsky puts it, is my prefrontal cortex, another small subunit of the cerebral cortex. The role of the prefrontal cortex is to help set long-range goals and inhibit potentially detrimental behavior. "It has executive control over the rest of the cortex," Sapolsky explains. "It keeps you from doing things like belching in public. It's the thing that corresponds most closely to what we mean by a superego."

Ordinarily, the prefrontal cortex would not confuse traffic noise and ocean noise. But funny things happen during sleep. When you enter a dream state, as you do when you first fall asleep and at numerous other times during the night, metabolic activity remains constant or even increases in many regions of your brain. Those regions include parts of the auditory cortex and parts of the autonomic motor system, which controls breathing, heart rate, digestion, and the like. But in the prefrontal cortex, metabolism declines; the chief executive stops paying attention. One reason dreams can be so nutty and so all over the map, Sapolsky believes, is that the prefrontal cortex is asleep at the wheel. "Big, loose, adventurous thoughts are allowed to happen."

Therein lies my problem. As I'm sleeping in my seaside house, my auditory cortex remains alert, registering the sound of the ocean and feeding my dreams with it. Under normal circumstances that wouldn't bother me. Even asleep, the prefrontal cortex can discriminate traffic from ocean noise; the resulting dreams presumably would have watery and nondisruptive themes (whirlpools and tidal waves excepted). Back in Manhattan, though, I'd already trained my prefrontal cortex to stop telling the difference, so at the shore, it's anything goes. My auditory cortex hears the ocean, but then, often as not, my brain cooks up dreams of loud traffic, jolting me from a dead sleep. These dreams can be so vivid that even after waking, I have the momentary illusion of hearing the busy clamor of Broadway.

Too late, I realized I'd created an internal traffic nightmare. In Manhattan, I'd beaten a neural path from Broadway to the ocean; I'd found a shortcut from one neural intersection (Traffic Sounds) to the other (Ocean Sounds). Little did I know I was opening up a two-way highway—a very popular one, apparently. Who's in charge in there? No one: I'd fired the only traffic cop on duty. Now, no matter where I turn in the neural network, I keep hitting traffic: Midtown gridlock, tunnel backups, bumper-to-bumper processions of weekend beachgoers returning home. How's a guy supposed to get any shut-ear around here?

Somewhere in your brain, neurologists figured, they'd find a "grandmother neuron" that responds, say, to a recording of your grandmother's voice. But they never found it, because it doesn't exist.

Alan Burdick is a writer living in New York City. He is at work on a book about nature for Farrar, Straus and Giroux.

Searching for Your Inner Chimp

Can a few thousand genes make all the difference between people and their closest living relatives?

By Carl Zimmer

James Balog, *Chimpanzee Holding Man's Head,* 1992

In the past decade, as molecular biologists have learned to read DNA sequences rapidly, the chimpanzee has clearly emerged as humanity's closest living relative. Our DNA is astonishingly similar. You can see for yourself by visiting the "Silver Project" Web site of Japan's National Institute of Genetics (sayer.lab.nig.ac.jp/~silver/), which is home to a growing database of chimpanzee DNA. With a couple of clicks you can compare the sequence of DNA nucleotides for a particular chimpanzee gene—molecular fragments whose identity is given by one of the four "letters" in the DNA "alphabet"—with the sequence in the corresponding human gene.

Say, for instance, you decide to look at a gene known as *CHRM2*, which codes for a kind of receptor on nerve cells. Stretched out alongside the human sequence is the sequence of nucleotides for the same gene in the chimpanzee. If you read the letters in the sequence—*A, C, G,* and *T,* shuffled and repeated line after line—you'll find that the two sequences are identical for hundreds of nucleotides at a stretch. Only here and there are they punctuated by a rare difference. Such differences would have evolved sometime after the chimpanzee and human branches split from their common ancestor, and one lineage or the other (or perhaps, even more rarely, both) picked up a mutation.

Molecular biologists still don't know exactly how many such differences exist between the human and chimpanzee genomes. In spite of the hoopla in June 2000 over the "essentially complete" sequencing of the human genome, enough mopping up still remained that the sequence will be truly complete only as of this coming April. As for the chimpanzee genome, only isolated fragments have been determined—though it is a top priority for the next full sequencing of an organism's genome. So far, the biggest published surveys extrapolate from less than 1 percent of the two species' DNA. Nevertheless, most of the surveys have converged on the conclusion that the two genomes are about 98.7 percent identical.

What is one to make of this? If humans and chimpanzees are really so similar genetically, why have they turned out to be so different "in the wild"? Is genetic similarity a mismeasure of the species? Is there something else, biologically, that accounts for our obvious differences? Or are chimpanzees and human beings genuinely the close cousins that the genetic counts suggest, making the differences we notice at the level of the organism little more than skin deep? The answers to these questions are still up for grabs, but however they come out, they promise to echo far beyond the halls of genetics and on to the centuries-old debate about what is unique and what is not about *Homo sapiens.*

Chimpanzees have been disconcerting Western scientists since at least the 1690s, when the English anatomist Edward Tyson became the first to dissect one. He noted that the chimp and the human brain bore a "surprising" resemblance, writing that "one would be apt to think, that since there is so great a disparity between the *Soul* of a *Man*, and a *Brute*, the *Organ* likewise in which 'tis placed should be very different too."

In the nineteenth century, the English anatomist Richard Owen begged to differ. The contrast between the brain of the chimpanzee and that of a person, he maintained, was actually quite sharp; no human could ever be thought of as merely a modified chimpanzee. Owen was a fierce opponent of Darwin's evolutionary ideas, as well as of those espoused by the French naturalist Jean Baptiste Lamarck, one of Darwin's intellectual predecessors. He looked intensively for something unique in the human brain that would set us off from other primates. The only thing he found was a small fold in the back of the brain, which he could not identify in any ape. But that was enough for Owen—he made it the seat of human reason and, on that sole basis, assigned humanity to a class of its own, which he dubbed Archencephala, or "ruling brain."

When Darwin heard about Owen's claims, he wondered, in the shorthand of a notebook, "what a Chimpanzee wd say to this." But Darwin left it to the biologist Thomas Henry Huxley, Owen's nemesis and a tireless defender of Darwinism, to publicly demolish the idea of Archencephala. (Not one to mince words, Huxley privately declared that Owen had built his classification like "a Corinthian portico in cow dung.") Huxley maintained that Owen had blatantly overlooked the presence of Owen's own "fold of humanity" in the chimpanzee brain. In fact, Huxley argued, a human differs much less from an ape, such as a chimpanzee or gorilla, than an ape does from a baboon.

Of 731 genes investigators checked in mice, all but fourteen had a human match. But does that mean we have a primordial taste for cheese?

Huxley had essentially one source of information on the evolution of people and apes: their living anatomy. Neanderthal fossils first attracted scientific attention in the 1860s, but it wasn't until after Huxley's death in 1895 that a steady stream of hominid fossils emerged. In contrast, today's paleoanthropologists count some twenty precursor species that were early relatives or direct ancestors of modern people. In fact, as recently as July 2001, investigators in Chad began to find fossil fragments of the oldest hominid precursor yet known, the six- to seven-million-year-old *Sahelanthropus tchadensis.* Many of these species display a mix of both humanlike and chimplike features, blurring the distinction between the two.

Huxley also had no way to compare the biochemistry, much less the genes, of people and chimpanzees. The first glimmerings of our biochemical bond with chimpanzees came at the dawn of the twentieth century. Biochemists figured out how to make antibodies tailored to recognize proteins that occur in human blood. They then tested the antibodies on proteins from other animals. It turned out that the antibodies for human proteins formed bonds with chimpanzee and gorilla proteins far more readily than with the proteins of other animals. That suggested that chimpanzee and gorilla proteins had a shape similar to that of human proteins. In the 1960s Morris Goodman, a geneticist at Wayne State University in Detroit, and his coworkers learned how to compare the building blocks of the proteins in humans and apes. They found that many proteins in people and chimpanzees appeared to be nearly identical.

By the 1980s scientists were able to switch their gaze from proteins to the genes that encode them. (Each gene serves as a template for making what can become many copies of a single kind of protein.) At first they could only make simple comparisons between chimpanzee and human DNA. They unzipped the twin strands of a human DNA fragment, then zipped each one back up with a strand of DNA from another animal. Workers measured the strength of the bonds by measuring the amount of heat needed to make the hybrid DNA fall apart. (The weakest bonds began to let go at about 60 degrees Celsius; the strongest ones held together at 90 degrees.) They reasoned that the more closely related the two species, the more stable the bonds between two strands of hybrid DNA. The experiments supported the idea that apes and people have highly similar DNA. And that general conclusion has been borne out by the revolution in DNA sequencing of the past decade.


Mark Tansey, *Nature's Ape*, 1984

But just how similar is "highly similar"? This past October Roy J. Britten, a geneticist at the California Institute of Technology, published a study asserting that estimates in the range of 98.7 percent are too high. Too much attention, he argues, has focused on mutations that change a single nucleotide in the genome. DNA also mutates when an entire stretch of the molecule gets copied and inserted somewhere else in the genome, or is simply deleted altogether. When Britten searched for these additional kinds of mutations, he concluded that the human and chimpanzee genomes are 95 percent identical, nearly quadrupling the previously estimated difference of 1.3 percent.

Britten has discovered a real shortcoming in previous estimates, but other biologists may still be reluctant to start adopting his figure. Most of the insertions and deletions Britten studied occur in long stretches of so-called junk DNA, which includes no functioning genes. The parts of the human genome that actually carry codes for our body's proteins are much more similar to the genes of chimpanzees. Britten's work also shows how tricky it is to describe our similarity to chimpanzees with a single number. Suppose a stretch of our DNA 6,000 base pairs long disappeared a million years ago. Britten would count that as 6,000 separate changes, yet other geneticists would count it as a single evolutionary event.

Even if ten years from now biologists can state the exact percentage of DNA we humans share with chimpanzees, the number by itself won't really mean very much. Our DNA most resembles that of chimpanzees, but we share a lot of DNA with other animals as well. Geneticists recently surveyed a chromosome in mice, looking for genes related to the ones in the human genome. Of the 731 genes they checked in the mice, all but fourteen had a human match. Yet no one would—or should—conclude on that basis that we have a primordial taste for cheese.

Putting a number on our genetic similarity isn't pointless, though. It helps biologists in their quest to pinpoint the genes, and the biochemistry those genes control, that make us truly human. The quest is a hard one because most of the mutations our ancestors acquired probably had no effect on human evolution at all. Most of the harmful mutations were weeded out over time, and many of the rest had no effect one way or another. Some of these harmless mutations may have spread thanks only to chance—a process known as neutral evolution (see my column "Tuning In," September 2001).

The only changes that really mattered were the ones that altered the proteins that were themselves responsible for changing the reproductive success of the people who inherited them. These mutations spread thanks to natural selection. But distinguishing neutral from selected changes has proved a tricky statistical challenge. On the basis of early results Derek E. Wildman, a biologist also working at Wayne State University, and his colleagues project that between 2,800 and 4,000 of our genes underwent substantial change after the human branch of the evolutionary tree split off from that of the chimpanzee.

A lot of those altered genes could well turn out to specialize in regulating other genes. Regulatory genes code for proteins that help switch on other genes or shut them off, thereby promoting or inhibiting the production of the proteins those other genes are responsible for. Hence a single regulatory gene can "leverage" its effects, and if a regulatory gene evolves into a different form, it could alter not only whether but also when and where various proteins are transcribed. Small genetic alterations can create an avalanche of changes in an animal's anatomy and way of life.

Svante Pääbo of the Max-Planck-Institute for Evolutionary Anthropology in Leipzig has uncovered the first solid evidence that our regulatory genes set us apart from chimpanzees. Pääbo and his coworkers surveyed the genes that are active in human and chimpanzee cells. They found that the cells in a human liver use many of the same genes that are active in the cells of chimp livers. But in the neurons of the brain, very different sets of genes become active in the two species.

Pääbo concluded that the livers of chimpanzees and people still work much the same way they did seven million years ago. Despite the similarity of the human and chimp genomes, however, evolution has created a big difference in the way genes work in our brains. That fits well with what we can see with our own eyes: in many ways people look a lot like other apes, but they have large, intricately wired brains that enable them to do things no other primate can do. Pääbo's group is now trying to figure out exactly how these genes function in the brain.

In spite of Wildman's estimates for thousands of altered human genes, geneticists have identified only a few of them. They barely understand what those few genes do, or how they do it differently from related genes in chimpanzees. One of these genes (called *CMAH*) codes for an enzyme that helps make a sugar that coats the surfaces of cells. More precisely, this sugar, known as Neu5Gc, coats cells in chimpanzees and other mammals studied so far, but not in humans. In us the gene that makes the enzyme is useless. At some point in hominid history a long stretch of junk DNA was substituted for part of the gene, rendering its code nonsensical. The useless version now occurs in every human being.

Ajit Varki, a biologist at the University of California, San Diego, who discovered this inactivated gene, teamed up with Pääbo and several other investigators to figure out exactly how long ago the gene shut down. They were able to extract a sugar from the fossils of Neanderthals that is closely related to Neu5Gc, but is not Neu5Gc itself, suggesting that Neanderthals also lacked a functioning *CMAH* gene. If that's true, the gene most likely shut down before our two lineages parted. Many leading experts now think the last common ancestor of Neanderthals and modern people lived at least 500,000—and perhaps as much as 800,000—years ago [see "Requiem for a Heavyweight," by Juan Luis Arsuaga, page 42]. If that's true, the gene must have shut down before then.

Varki, Pääbo, and their colleagues found two other ways to estimate the gene's shutdown date. Once the stretch of junk DNA precluded the action of the *CMAH* gene, the junk DNA picked up a few mutations in various groups of people. A lot of evidence suggests that such mutations pile up at a steady, clocklike rate. On that basis, the investigators estimated that the gene shut down about two million years ago.

The second estimate came from a comparison of the junk DNA in the human *CMAH* gene with related stretches of junk DNA present elsewhere in the genomes of chimpanzees and other apes. The differences in the stretches of junk DNA also suggested that the human gene became inactive two million years ago.

That date turns out to be fraught with significance in hominid history. Until then, hominids weren't all that different from chimpanzees. They were bipedal and lived in more open habitats than chimpanzees, but their brains were still small and they showed no ability to make sophisticated tools. Then, around two million years ago their brains began to expand, a process that continued, in fits and starts, until about 100,000 years ago. And when hominid brains began to expand, the first stone axes also began to become part of the archaeological record.

Varki and his colleagues suspect that losing Neu5Gc sugar may have had something to do with that change. In chimpanzees and other mammals, Neu5gc can be found on the surfaces of cells throughout the animals' bodies. But in the brains of the same animals, other genes slow down the production of Neu5Gc, so little is found on neurons. The biologists speculate that such inhibition evolved because Neu5Gc has some harmful, though unidentified side effect on brain cells. So our ancestors may have been lucky to lose the functioning of the *CMAH* gene two million years ago. The loss may have entailed some kind of disadvantage, but it enabled the evolution of the brain to proceed in unique ways.

Geneticists discovered that a single genetic mutation robs people of fine motor control of the mouth, and of their ability to understand some aspects of grammar.

A second gene that seems to have taken on a unique form in humans is a gene that may have been crucial for the evolution of language. Linguists think the advent of language depended on new genes for forming and controlling the vocal tract and for the abstract thought needed to string words together meaningfully. In 2001 a team of geneticists from the University of Oxford discovered that mutating a single nucleotide of a gene called *FOXP2* robs people of fine motor control of the mouth, and of their ability to understand some aspects of grammar.

The geneticists teamed up with Pääbo's group to study the evolution of the gene. Many mammals, they noted, have related versions of *FOXP2*, though no one knows what it does for them. But the investigators found that after the human lineage split from that of the chimpanzee, *FOXP2* underwent rapid evolution by natural selection. In fact, minor variations in the present-day forms of the gene point to its rapid evolution and subsequent spread throughout our species less than 200,000 years ago—just around the time when modern people emerged.

Human evolutionary genetics is an infant science. *FOXP2* and *CMAH* are only two out of thousands of genes that likely set human beings apart from chimpanzees. And biochemists have yet to understand how the two genes operate in either species—much less the workings of any other genes. Even with the growing sophistication of genomic technology, biologists are still, fundamentally, as confused about the differences between chimpanzees and people as Edward Tyson was 300 years ago. But the fact that science can begin to address such questions at the level of brain chemistry is cause for amazement; it gives us reason to hope that the confusion won't last forever.

Carl Zimmer's latest book, Evolution: The Triumph of an Idea, *is available in paperback from HarperCollins.*

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Requiem for a Heavyweight

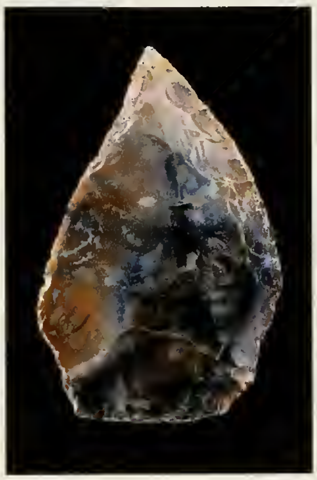
Superior strength and keen intelligence enabled Neanderthals to flourish for more than 200,000 years—until they faced unrelenting cold and minds even more cunning than their own.

By Juan Luis Arsuaga

It has sometimes been said that Neanderthals so closely resembled modern people that, dressed in contemporary clothing, they could have passed unrecognized on the New York City subway. I know from firsthand experience that this is not true. Not that I have ever run into a Neanderthal on the Madrid metro, which I frequent, much less in New York City, but I did take part in the reconstruction of a head based on a fossil of one of their close relatives. I can assure you that when those of us working on the head masked one of our colleagues with a copy of the reproduction, it had a big impact on us all. When a more primitive hominid is reconstructed—an australopithecine, for instance—the creature that appears before your eyes is somehow familiar, less startling. It reminds you of a chimpanzee, even if a nonexistent bipedal one. But there is no familiar equivalent to the Neanderthal, so similar to us, so human yet so different. To come across a Neanderthal, even a reconstructed one, is a thrilling experience. It was no doubt even more thrilling to our ancestors, who met them in the flesh.

The Neanderthals *(Homo neanderthalensis)*, based in Europe, and modern humans (*Homo sapiens*), originating in Africa, may first have laid eyes on each other in what is now Israel perhaps 100,000 years ago. To our ancestors, the Neanderthals must have appeared stocky, with broad trunks and relatively short forearms and shins. Their sloping foreheads and forward-projecting faces would have looked strange, and the heavy brow ridges that formed a continuous double arch above their eyes and nose gave them a proud and fierce profile, like the daunting visage of an eagle. The Neanderthals' habit of using their jaws as a "third hand" might have been noticed (patterns of tooth wear indicate such behavior). And their skin would have seemed unusually pale, an adaptation that would have enabled them to make vitamin D even in the relatively dim ultraviolet light available in the northern latitudes the Neanderthals called home.

For their part, our ancestors, though tall, were lighter-boned, with high foreheads that rose above minimal brow ridges and small faces. Among mammals, both a prominent forehead and a small, less protruding face are universal features of immature individuals—and, in some cases, of adult females—and they elicit feelings of protectiveness and tenderness that inhibit aggression. Our ancestors likely reminded the Neanderthals of their own children, and perhaps they even seemed a bit cuddly. The two species probably recognized their common humanity: they had brains of about the same size, and both made stone tools, used fire, and may have shared other abilities.



The family reunion in Israel was a long time coming. In 1994, at the Gran Dolina archaeological site near the city of Burgos in northern Spain, my colleagues and I discovered the remains of a species that may have been the last common ancestor leading to both hominid lines. The fossils we found—so far we have eighty fragments representing at least six individuals—are about 800,000 years old, the oldest known in Europe. Anatomically they appear more advanced than *Homo ergaster,* a hominid species that arose in Africa nearly two million years ago and later spread out of that continent eastward into Asia (where the species is known as *Homo erectus*). We have therefore named our distinctive fossil hominid *Homo antecessor* (Latin for "human forebear").

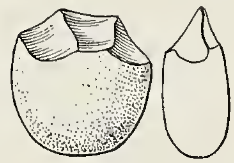
The Gran Dolina people apparently made relatively primitive stone tools: none of the tools associ-

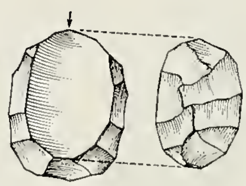
A 400,000-year-old skull from Spain's Sierra de Atapuerca, opposite page, belonged to a Neanderthal ancestor. Sima de los Huesos (the Bone Pit), where it was discovered, has yielded more remains of early hominids than any other single site. Left: A stone flake from northern France, possibly a spearpoint, exemplifies the "Mousterian" tool-making style associated with the Neanderthals.

Adapted from The Neanderthal's Necklace: In Search of the First Thinkers, *by Juan Luis Arsuaga, translated by Andy Klatt (New York: Four Walls Eight Windows, 2002). ©2001 by Juan Luis Arsuaga; translation ©2002 by Four Walls Eight Windows.*

ated with their remains include the bifacially chipped, symmetrical Acheulean "hand axes" already being manufactured in other parts of the world (named after an archaeological site near the town St. Acheul, in northern France). One remarkable feature of some of the fossils, though, is the presence of cut marks left by stone tools. Flesh was sliced from the bones, as if they had belonged to game animals captured for their meat. We interpret these marks as evidence of cannibalism. As we excavate more of this site, we may learn other surprising—and disturbing—things about *H. antecessor.*

Meanwhile, however, we have had our hands full with a site that came to light earlier: Sima de los Huesos (the Bone Pit). Situated less than half a mile from Gran Dolina, Sima stands out as the largest concentration of early human remains in the world. Deposited 400,000 years ago, the skeletons of at least twenty-eight individuals there are so well preserved that we are finding even the tiniest of their bones—the so-called hammer, anvil, and stirrup of the middle ear. What led to the accumulation of so many of their fossils at this one site makes for an intriguing detective story [*see "The Bone Pit," page 46*].



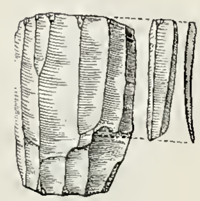


The evolution of stone tools: A chopping tool, upper left, was formed by removing several flakes of stone, whereas more work and a clearly envisioned pattern are evident in the creation of a bifacially symmetrical Acheulean "hand axe," upper right. To produce one Mousterian flake, lower left, the tool maker first shaped a stone "core." A more sophisticated kind of core, lower right, could yield numerous elongated blades.

Both sites lie within the hills of the Sierra de Atapuerca, a mass of limestone that rises 3,550 feet above sea level and overlooks an inland plateau. In prehistoric times the region would have been a hospitable setting, where people could have found shelter in caves eroded out of the karstic landscape. One can almost picture them standing on the hillsides, gazing down upon herds of herbivores grazing peacefully beside a lazy river on the plain below. The richness of the region for paleoanthropology first became apparent in 1976, when cavers came upon some of the fossils at Sima de los Huesos. It took six years to remove the tons of sediment that covered the fossil-bearing strata, and even now the excavations are only partly complete. Probes nearby revealed the Gran Dolina site, as well as others that remain to be explored.

I have hypothesized that the remains buried at Sima de los Huesos belong to descendants of our Gran Dolina hominids. By the time the descendants appeared, however, they had evolved to become a new species we call *Homo heidelbergensis,* whose earliest known fossil remnant (a mandible discovered near Heidelberg, Germany) is perhaps half a million years old. Members of *H. heidelbergensis* lived and evolved in Europe and were the "grandparents" of the Neanderthals, who succeeded them. Typical Neanderthal physical traits begin to be evident in fossils from at least 250,000 years ago, and are full-blown in those from 127,000 years ago.

The tool kit of *H. heidelbergensis* included the Acheulean hand axe, whereas by 250,000 years ago even more sophisticated tools are present, of the Mousterian type (named after Le Moustier, a rock-shelter in southwest France) [*see illustration at left*]. Mousterian toolmakers—Neanderthals are the prime examples—carefully trimmed a stone so that then they could strike off a flake of some useful shape. That two-step process, which required more planning than earlier methods, may have been mastered thanks to an increase in brain size.



Our own ancestors in Africa also began to make Mousterian tools (or their variants) at roughly the same time their own brains became larger. On the basis of these similar developments in the European and African hominid populations, as well as other evidence, some physical anthropologists argue that there must have been a continuous genetic exchange between the two populations, that they never became totally separate. But those who take this position are in a distinct minority. The weight of evidence is that the populations followed a parallel course biologically, though techniques of toolmaking could have been transmitted between the species. After the two species eventually came into close and steady contact in Europe, the Neanderthal population seems to have faded away without leaving any descendants.

In their heyday, between 127,000 and 40,000 years ago, the Neanderthals were quite successful, spreading out from Europe to populate the Middle East and southwest Asia. But then the first European representatives of modern humans, popularly known as Cro-Magnons, began to turn up. Two factors may account for the triumph of our ancestors.

First, they had developed a new tool kit that included various side scrapers, the burin (a chisel-like tool), and the awl, all made by modifying long thin flakes, or blades, of stone that had been struck off a prepared core [*see illustration on opposite page*]. With this lithic tool kit, the Cro-Magnons were able to manufacture points for hunting from materials such as antler, bone, and ivory. As the Belgian archaeologist Marcel Otte says, people turned the animals' own weapons, their horns and tusks, against them. Nevertheless, some Neanderthals—those who survived in relatively dense populations in close proximity to Cro-Magnons—were able to take up the new technology.

The second reason for the success of the Cro-Magnons was, paradoxically, the increasingly inhospitable climate. Although the most bitter glacial conditions had not yet descended on Europe 40,000 years ago, the center and north of the continent were cold. The irony here is that Neanderthals were biologically better adapted to the cold than Cro-Magnons were. But through language and other symbolic systems, the Cro-Magnons were able to make more effective cultural and ecological adaptations to the climate, and to form alliances among groups separated by great distances.

Those accomplishments of modern humans may have arisen through the sharing of stories and old myths that linked people with the natural world and with their common ancestors. Modern humans were also proud wearers of personal ornaments, whose use probably supported group organization and identification. As worsening environmental conditions reduced the human population in number and density, symbolic communication took on even greater importance. Finally, even the stable Mediterranean world was dramatically affected by climate change. Forests gave way to steppes and large herds of horses, soon to be followed by horse hunters: none other than our ancestors the storytellers.

800,000-year-old fossils of *Homo antecessor* include (top row) cranial fragments, (second row) toe and foot bones, (third row) jaw fragments and a radius, and (bottom row) teeth, a wrist bone, and a kneecap.

The difference in the ways Neanderthals and Cro-Magnons confronted the hostile climate is dramatically apparent if one looks east, to the Russian Plain. This vast, low-lying plain stretches from the Carpathian Mountains in the west to the Ural Mountains in the east and to the Arctic Ocean in the north. In the south, it ends at the Black Sea, the Caspian Sea, and the solid wall of the Caucasus Mountains that lies between the two. In the present warm period of the twenty-first century, the average January temperature at the center of this area, at 50 degrees north latitude, is 14 degrees Fahrenheit. It is by no means a hospitable place to spend a night in the open.

The first humans who dared to migrate into the Russian Plain were Neanderthals. The migration began about 120,000 years ago, in the interglacial period that preceded the last glaciation. They reached sites as far as 52 degrees north latitude. There is no doubt, then, that they were able to adapt to extreme conditions, and it is hard to deny that they must have possessed an extraordinary aptitude for organization and planning. Would human existence in such circumstances be possible without it? Nevertheless, the coming of the last glaciation forced a Neanderthal retreat to the south, where they took refuge on the Crimean peninsula and the northern slopes of the Caucasus Mountains. The last of them probably disappeared from the area between 25,000 and 30,000 years ago (that is when they disappeared from Iberia, the Spanish peninsula, where we have the best dates for late Neanderthals).

The Cro-Magnons, in contrast, succeeded in conquering the Russian Plain, apparently using bone awls and needles to make garments as warm as the ones of the modern Inuit. As the last ice age drew to a ferocious climax, the Cro-Magnons learned to build shelters framed with mammoth bones and covered with skins, and to keep their hearths burning continually within the shelters. When other fuels were scarce, they fed the fire with mammoth bones. When the cold was at its fiercest,

The Bone Pit

Discovered in 1976, Sima de los Huesos (the Bone Pit) is a crevice packed with the well-preserved fossils of people who perished 400,000 years ago. Apparently their comrades sought a secluded spot in which to deposit the bodies of the deceased and so shield them from the depredations of carrion eaters. In the cave-riddled hillsides of what is now called Sierra de Atapuerca, they found a narrow entrance leading into a spacious, unlit chamber, never occupied by people, though bears had hibernated there. In one corner not far from the entrance, there was a mysterious vertical shaft almost forty-six feet deep, the bottom invisible from above. Here they let the bodies drop, in what is the earliest known case of human funerary activity.

The bones, which I believe belong to the species *Homo heidelbergensis,* are piled one on top of the other, so my colleagues and I are proceeding carefully with the excavation. For now, the best way to identify individuals from among the many sets of remains is by their teeth. José María Bermúdez de Castro of the National Museum of Natural Sciences in Madrid (one of the three directors of the Atapuerca Project, along with Eudald Carbonell of the Universitat Rovira i Virgili in Tarragona, Spain, and me) has identified at least twenty-eight individuals. Perhaps a particular human group that moved around a great deal took occasional shelter in the caves. When a member of the group died near the cave, the body was carried to the hidden niche and deposited there. Such a burial tradition could have been maintained for generations, with the pit gradually becoming home to an impressive collection of human skeletons.

But there is also the intriguing possibility that all the people whose remains were deposited at Sima de los Huesos died together, or at least within a short period of time. Jean-Pierre Bocquet-Appel, a paleodemographer at the Museum of Man in Paris, has proposed a conceptually simple test: identify the dead by their teeth, and tally only the individuals between age five and age twenty-four. In known populations without access to modern medicine, there are about as many living people between the ages of five and fifteen as there are between fifteen and twenty-four. Nevertheless, in the cemeteries of the same communities, which reflect mortality by age, the younger group is more than two times as populous as the older.

At Sima de los Huesos, it turns out that the proportion of dead in the targeted age groups closely matches a living population, suggesting that death struck catastrophically across a community. An epidemic is one possibility that immediately comes to mind, but large-scale epidemics were unlikely in prehistoric times, because the human population was too small and dispersed for the quick spread of pathogens. Bocquet-Appel and I imagine instead an ecological crisis, such as a protracted drought or a succession of severe winters.

Human groups do not wait passively for such crises to pass. They take off in search of better circumstances. Perhaps one such struggling group sought relief in the Sierra de Atapuerca, usually a resource-rich locale. Some—the aged, the sick, the disabled—fell by the wayside. Once they arrived, the suffering may have continued, or perhaps they arrived in such a debilitated state that they just did not last much longer. In either case, many more died. The survivors deposited the bodies in the cave, where they remained until rediscovered by cavers, 4,000 centuries later. —J.L.A.

Skeleton **known as Kebara 2** was unearthed from an Israeli cave. It is the most complete skeleton of a Neanderthal ever found, despite the missing skull, legs, and feet.

beginning 25,000 years ago, modern human beings were prepared to survive the desolation of what must have been a terrifying northern world.

Meanwhile, by 32,000 years ago, modern people had occupied almost the entire European continent. Spectacular examples of their symbolic expression are preserved in what is called Paleolithic art—from painted friezes in Chauvet Cave in southeastern France to animal statuettes of ivory in Vogelherd Cave in Germany. Perhaps the most surprising of all is a half-human, half-lion ivory figurine unearthed in Hohlenstein-Stadel, Germany.

By this time the Neanderthals had lost a lot of their former territory, though they still occupied the entire Iberian Peninsula, except for a band across the far north. The Portuguese archaeologist João Zilhão of the University of Lisbon calls the geographical boundary between Cro-Magnons and Neanderthals in northern Iberia the Ebro Frontier, after the Ebro River. In general terms, that boundary also fell between two large biogeographical regions: the green "Euro-Siberian" part of northern Iberia and the drier Mediterranean Iberia. According to Zilhão, that is no coincidence. The Cro-Magnons came to Iberia from the northern ecosystems of the Euro-Siberian world—misty forests filled with red deer, roe deer, and boar; steppes where great herds of horses, reindeer, mammoths, woolly rhinoceroses, saiga antelope, and musk oxen grazed. Their forests and grasslands were home to aurochs and bison; chamois and goats inhabited the rocky heights.

In contrast, the Neanderthals stuck close to their evergreen forests of holm oak and cork oak, without arctic fauna and perhaps without bison. Their ecological equilibrium was upset when the wave of cold blowing over Europe penetrated deep into the confines of Iberia, drastically affecting the Mediterranean ecosystems and effectively destroying the world of the last Iberian Neanderthals. While the Cro-Magnon people of the steppes swept down into southern Europe in the wake of this climate change, the last Neanderthals probably retreated to milder lowlands near the sea.

This reconstruction of the end of the Neanderthals is appealing because it links human events to the natural environment. But there is an enormous paradox to accommodate: why were the Neanderthals, a group of human beings who had evolved and adapted to the cold on a continent far from the equator, replaced by other people, more recently arrived from tropical Africa? In answering this question, many paleoanthropologists attach considerable importance to the fact that the Neanderthals, for the most part, did not use personal ornamentation (the exceptions apparently arose when Neanderthals imitated the Cro-Magnons, just as they imitated Cro-Magnon stone-working techniques). Not that scholars think that ornamentation itself offered some great advantage in combatting a harsh environment; but rather they see it as a sign of a different mentality.

Even the hyoid bone, shown above the mandible, at right, was preserved in the Kebara 2 skeleton. The bone, situated at the base of the tongue, appears modern, suggesting to some scholars that Neanderthals had the capacity for speech.

One possible hypothesis is that ornamentation was not meaningful to the Neanderthals because they had not attained the intellectual capacity to capture the symbolism behind it. In this view, their brains had developed to favor "natural" intelligence, a kind of "instinctive intuition." Although that served them well in hunting and other cooperative enterprises, it could not match the Cro-Magnon facility for abstraction or symbolic communication. (Or to put it another way, compared with Cro-Magnons, Neanderthals were deep-seated realists, not so carried away by their imaginations.)

A second hypothesis is that the Neanderthals did have a fully modern capacity for language and for the use of symbolic communication, through objects and otherwise, but became extinct before having the chance to develop those capacities to the extent that our ancestors did. In my view, the truth lies somewhere between the two hypotheses.

Some paleontologists wonder why our species, thought to have originated between 150,000 and 200,000 years ago, took so long to reach Europe and eclipse the resident humans (or near-humans, according to this school of thought). One proposed answer is that though early modern humans were anatomically, or at least skeletally, modern, a few of their neuronal circuits had yet to be fully connected. Until those circuits were completed, they lacked the creative consciousness possessed by fully developed Cro-Magnons.

I do not see it that way. I believe the less robust physique of *H. sapiens* was closely related to the emergence of our species' capacity for articulated language. The first modern humans in Africa were surrounded by other populations as robust as the Neanderthals, but modern people followed a different strategy to solve the same ecological problems. They developed a brain specialized for the manipulation of symbols, a less protuberant face that was part of a magnificent articulatory instrument, and a body less powerful when suddenly called on to exert concentrated force, but more energy-efficient in the long run and so better suited to extended migration. In sum, modern humans were completely modern from the beginning—and could readily have melted into a modern subway crowd.

So what enabled Neanderthals to hold on as long as they did? My answer is that—in addition to being stronger and better adapted to the European environment—they were humans too, and highly intelligent ones at that. Our hypertrophic capacity for symbolic communication and linguistic articulation is useful for telling stories, but that would not necessarily have given us a decisive advantage.

From the point of view of history with a capital *H,* however, there is little anthropological question about what happened. The Neanderthals were replaced by modern humans. There may have been some genetic mixing, but not enough for any Neanderthal genes to reach us. It would thrill me more than anything if I could say that I had even a drop of Neanderthal blood to connect me with those powerful Europeans of long ago. But I am afraid my relationship with them is strictly sentimental. □

Dry, Dry Again

To survive in its desert home, the tortoise of the American Southwest must tolerate immense swings in its body chemistry.

By Kenneth A. Nagy

A desert tortoise *(Gopherus agassizii)* pauses after taking a drink from a shallow pothole. In the Mohave Desert even a patch of moist sand is a bonanza.

Life is tough in the desert. Temperatures can be blisteringly high or chillingly low, sometimes both in a single day. Rains are infrequent and often too fleeting or, paradoxically, too hard to be of much benefit to the organisms living there. Finding enough food year-round in a dry climate can also be a tricky business. Some arid regions, such as the central portion of Chile's Atacama Desert, are so inhospitable they are essentially barren, with no known plants or animals in thousands of square miles. Yet some deserts can be surprisingly rich and diverse in life. Among the latter are the Mojave and Sonoran Deserts of southwestern North America, where I have spent a good part of the past thirty-five years studying how native wildlife survives and even prospers.

Animals that persist in such arid regions do so largely because they are able to maintain a constant internal environment in the face of harsh and changing external conditions. In most vertebrates, when body temperature, water and salt concentrations, or a host of other factors stray from their optimum levels, regulatory mechanisms kick in to reestablish internal equilibrium. The cells of many mammals, for instance, live in a water-based solution that must be kept at relatively unvarying conditions of temperature, pH, and osmotic pressure with respect to the surrounding environment. The cell's internal chemical stability is maintained despite changing rates of nutrient input and waste output, as well as changing concentrations of dissolved minerals in the fluid surrounding the cell. This complex internal balancing act gets repeated above the cellular level as well, because tissues and organs, too, can function efficiently only within a narrow range of conditions. The general process of maintaining equilibrium in the body is called homeostasis.

Among vertebrates, mammals and birds are the masters of homeostasis. They are endotherms, or warm-blooded animals, generating their own body heat, and they can finely tune the thermal, water, and chemical balance of their bodies from minute to minute. That fine-tuning, and the self-containment it makes possible, has enabled mammals and birds to occupy many of the habitats on Earth, including deserts.

Reptiles, in contrast, tend to respond more slowly to environmental changes than endotherms do, and their physiological adjustments are less precise. As ectotherms, or cold-blooded animals, most desert reptiles control their body temperature, for instance, by basking on a sun-warmed rock in the morning and seeking shade at noon. The method is energy-efficient, but it also affords less exact and less continuous control over temperature than does the internal furnace of mammals.

But most reptiles don't really "go with the flow" and allow their body composition to change when their surroundings vary. They maintain chemical homeostasis nearly as well as birds and mammals do. That, of course, consumes resources, and suggests that even in a resource-poor environment such as

the desert, internal stability is well worth the relatively expensive homeostatic lifestyle. Yet life is always on the lookout for an open niche; it would be surprising indeed if every form of vertebrate life showed blind devotion to the homeostatic dogma. Two species of reptile—the ornate dragon, a lizard of western Australian deserts, and *Gopherus agassizii,* the desert tortoise of the Mojave—are known to tolerate wide swings in their internal biochemistry. And the desert tortoise stands alone in appearing, at times, to abandon homeostasis altogether.

The desert tortoise begins the year in a state of hibernation, "sleeping" from roughly November through February in a slanting burrow dug three to six feet deep in sandy soil. The burrow provides the tortoise with a relatively humid and cool, but not freezing, microhabitat during winter. A hibernating tortoise burns little energy from its store of fat, and the humid air in the burrow keeps the animal from dehydrating.

In decades of fieldwork, my students and I have followed more than a hundred tortoises—some for

At the entrance of its burrow, a desert tortoise peers out at a dry, brown world. The burrows, which are from three to six feet deep, serve as hibernation chambers for the tortoises in winter and as cool retreats in summer.

as long as five years—at four study sites across the Mojave Desert. By tagging individuals with miniature radio transmitters, we discovered that the tortoises often hibernate in the same burrow over several years. We also determined that most tortoises weigh roughly as much after hibernation as they did when they entered their burrows the preceding fall—about six and a half pounds for an average middle-aged (thirty- to forty-year-old) adult. Their constant weight attests to their amazing ability to conserve both water and energy over the winter—a key factor in their survival.

Imagine now that you are a vegetarian tortoise in the Mojave Desert, and you have to depend solely on the plants around you (mostly the annuals) for all of your nutritional needs, including water. The Mojave is green only every other year or so, when enough winter rain has fallen. Even then, new plant growth lasts only from February to mid-May. During long dry periods nothing grows for two or even three years, and the desert becomes dry and brown. In such conditions, your survival depends on having a "relaxed" homeostasis—in this case, a high tolerance for nutritional stress. My students and I have often been surprised to find tortoises active even when no green food is available.

In March, rousing yourself from hibernation, you emerge from your burrow and begin to eat. If the winter rains have been kind, your menu can include desert dandelion, evening primrose, bristly langlosia, and other succulent young wildflowers. Such a diet is easy to digest, and it provides you with more than enough protein, water, and minerals to meet your immediate needs. But rather than excreting the excess in urine, as would most other animals, you retain it. That water, which can be reabsorbed as needed through your bladder wall, will carry you through the inevitable dry periods later in the year. When your internal "canteen" is full, it makes up as much as 30 percent of your total body weight.

In good—that is, rainy—springs you gain weight, but at the same time you may be slowly losing body fat. Succulent greens can contain so much water that a stomach full of food holds fewer calories than you burn while moving around the desert. Even when the spring desert is a flower garden, it's more important to store extra water and protein for the stresses ahead than to sustain perfect nutritional balance. You simply make up for the energy deficit by burning stored fat.

The green season, if it has come at all, lasts only until mid-May, and by June the desert plants have mostly wilted and died. For a while, you continue to devour the dry grasses, but you also retreat more often into your burrow to escape the heat and dryness. By this time, the extra water you gained in the spring has been lost through defecation and respiration. But you still don't empty your bladder, and the concentrations of dissolved mineral salts (mainly potassium, sodium, and chloride ions) absorbed from your food are building up in the scant

As If the Desert Weren't Stress Enough . . .

In 1990, as desert tortoise populations began to decline catastrophically at some sites, the species was listed as "threatened" in the Mojave and western Sonoran Deserts. Yet despite that protection, recent observations and censuses show that the remaining populations are continuing to fall. Today desert tortoises in southern California must contend with even more than drought and disease.

Predation is on the rise—notably by ravens, coyotes, feral dogs, and other desert predators that are drawn to the water, food, and garbage that are plentiful near human habitations. Poachers also prey on the tortoises, and highway crossings pose ever-increasing risks. The desert habitat of the tortoise is crisscrossed by off-road vehicles, turned into pasture for cows and sheep, and lost to wildfires. Entire populations of tortoises have been bulldozed away, together with their habitat, to make room for suburban backyards and golf courses.

Kristin H. Berry of the Western Ecological Center of the U.S. Geological Survey in Riverside, California, is leading a team of veterinarians, biologists, and conservationists in an effort to understand the causes of disease and death in wild tortoises. Their goals, for now, are to keep the "threatened" status of the tortoise from worsening to "endangered." —K.N.

liquid that is not reabsorbed by your body. Unlike marine turtles and many desert lizards, you have no specialized glands that help you get rid of extra salts. So your "canteen" becomes packed with excess salts and waste uric acid and urea, but holds relatively little water.

If you continue to lose water—but not salts or other dissolved substances—by respiratory evaporation, and if the osmotic concentration of salts and other wastes in your urine reaches the osmotic concentration in your blood, the concentrations in your blood and urine will begin to increase together. By the time the full-blown summer drought hits, you are spending nearly all your time underground, dropping any pretensions to maintaining osmotic homeostasis. All you can do is hunker down in your burrow, enduring internal concentrations of chemicals well beyond those that would kill any mammal or bird and nearly all other reptiles.

In a drought all a tortoise can do is hunker down underground, storing internal concentrations of chemicals that would kill most other creatures.

How do we know all this? One of the goals of our research is to account for all the water the tortoise obtains, uses, and retains. The basic technique is to label the tortoise's body water by injecting it with "heavy" water, which is made up chemically of heavy isotopes of hydrogen or oxygen. Heavy water acts like ordinary water to the tortoise, but for us it tags any water it mixes with and tells us the volume of water in the animal by the principle of dilution. When we recapture the tortoise weeks or months later, we measure the rate of isotope loss from its body water over time, which tells us its rate of water gain and rate of water loss. Charles C. Peterson, a physiologist at the College of New Jersey in Ewing, and others have found that dehydrated desert tortoises can survive with osmotic concentrations in their blood as much as 200 percent greater than those of well-watered tortoises. People and many other mammals are in trouble if dehydration raises blood osmotic concentration by as little as 8 percent. Even desert camels can tolerate only an increase of 40 percent.

If the summer and fall remain dry, tortoises stay in their burrows and go directly into hibernation in October, without having eaten any food since early summer. If it rains, however, they rouse themselves and emerge en masse to drink copiously and replenish their "canteens." No one knows how tortoises, while still in their burrows, realize that it is about to rain. Philip A. Medica, a biologist at the U.S. Fish and Wildlife Service in Las Vegas, observed some tortoises emerge from their burrows as a summer thunderstorm approached. The tortoises scraped out shallow depressions in the soil, which caught the rain. Then more tortoises emerged, put their faces into the puddles, and sucked the water in through their noses and mouths for long periods.

If the tortoises get a chance to drink their fill before the onset of winter's hibernation, they will finally discharge the old urine they have been holding since the preceding winter or spring. Then they drink some more. In a day or two their osmotic

Taking a bite out of the desert floor, a tortoise ingests gravel. A fairly common habit, gravel eating may help alleviate mineral shortages.

Thunderstorms quickly draw tortoises out of their burrows. After a rain, the tortoise shown in the sequence of photographs above negotiated boulders to reach a small pool, then plunged in and drank tortoise-style, through its nose.

concentrations are back to normal, their bladders are full of clear, dilute urine, and they resume feeding, mainly on dry grasses left over from spring.

When the weather is dry, the tortoises can take in extra calories and build up fat deposits rapidly. Because they consume so much more plant matter per stomachful of food on the dry diet of summer and fall than they do on the wet spring diet, the tortoises can store more energy than they burn. But there is a downside. Dry grasses contain salts but little protein or water, and so once again the tortoises' chemistry falls out of balance.

To tolerate all the chemical seesawing in the course of a year, tortoises orchestrate a distinct brand of chemical management. They do not balance their nutrient budgets day to day, as endotherms do, or even week to week; their schedule is an annual one. But if no rains fall during the warm seasons and the tortoises don't get a chance to drink, they will enter hibernation dehydrated, malnourished, and with a bladder full of toxic waste. Some tortoises may perish in hibernation after a dry year, and multiyear droughts can be particularly deadly. During a prolonged dry spell at one of Peterson's study sites, many tortoises died, apparently from lack of food and water.

In spite of near-constant challenges to their survival, tortoises must nonetheless attend to the task of perpetuating the species. Males, always interested in sex, court females throughout the spring and summer. (Although desert tortoises usually hibernate alone, a male may try to "body block" a female into a burrow for the winter, thereby gaining exclusive access to her when it's time to emerge for spring breeding.) Males contribute only sperm, which is easy to produce. Females, however, must generate much more organic material in the form of eggs, and that requires more resources.

In good, wet years females may have little difficulty finding food that provides them with enough water, energy, and protein to produce eggs. In May or June they normally lay about seven eggs, which are deposited in shallow holes dug just inside the burrows. Even in lean years, though, many females still manage to lay three or four eggs, as Brian T. Henen, a physiologist at the University of the Western Cape in Cape Town, South Africa, has discovered. Thus, instead of skipping reproduction for a year, as some other desert reptiles and birds do, female tortoises sacrifice their own body stores of proteins, fats, and water—the very materials on which their own survival may depend—to reproduce.

How might such a seemingly unfavorable reproductive option have evolved? One possible explanation is that natural selection has favored the descendants of female tortoises that hedged their bets. Producing eggs takes time, and so female tortoises must begin the reproductive sequence of events for the year in the early spring. Yet if the offspring are to survive, the eggs need somewhat moist sand in summer, and the young need green food and perhaps a drink of water in the fall, before they enter their first hibernation. But the vagaries of the desert climate make it impossible to predict when rains will occur. The females can't know in early spring whether or not the energy they spend in reproduction is likely to pay off in surviving babies. So they risk their own well-being every year on the

gamble that rain will soon come, and that their hatchlings will emerge from the burrows into conditions conducive to feeding and growth.

Once she lays and buries her eggs, the female desert tortoise is finished with her parental role. She has, however, provisioned each egg with a grubstake: a substantial amount of nourishing yolk, which, soon after the egg hatches, is safely enclosed in the baby's gut. The energy and water in the yolk lasts for weeks, giving the hatchling time to stray from the nest site, find or dig a burrow, and locate sources of food.

Recently a team of investigators led by David Morafka, a biologist at the California Academy of Sciences in San Francisco, found that young desert tortoises are much more vulnerable than adults to dehydration, starvation, and predation. The shells of hatchlings and juveniles stay soft until they reach six or seven years of age. While desert predators, particularly ravens and coyotes, can't do much damage to adults, they can easily penetrate the shells of young tortoises.

Although relaxed homeostasis enables adult desert tortoises to make it through tough times, nutritional stress is a nearly constant feature of their lives. Exactly what effects that stress may have on tortoises is not known, but in vertebrates, stress of any kind generally triggers the release of the stress hormones corticosterone and cortisone. Prolonged high levels of those hormones can reduce the effectiveness of the immune system, thereby allowing infections or diseases to become established.

Whatever the mechanism, stress combined with disease has proved to be deadly for tortoises. In the late 1980s and early 1990s in the western Mojave, desert tortoise populations crashed [*see sidebar on page 52*]. Elliott R. Jacobson, a veterinarian and zoologist at the University of Florida in Gainesville, and his colleagues discovered that a respiratory disease caused by *Mycoplasma* microbes was spreading rapidly in wild tortoises that were already weakened by drought. The benefit of relaxed homeostasis—having a better chance of surviving drought—comes at the cost of greater susceptibility to disease. In the modern world of disease microorganisms that spread by jet plane, that cost may be a high one.

Tortoises and turtles are the descendants of an ancient lineage, well known for their keen survival skills. However precarious their lives in the desert, tortoises have persisted for millennia by adapting their biochemistry in unusual but effective ways. But those techniques could soon become a lost art. Today there may be fewer desert tortoises in the Mojave Desert than there are living as captive pets in the backyards of Los Angeles County. Our ongoing efforts to understand how tortoises live in the wild can help ensure that after conquering the desert, they will still be able to survive without being relegated to captivity in suburbia. □

In the full desert heat, tortoises rarely leave their burrows. But if it rains, they emerge en masse to replenish their "canteens."

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Dodging Mass

All around, species were dying off. But in

Extinction

this Devonian reef, life went on. Why?

By Rachel Wood

Windjana Gorge, during northwestern Australia's dry winter, is a magical place. An inconspicuous cleft within steep red cliffs marks its entrance; the cliffs themselves rise abruptly from a wide, dry plain, dotted with ancient boab trees. But who, upon entering the lush gorge, could remember the barren landscape just left behind? In deep ponds—the seasonal remains of the mighty Lennard River that floods the gorge during the wet season—swim freshwater crocodiles. In the surrounding trees cockatoos chatter. Farther into the depths, the gorge widens; here, in the heat of the day, large colonies of fruit bats fidget in the eucalyptus trees, and an occasional wallaby bounces across the trail.

But Windjana Gorge is remarkable not only for its living natural history. The steep limestone cliffs also record in their sediments one of the most fascinating events in the history of life on Earth: a mass extinction of reef species that took place some 370 million years ago, at the end of the Devonian Period. Even more, the limestone bears silent witness to the subsequent recovery of an entire marine ecosystem of the time.

Mass extinctions are extraordinary natural phenomena that have surged to the fore of scientific and popular attention in the past two decades, though paleontologists have recognized their existence for more than a century. In part, that attention is propelled by the idea that a collision of a giant meteorite with the Earth wiped out the dinosaurs at the end of the Cretaceous Period, some 65 million years ago. Even more compelling, both the threat of nuclear war and the ongoing loss of biodiversity have raised the possibility of mass extinctions in a contemporary context. But even before the demise of the dinosaurs, the Earth had undergone no fewer than four such events.

In mass extinctions, some species that make up a community often disappear immediately; a variety of ecological effects then cascade through what remains. Yet despite the special status that evolutionary biologists now assign to mass extinctions, there is little consensus about the scope and intensity of those cascading effects. How rapidly do they unfold? To what degree can they remodel ecosystems? How important a role have they played in shaping the history of life? To help explicate the answers biologists have proposed, I have spent the past few years

The Lennard River cuts through northwestern Australia's Kimberly Plateau. The 200-foot cliffs left by the cut expose the remains of a great barrier reef from the continent's ancient past, and clues to a massive extinction some 370 million years ago.

Some fossils at Windjana Gorge date from the Frasnian stage, before the Devonian mass extinction forever changed the communities that make up fossil reefs. (Upper image): Sticklike stromatoporoids (short white veins) of the genus *Stachyodes*, encrusted in calcified cyanobacteria. (Lower image): Central part of a twenty-one-foot-wide stromatoporoid. An important member of Frasnian reef communities, it became extinct at the end of the Frasnian.

studying the details of the Devonian catastrophe recorded at Windjana Gorge. Surprisingly, the evidence I have uncovered suggests a less calamitous, more encouraging outcome to at least one aspect of these ecological disasters: after the Devonian extinctions, species diversity recovered much more rapidly than evolutionary biologists had thought possible.

The Devonian world offers little that we can recognize in our own. Atmospheric levels of carbon dioxide, a greenhouse gas, were between twelve and twenty times higher than they are today; as a consequence, tropical seas were considerably warmer. Tropical forests had just begun to establish themselves, and mammals, reptiles, and birds had not yet made their appearance.

Reef communities were also quite different. Modern corals had not yet evolved, and two now-extinct groups, known as tabulates and rugosans, flourished in the reefs. Sponges, particularly the now-rare stromatoporoids, were not at all like most of their modern counterparts; they possessed a solid skeleton made of calcium carbonate, rather like that of corals (most sponges now rely on silicates). The ancient sponges provided much of the backbone of the undersea reef structures. Algae-like microbial communities were also of far greater importance than they are in modern reefs. Such microorganisms could trap sediments and precipitate limestone, and though they rarely fossilized, they did leave characteristic freestanding mounds and columns, built on the seafloor.

The catastrophe of the Late Devonian was roughly equivalent in magnitude to the event at the end of the Cretaceous that killed the dinosaurs. At least 57 percent of all species eventually perished as a result. But the fossil record shows that the extinction rate was particularly severe in the tropics—especially within reef communities such as the one at Windjana Gorge. Before the extinctions, reefs grew virtually wherever there were warm, shallow seas that fringed large continental landmasses; worldwide, they covered an area of some two million square miles. After the extinctions, that area shrank to what was probably a fifth to a tenth of its former size. Paleontologists find remains of reefs that grew after the extinction event only in rocks from what are now Canada, northeastern Russia, the northern Caspian Sea region, and the Canning Basin of northwestern Australia. In most regions the reefs simply perished.

To understand what causes mass extinctions, paleontologists and geologists must unravel the clues embedded in sedimentary rocks and in the fossil record the rocks contain. Initial analyses, which simply plotted the number of species against their age, suggested that most extinctions took place between the Frasnian and Famennian stages, at the end of the Devonian Period (stages are subdivisions of periods of geological time). In some parts of the world, layers of black shales, rich in organic matter, mark this interval, and investigators thought that such distinctive sediments might yield some indication of what caused the global disruption.

At the time represented by the Frasnian–Famennian boundary, sea levels began to fluctuate rapidly up and down by as much as 300 feet; the cycles of rise and fall were at least as rapid as any of the oscillations predicted for the next few decades of the twenty-first century as a result of global warming. The fluctuations intermittently exposed large regions of continental shelf, then plunged the regions back under the sea. There is no known phenomenon on Earth today that would explain them, but whatever their cause, oceanographers reckon that the result could have been upwellings of cold, oxygen-poor, nutrient-rich waters from the ocean depths onto shallow marine shelves. The upwellings would have led not only to the development of distinctive sediments deposited in these shallows (such as the black shales of the Late Devonian) but also, and more importantly, to the asphyxiation (and extinction) of much tropical marine life.

More recent analyses, however, based on more accurate global counts of species, suggest that extinctions took place most rapidly just *after* the deposition of the black shales. That finding has led to a quite different, and perhaps more compelling, explanation for the die-offs. Toward the end of the Middle Devonian, the concentration of carbon dioxide in the atmosphere dropped precipitously—possibly the greatest decline in atmospheric carbon dioxide at any time in the past 550 million years. That decline caused an equally dramatic drop in global temperatures. So, many scientists now think that a uniquely deep and rapid global cooling event may have triggered the Late Devonian extinctions. The cooling, together with global regressions of the sea, a shift in the weathering of rocks, the rise of tropical rainforests, and the consequent accumulation of substantial amounts of soil, points to a time of massive global disruption.

The fossil record agrees with this scenario. Warm, shallow-water corals—the tabulates and the rugosans—perished, but those living in cooler, deeper waters seem to have survived. Reef-forming algae apparently emerged from the environmental changes nearly unscathed; the simple communities they formed may have been tolerant of stressful conditions. And most persuasively, sponges and brachiopods that preferred cold waters proliferated throughout the time of the most rapid extinctions.

Few places on Earth can match the Canning Basin in northwestern Australia for its continuous record of reef succession in the Frasnian and Famennian stages of the Devonian. The Canning Basin is a limestone outcrop nearly 220 miles long and as much as thirty-one miles wide; Windjana Gorge cuts through the northern part of the outcrop. Much of our knowledge about the geology and evolution of these reefs comes from the classic work of Phillip Playford of the Geological Survey of Western Australia, together with many international collaborators. Playford and his colleagues discovered that the large reef exposure at Canning Basin is a remnant of a much larger belt of reef complexes that once extended some 630 miles farther to the north. They also established that the reef complexes developed in shallow, tropical seas on the flanks of a trough that was bounded by faults, and that the Canning Basin rocks record almost 15 million years of continuous reef building.

The gorge cliffs display a classic section of limestone sediments that include the remains of a fringing reef. The reef itself created a wave-resistant margin; sediments bearing corals and stromatoporoids formed "behind" it—that is, facing inland from an ancient ocean. "In front" of it a steep slope developed, plunging into the ancient ocean basin. Toward the western end of the gorge the exposed rocks are progressively younger, passing from the pre-extinction Frasnian community to the post-extinction Famennian. Yet these sediments lack the obvious changes that other sediments show from the same epoch. None of the black, low-oxygen shales so common at other sites are present in Windjana Gorge, indicating that the marine environments in this ancient precursor of northwestern Australia might have simply been too shallow for low-oxygen bottom waters to have reached them.

Until recently geologists and paleontologists had agreed not only that reef communities are more susceptible to mass extinctions than are other ecological communities, but that they recover more slowly, too. It was thought that the high biodiversity of reef communities and their complex ecological interactions would substantially delay their return to the fossil record—perhaps by as much as two million to ten million years. Thus when I began to explore the cliffs of Windjana Gorge, I expected to find that in the few areas where reef building persisted into the postextinction, Famennian stage, the reefs would appear only as low-diversity, remnant communities, dominated by a few species of limestone-depositing algae.

But close scrutiny of the fossils has revealed quite a different story. There are indeed radical differences between the pre- and postextinction reef communities, but not the ones I expected. Communities of microorganisms and stromatoporoid

Postextinction reefs were different but not simpler; the players changed, but the game remained the same.

Rugose corals of the Devonian Period make obvious the group's affinity with free-swimming animals living today, such as jellyfish. Corals similar to the ones pictured in this diorama, representing the reefs of what is now north-central Texas, were present in the Australian reef.

sponges dominated the earlier, Frasnian reefs. Extensive mounds and columns of microbial limestone were deposited, some as high as eighteen inches and often encrusted with stromatoporoids. Other calcium-depositing microorganisms also inhabited the reefs, particularly in areas sheltered by overhangs and in small cavities within the framework of the reef. A tremendously diverse range of unusual growth forms arose among stromatoporoid sponges, ranging from thickets of small, branching individuals to remarkably large and spectacular domes, columns, and giant, flowerlike whorls as much as twenty-one feet in diameter. Many of the sponges grew in ways reminiscent of the living corals that form reefs today.

In the remains from postextinction Famennian times, instead, dramatically different reef communities appear—but not the simple, low-diversity communities paleontologists formerly expected. The stromatoporoid sponges have almost totally

disappeared, and a variety of diverse microorganisms have taken their place. These communities were present in the earlier, Frasnian reefs, but here they formed strange new platelike structures of flaky layers that grew tall and wide in complex tiered configurations. As they had in the Frasnian communities, some microorganisms grew in the sheltered areas between the huge platy growths.

A snorkeler exploring the Famennian reef slope would also have found clusters of tubular and vase-shaped sponges encrusting the exposed surfaces of the structure, and a rich, hidden biota thriving on the protected undersides. Even the smallest mud-filled cavities of the reef harbored abundant life, such as the tiny, shelled arthropods known as ostracodes. In fact, the postextinction reefs hosted a remarkably diverse fauna, including twenty species of sponges as well as many species of brachiopods, bryozoans, and crinoids.

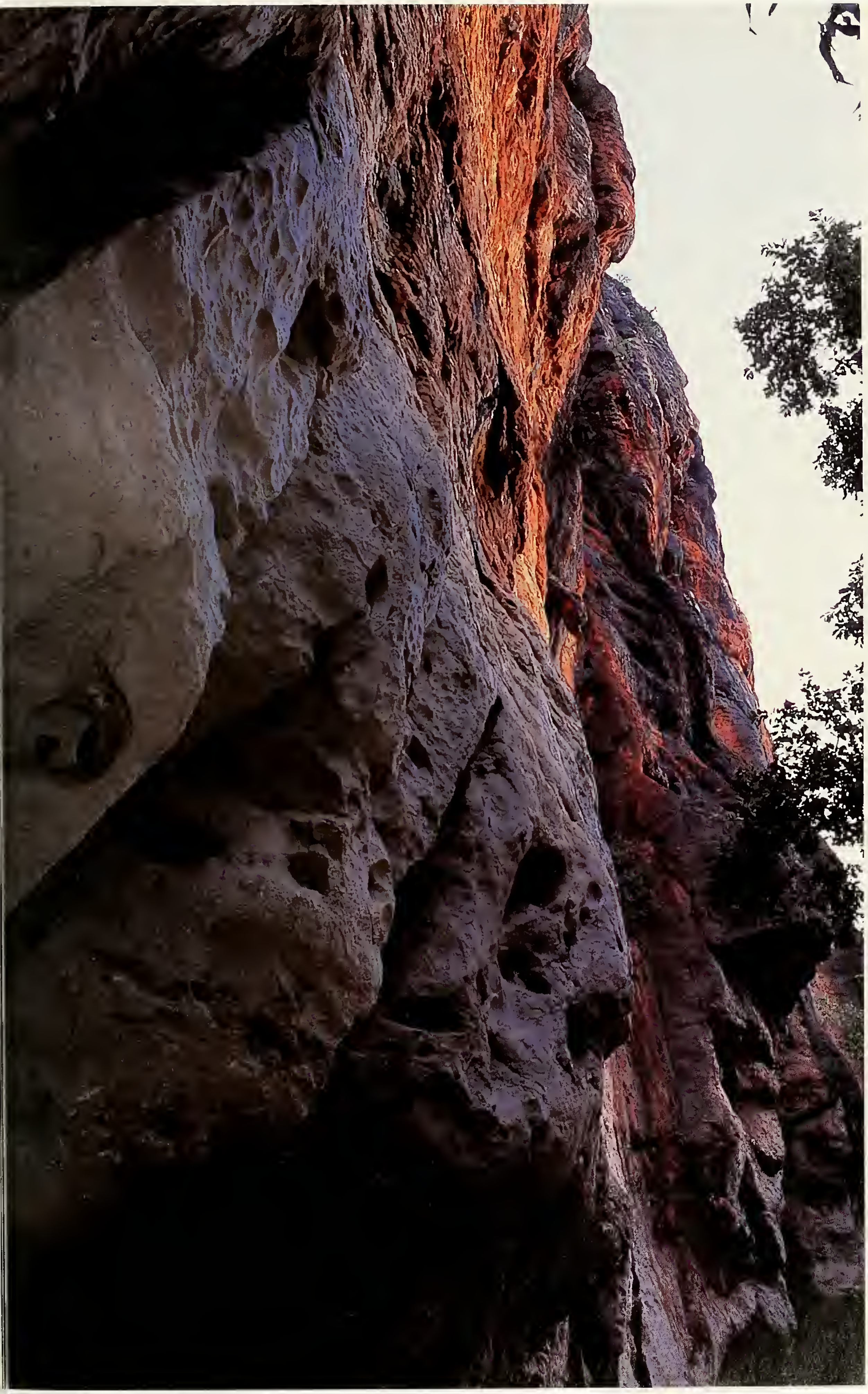
What do these findings say about the past as revealed in Windjana Gorge? Certainly, that the history of postextinction life in the reefs is far more complex, and far more interesting, than anyone had previously supposed. Many of the species found in the gorge's Famennian sediments were newcomers. Furthermore, though the mass extinctions certainly killed off a great many species, these strange communities seem to have suffered no substantial loss of biodiversity as a result, nor any simplification of their ecological interactions. In short, the players changed, but the game remained the same.

These observations have overturned the assumption that reefs can only recover from mass extinctions slowly. In spite of the almost complete loss of large, heavily calcified animals following the Late Devonian extinctions, the record of reef building at Windjana Gorge is virtually continuous. The stones there demonstrate that after a mass extinction, reefs can recover their ecological stability, and even develop completely new ecologies, in "just" a few hundred thousand to a million years.

That conclusion reinforces current ecological thinking—based on analyses of living populations—that communities are simply chance associations of species with similar ecological requirements, rather than fixed networks of interactions. They can change, but need not die out, when one or more of their species become extinct. New communities can form by taking in new species from the groups close at hand. Associations between community members likewise are not fixed; the ecology clearly changes as new species join the fray, while older species persist.

The record of reef recovery in the Windjana cliffs should not, however, be misinterpreted. The extraordinary resilience of the ecosystem there was due, in large part, to the region's microbial communities and their contribution to reef building. Cyanobacteria and other microorganisms can tolerate a wide range of stressful conditions, such as reduced productivity in the surrounding environment or rapid declines in seawater temperatures. Their tolerance may account for the continuity of the communities in which they played a role.

In communities of larger organisms that succumb to extinctions—for example, the plants and animals that are being lost today as a result of the current crisis in biodiversity—the process of reconstitution after a mass extinction would presumably occur far more slowly. And the evolution of any subsequent ecosystem, if one were to develop, would almost certainly take a radically different course. □



Massive global cooling probably led to the Devonian extinctions, leaving the Frasnian sponges and corals high and dry, so to speak, as fluctuating sea levels exposed the shallow reefs to the air. The extinctions opened the way for the development of a new ecological community—which itself eventually gave way to today's landscape of wallabies and crocodiles, but nary a living sponge.

BIOMECHANICS

How Does That Grab You?

Biologists are discovering that bacteria can cling to your cells much the way a "finger trap" grasps your finger.

By Adam Summers ~ Illustration by Shawn Gould

Cranberry juice, and lots of it: that's all most people know about urinary tract infections. But I always find my thoughts drifting from juice to the troubling question of invasion. Some strains of *Escherichia coli,* the same bacterium that lives in your gut, invade the bladder through the urethra, despite the fact that sterile urine, flowing at nearly five feet a second, scours it several times a day. Why aren't the bacteria simply washed away, like the itsy-bitsy spider climbing up the water spout? The answer lies in the ability of bacteria to stick to cells—a biomechanical feat on a molecular scale.

Covering the surface of *E. coli* are hairlike projections called fimbriae. Each fimbria bears a protein tip that can bind to sugar (or to sugar-coated or sugar-containing) molecules on the surfaces of cells. But getting the stickiness just right is tricky. If the fimbriae are too sticky, they'll adhere to anything that happens to be floating around—which is just about as useful as unrolled strips of masking tape collecting dust bunnies. But if the fimbriae grip too loosely, the bacteria will detach from the surface of a cell at the slightest joggle.

It turns out that not all *E. coli* strains are equally gummy. Some glom on tightly, sacrificing mobility for a nice stable home. Sticky strains stirred into a suspension of red blood cells "glue" the cells together, eventually resulting in cell globs that are big enough to be seen with the naked eye; the globs remain even after the stirring stops. Other strains hardly stick at all, like vagrants drifting wherever the surrounding fluid takes them.

But there's more to stickiness than bacterial strains. Evgeni Sokurenko, Viola Vogel, and their colleagues at the University of Washington in Seattle have found that even for some invasive bacteria, adhesion is not a fixed trait. Working with strains of *E. coli* that don't form permanent globs in suspensions of cells, they discovered that the strength of the bond between the proteins on the bacterial fimbriae and the molecules on the outer membranes of other cells can vary, depending on the strength of the force threatening to remove them. Specifically, when the suspensions were stirred, the blood cells immediately clumped together, but when the stirring stopped, the globs dissipated and the cells went back into suspension.

What seemed to be happening was that the bacteria clung tightly to the cells in response to the large shear force exerted on them by the fast-moving fluid. But as the fluid came to rest, the fimbriae's grip on the red blood cells loosened. In other words, the fimbriae seemed to act like a "finger trap," the children's toy made of woven wicker or plastic in the form of a tube. When a child inserts a finger into each end of the tube, the weaving bunches together and both fingers slip in easily. When the child tries to pull them out, though, the tube lengthens and so tightens around the fingers: the harder the pull, the tighter the hold.

Of course, a number of mechanisms have the same effect as a finger trap. And until recently investigators could not analyze how such an effect might be operating at the scale of individual fimbriae. After all, a bacterium is so small that thirty or more of them, laid end to end, would barely span the width of a human hair. And the width of a fimbria compared with the size of a bacterium is roughly as the width of our hair is to us. That makes fimbriae too small for light microscopy, high speed video, and most of the other tools familiar to readers of this column.

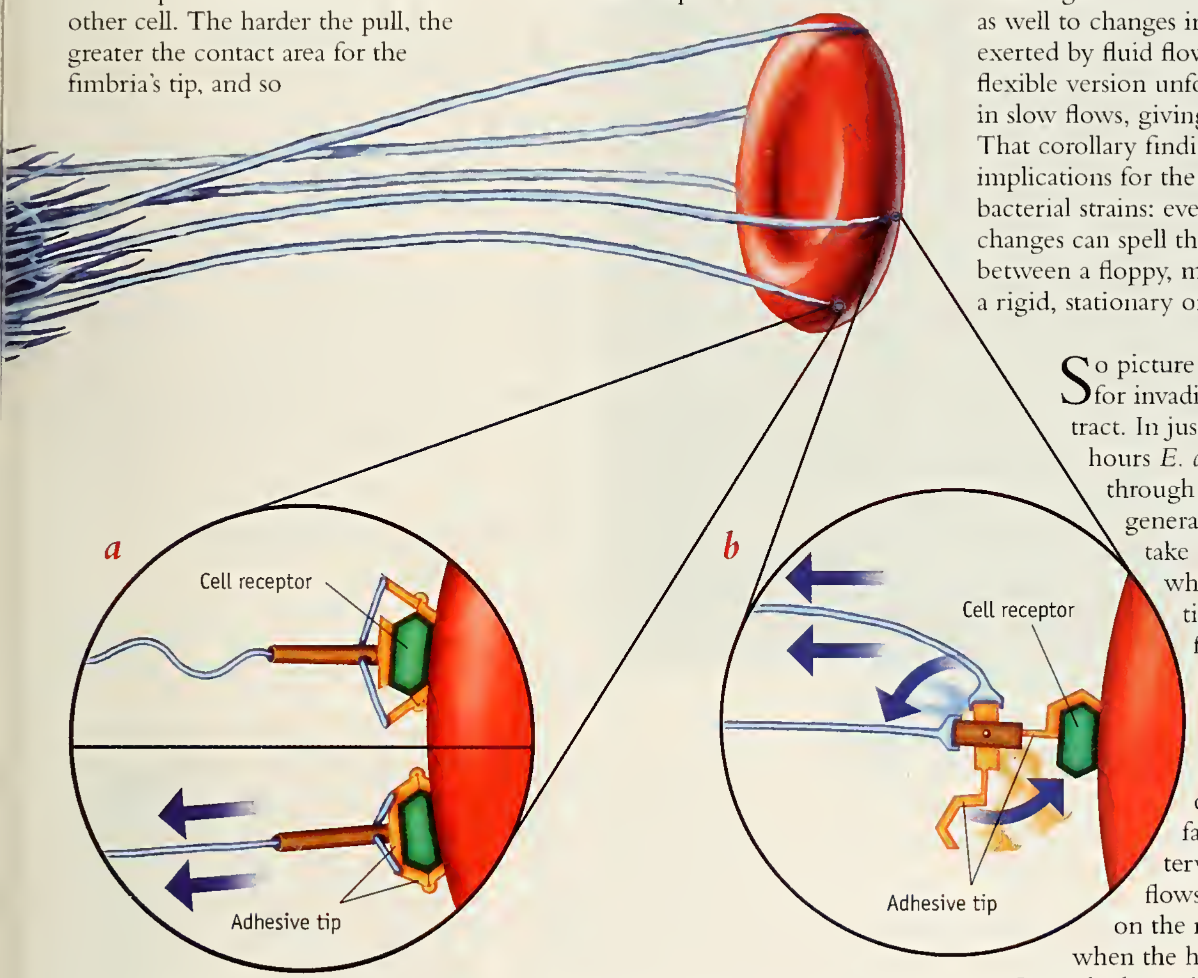
So Sokurenko and his colleagues turned to computers to test how some bacteria might vary the strength of their grip on other cells. The biologists built computer models of the complex protein that forms the fimbriae. As the biologists "pulled" on the computerized chemical models, the protein unfolded, bringing more of its sticky tip into contact with its point of attachment on the other cell. The harder the pull, the greater the contact area for the fimbria's tip, and so the harder it grabbed—just like the finger trap [*see illustration below*].

The biologists also manipulated the chemical structure of the protein in the model. When they replaced just one amino acid in the fimbrial protein (to simulate the effect of a simple mutation at one site in the bacterium's DNA), the structure of the fimbria's tip became more rigid, and so the shape of the tip changed less when the protein was pulled. A different substitution in the amino acid chain made the fimbria more flexible, enabling the protein to unfold more readily, even under low flow.

The investigators then tested the effect of rigidity on the grip strength of actual *E. coli* bacteria with various kinds of fimbriae. Sure enough, the more rigid structure could not adapt as well to changes in shear force exerted by fluid flow, but the more flexible version unfolded fully, even in slow flows, giving it a strong grip. That corollary finding has important implications for the evolution of bacterial strains: even small genetic changes can spell the difference between a floppy, mobile strain and a rigid, stationary one.

So picture this battle plan for invading the urinary tract. In just twenty-four hours *E. coli* can run through more than sixty generations—enough to take advantage of what natural selection can do for its foot soldiers. The infection is launched by the variably adhesive bacteria, which can move the fastest during intervals between high flows, and can hang on the most tenaciously when the high flows come.

Once the bacteria have "captured" an area, a small genetic change can turn them into highly adhesive, always-sticky colonizers. Urination won't dislodge either group; the only hope is large doses of cranberry juice (whose tannins make *E. coli* less sticky)—or a good antibiotic.



Two different schematic mechanisms have been proposed to explain how shear force could make the bacterium *Escherichia coli* (shown covered with blue "hairs," or fimbriae) bind tighter with host cells. In what biologists call the "catch-bond" mechanism (*a*, left), the force pulls a string connecting a hinged vise (in orange, representing the adhesive tip of a fimbria) to the bacterium. (The string represents the pilin domain, the part of the fimbrial protein that connects the tip to *E. coli*.) This action closes the hinges, strengthening the bond between the protein and a cell-receptor molecule (a sugar called mannose, in green) on the surface of the cell (red). In the "cryptic-bond" mechanism (*b*, right), the force on the pilin causes a previously unrecognized binding site to swivel toward the cell, creating a stronger bond between the cell's sugar molecule and the fimbria's adhesive tip. Note that an actual bacterium's fimbriae are all roughly the same length; for clarity, some are shown longer here.

Adam Summers is an assistant professor of ecology and evolutionary biology at the University of California, Irvine (asummers@uci.edu).

The Sierra Buttes loom over Sand Pond.

On Golden Pond

Miners and beavers have created a lovely, quiet California wetland—through no fault of their own.

By Robert H. Mohlenbrock

In 1884 prospectors entered a tranquil valley in the northern Sierra Nevada mountains of California. A forest of lodgepole pines, set off by a cluster of picturesque lakes known as the Sardine Lakes, covered the moist, twenty-acre basin. From various vantage points in the valley the men could see the serrated crests of the Sierra Buttes rising in the distance. But the peaceful setting was about to be disturbed: the prospectors found gold in the quartz strata of the surrounding hills, and soon the Young America Mine was in full production.

To get at the gold, the miners cut down much of the lodgepole-pine forest. Without the trees to absorb the moisture, most of the basin began to develop into a wetland. And once the mine was worked out and the prospectors moved on, beavers added to the wetland by felling more trees. Then, in the early twentieth century, cleanup crews hauled away the tailings from the gold mine, leaving a depression that created a lake. The result was far more inviting than this history would suggest. The lake, known as Sand Pond, is a popular swimming area in the Tahoe National Forest. A marsh has developed just east of the pond, and only a few lodgepole pines remain as a relic of the earlier forest.

I found the drive to Sand Pond breathtaking. From Interstate 80 near Lake Tahoe, I proceeded north on California Highway 89 to Sierraville. From there, for the next five miles, I enjoyed the view of a broad valley where cattle roam and graze. Near the small community of Sattley, I turned west on California Highway 49 and followed the circuitous ascent to Yuba Pass, climbing from 4,940 feet in the valley to 6,700 feet at the pass. A U.S. Forest Service campground is beautifully situated at the top of the pass. Descending westward, I entered the charming village of Bassetts, where I caught my first glimpse of the scintillating Sierra Buttes. From Bassetts, I took the Gold Lake Highway north for nearly two miles, then followed the forest service road to Sand Pond and the Sardine Lakes.

The forest service has constructed

a mile-long looped nature trail that begins about 200 feet east of the Sand Pond parking lot. The trail traverses the marsh from one end to the other along an extensive boardwalk, after which it passes through a coniferous upland forest on its south side. After twisting around large boulders, dropping down out of the upland woods, and crossing a stream, the trail ends back at the Sand Pond parking lot.

Just north of Sand Pond, but in Plumas National Forest, are two other areas worth visiting. One is a short trail to Frazier Falls, a 176-foot cascade. The other is the Red Fir Nature Trail, off a dirt county road. The trail loops through an ancient forest of red firs, some of them more than 150 feet tall.

HABITATS

Marsh Except for a few lodgepole pines, the marsh is a dense covering of grasses, sedges, and rushes among small pools of standing water. Sedges of the genus *Carex* are the most diverse group of plants. Bluejoint grass is common, its silver-green spikelets borne on slender, four-foot-tall stems. Soft rush, with its hollow stems, grows in tufts as large as two feet in diameter; other, lower-growing rushes appear singly or in small colonies. Near the edge of the marsh, and also scattered within it, is rose spiraea, a lovely pink-flowering shrub. Wildflowers include yellow monkey flower, willow herb, and Bigelow's sneezeweed.

The shallow pools contain leafy pondweed, whose two-inch-long leaves float on the water. Bladderworts, whose intricately branched, bladder-bearing stems are completely submerged, send up small aerial stems with inch-long yellow flowers. Bordering the open water and sometimes growing in it is threeway sedge. If you look straight down on this foot-tall sedge, only three of the plant's twelve or fifteen leaves will be apparent, so perfectly are the others aligned beneath them.

For visitor information, contact:
Tahoe National Forest
631 Coyote Street
Nevada City, CA 95959
(530) 265-4531
www.r5.fs.fed.us/tahoe

Moist woods Just before reaching the boardwalk you pass through a small forest of lodgepole pine, quaking aspen, and white fir. The understory is a diverse mix of ferns and wildflowers. The most conspicuous plant is corn lily, a perennial that can grow four feet tall and whose fifteen-inch-long, ten-inch-wide leaves appear corrugated because of their thick veins. Other wildflowers to look for are western mountain aster, meadow rue, pink wintergreen, and Chinese houses (a plant in the snapdragon family).

Streamside A stream that borders one edge of the marsh and eventually empties into Sand Pond is lined with a dense thicket of shrubs. The major species are mountain alder, rose spiraea, red osier (the same species found in the eastern United States), and at least three species of willows (Scouler's, arroyo, and *Salix lasiandra*). Several sedges and rushes from the marsh grow entangled beneath the shrubs.

Upland forest harbors California goldenrod, above left. Western azalea, top, and yellow monkey flower, above right, inhabit the marsh.

Upland forest The higher and drier terrain east and south of the marsh supports Jeffrey pine, white fir, incense cedar, and Douglas fir. In the shrub layer are green-leaf manzanita, bog bilberry, western azalea, and leather oak. Wildflowers include largeleaf avens, a pink honeysuckle, California goldenrod, false Solomon's seal, and Washington lily.

Robert H. Mohlenbrock is a professor emeritus of plant biology at Southern Illinois University in Carbondale.

REVIEW

The Unselfish Genome

The case for cooperating genes

By Menno Schilthuizen

Alexis Rockman, *Evolution,* 1992

Ever heard of *Demodex folliculorum*, a 0.4-millimeter-long mite and a relative of the spiders? Probably not—but if you squint you can get a close-up of one of its preferred habitats. The eyelash mite, as it is more commonly known, lives on almost everybody's face, feeding on dead skin cells and often burrowing into eyelash follicles. And that is not the only creature we share our bodies with. A veritable menagerie of microbes inhabits our various nooks and crannies. Spirochetes live in our gums; staphylococci, micrococci, and a small yeast from the genus *Pityrosporon* clothe our hides. And then, of course, there's the gut, home to species of bacteria that provide us with, among other things, some of our daily quota of B_{12} and K vitamins. In their most recent book Lynn Margulis, of the University of Massachusetts Amherst, and Dorion Sagan estimate that a staggering 10 percent of our dry weight is made up not of our own cells but of our symbionts.

Acquiring Genomes is full of such marvels of symbiosis. Another good one is the glow-in-the-dark squid *Euprymna scolopes.* In its belly is a two-lobed spotlight, complete with a translucent muscle covering it and a dark reflector behind. The light (which confuses predators) is emitted by the bacterium *Vibrio fischeri,* which hatchling squid recruit from seawater with a "welcoming ring" of beating cilia. Without the bacteria the light organs do not mature, and the squid remain unilluminated.

A flamboyant personality, Margulis has never avoided controversy. I once saw her dressed in purple velvet and perched on the edge of the stage at a congress, confronting, with her customary optimistic bravura, a hall full of skeptical bacteriologists. Beginning in the late 1960s, she brought into mainstream biology the idea that cell organelles such as mitochondria and chloroplasts are nothing less than relicts of symbiotic bacteria that were incorporated into the parent cells eons ago. In the ensuing three decades she has been the tireless champion of symbiosis, arguing with some success that other cell components have likewise evolved from bacteria, and that symbiosis is a pervasive and crucial process in evolution. Not surprisingly, then, in *Acquiring Genomes* Margulis and Sagan once again impress us with the wonders of microbial liaisons.

But their book goes further. The authors maintain that symbiosis is the stuff that evolution is really made of; in their view it should replace random genetic mutation as the main driving force of evolutionary novelty. To put it boldly (and Margulis and Sagan do): it isn't natural selection, but "the unseen beings" that "play the major creative role in the genesis of new species." The changes come about via the fusion of complete genomes, either through integration at the level of the chromosome (like most of the genes in the bacterium that later became our mitochondria) or through their union as joined, co-dependent organisms. The six known species of the single-celled marine organism *Euplotidium,* for instance, are distinguished from their *Euplotes* relatives by a band of bumps on their surface, from which defensive ribbons shoot when the *Euplotidium* are approached by other, predatory protozoans. On close inspection, the bumps turn out to be bacteria that are "body-farmed" by *Euplotidium* to serve as a defense organ.

Neither *Euplotidium* nor their bacterial bodyguards can live on their own, and so this life-form clearly evolved when one genome acquired the other.

In spite of such fine examples, however, Margulis and Sagan's argument loses some of its charm when the authors begin to downplay the relevance of natural selection to make way for evolution by symbiosis. Surely the merger of a *Euplotes*-like ancestor with a live bacterium, giving rise to a new organism, could not have been instantaneous. As with any other close ecological relationship, the merger would have required gradual mutual adaptation (presumably by the natural selection of gene mutations).

But Margulis and Sagan have decided that biology can do away with random mutations, now that a much more powerful originator of evolutionary novelty is available in the form of symbiosis. They maintain that the accumulation of small genetic mutations is virtually always destructive and "does not lead to new species or even to new organs or new tissues." It is a "half-truth whose lack of explicative power is compensated for only by the religious ferocity of its rhetoric"—an assertion that will raise the eyebrows of not a few evolutionary geneticists. And as for natural selection, the authors note that "a staunch resistance to any systematic effort to identify [its causal] agent or agents" persists: a slap in the face at evolutionary ecology.

Nevertheless, Margulis and Sagan do have a point—evolutionary biologists have largely ignored the formidable status of symbiotic interactions as ecological processes, as well as their potential for shuttling genes between genomes. With its wealth of detail, their book should act as an eye-opener. But I fear that its iconoclastic style may polarize rather than unify.

Much of the same ground is covered by Frank Ryan, an English physician and science writer, in *Darwin's Blind Spot*. But Ryan goes on where Margulis and Sagan leave off: in addition to proffering an appreciation of symbiosis as a new center of gravity for evolutionary biology, Ryan has a social-political agenda. He feels that neo-Darwinism, with its focus on competition and natural selection, has led to Darwinian justifications for such evils as social inequality, rape, and war. A better appreciation of the role of cooperation in nature, says Ryan, "would introduce some sense of balance into our understanding of these highly controversial aspects of human societal and psychosexual behavior."

So Ryan embarks on a quest for examples of peaceful collaboration in nature that will support his crusade against the excesses of Darwinism. *Darwin's Blind Spot* is well researched, covering the spectrum of comment on the topic from Adolf Hitler (who appropriated Darwinian terminology to justify the Holocaust) to Beatrix Potter (who was barred in 1897 from speaking before the Linnaean Society of London on the symbiotic lifestyle of lichens because she was a woman and who, in frustration, resorted to writing her famous series of children's books). Ryan has an eye for detail and a knack for spinning a yarn from many loose threads, and these talents make the book highly readable.

Acquiring Genomes: A Theory of the Origins of Species
by Lynn Margulis and Dorion Sagan
(Basic Books, 2002; $28.00)

Darwin's Blind Spot: Evolution Beyond Natural Selection
by Frank Ryan
(Houghton Mifflin, 2002; $25.00)

At some points, though, his conclusions become just too far-fetched. He points out, for instance, that our earliest ancestors lived near the shores of oceans and lakes, and so lived in "a diffuse exosymbiosis" with fish—which are rich in certain fatty acids that promote brain growth. Hence, he concludes, living in close association with fish caused the evolution of our large brains. Quite aside from the fact that I do not think killing and eating another species counts as symbiosis, the evolutionary rationale is naïve. Even if our littoral forebears grew larger brains because of their diet, the advantage could not be genetically inherited, so it is hard to see how it could have affected human evolution. Such uncritical reasoning, particularly toward the end of his book, where he increasingly focuses on human society, weakens Ryan's overall thesis.

Another flaw of the book is its tendency to invoke straw men. I do not think sociobiologists, as Ryan claims, actually believe altruism operates among the members of a species through acts of kindness that are constantly monitored for their future value. In fact, his alternative explanation—that "love, friendship and 'togetherness'" are "embedded in our human genome"—is entirely in line with Darwinian sociobiology. The latter view simply asserts that the possibility of reciprocation has given kind people the edge in the evolution of our species, and so morality has become hard-wired in our genomes.

Ryan, like Margulis and Sagan, appears to be picking a fight by exaggerating maverick biologists' disputes with traditional biology. He almost directly blames the horrors of the German concentration camps on such exemplary scientific figures as the English biologist T.H. Huxley. And his pages are littered with the unsung heroes of symbiology, who saw in natural symbioses the model and rationale for utopian and fully collaborative societies but who were suppressed, according to Ryan, by evil conventional biology. It makes an amusing read and a diverting story; but, unfortunately for Ryan's argument, it may be too good to be true.

Menno Schilthuizen is an associate professor of evolutionary biology at the University of Malaysia Sabah. He is the author of Frogs, Flies, and Dandelions: The Making of Species *(Oxford University Press, 2001).*

nature.net

Climate Watch

By Robert Anderson

Most people get their news about global warming second-hand, but for those who want to keep their own finger on the pulse of the planet, two Web sites merit special interest.

One site shrewdly keeps tabs on the coldest regions of the world—the high latitudes and high altitudes, collectively known as the cryosphere—because they are the regions most sensitive to global climate change. The reason for the sensitivity is that water there can readily shift back and forth between its liquid and solid phases, with dramatic results. Run by the National Snow and Ice Data Center (NSIDC) in Boulder, Colorado, the Web site reports conditions in the cryosphere on the basis of remote sensing from satellites and aircraft. The site tracks the waxing and waning of snow cover, glaciers, sea ice, and ice shelves. It also monitors rising sea levels and conditions in the permafrost. In its "State of the Cryosphere" (nsidc.org/sotc/intro.html), the NSIDC reports that "regardless of parameter or measurement method, the amount of snow and ice has been decreasing over the past several decades."

A more anecdotal look at global climate change in the polar regions and elsewhere can be found at "Global Warming: Early Warning Signs" (www.climatehotmap.org). Created by several leading environmental groups, the site has a world map you can click on to learn about the "fingerprints" and "harbingers" of climate change. The site also includes a report on the potential consequences of the warming climate for different regions of the United States and for sectors ranging from agriculture to human health.

Robert Anderson is a freelance science writer living in Los Angeles.

BOOKSHELF

Holiday Books for Children

By Diana Lutz

The world needs informational books, and so do I; they're the tools of my trade. But giving them to children for the holidays is a bit like putting vitamins and cough syrup in their stockings. So the informational books on this list are one-of-a-kind: more beautiful, better designed, more original, or better written than the ones they compete with.

FOR SMALL PEOPLE

Lizards, Frogs, and Polliwogs, *poems and paintings by Douglas Florian (Harcourt, 2001; $16)* Whimsical poems about amphibians are illustrated with watercolors on brown paper bags. Florian, who is gradually working his way through the animal kingdom, depicts himself on the flyleaf as a frog.

"Slowly, Slowly, Slowly," said the Sloth, *written and illustrated by Eric Carle (Penguin Putnam, 2002; $16.99)* Adam Gopnik recently worried in *The New Yorker* about his three-year-old, whose imaginary playmate, Charlie Ravioli, is always too busy to play. If your child's life is similarly full of busyness, she might take comfort in Carle's gentle defense of the sloth and the slothful life. A museum of picture-book art founded by (and named for) Carle opened in Amherst, Massachusetts, this past fall.

FOR MEDIUM-SIZE PEOPLE

The Lamp, the Ice, and the Boat Called Fish, *by Jacqueline Briggs Martin; pictures by Beth Krommes (Houghton Mifflin, 2001; $15)* While the good ship *Fish* was slowly being crushed in the Arctic ice, the captain sat in the galley and played each phonograph record one last time before tossing it into the stove. Based on a true account

EXPLORER GUIDE

of an ill-fated 1913 Canadian Arctic expedition, the book tells the story of an Inupiat family (including two young girls) whose cold-weather skills kept the members of the expedition alive. Written in blank verse and illustrated with black-and-white scratchboard drawings in the style of Inupiat art, the story is followed by photographs of the survivors.

The Dinosaurs of Waterhouse Hawkins, *by Barbara Kerley; drawings by Brian Selznick (Scholastic Press, 2001; $16.95)* "What first drew me to this story, of course, was the dinner party," Kerley writes. That would be the formal dinner party held on New Year's Eve, 1853, in the belly of a huge model of a dinosaur in London's Crystal Palace. But Hawkins, the first to sculpt the lumbering beasts whose fossils had recently been unearthed, met opposition as well as success. In America he ran afoul of Boss Tweed, whose thugs smashed his sculptures and buried them in Central Park.

FOR NEARLY GROWN PEOPLE

***Revenge of the Whale: The True Story of the Whaleship* Essex,** *by Nathaniel Philbrick (Putnam Juvenile, 2002; $16.99)* "Never before, in the entire history of the Nantucket whale fishery, had a whale been known to attack a ship," writes Philbrick. But on November 16, 1820, a huge bull sperm whale twice rammed the whaleship *Essex.* In ten minutes the ship sank, leaving twenty-two men stranded in small boats in the middle of the Pacific Ocean. *Revenge* is based on firsthand accounts of the voyage—including one by the ship's fourteen-year-old cabin boy—and on extensive knowledge of nineteenth-century whaling and the physiology and psychology of starvation and cannibalism. The combination of unflinching truth-telling and deep compassion for the men makes the story unforgettable. But because it is so powerfully told, the cannibalism may be unbearable for some readers.

Black Potatoes: The Story of the Great Irish Famine, 1845–1850, *by Susan Campbell Bartoletti (Houghton Mifflin, 2001 $18) Black Potatoes* tells the story of the havoc wrought by a fungus that arrived in Ireland in 1845 in shipments of guano. The crop failures, multiyear famine, and mass emigration that followed are familiar enough, but Bartoletti makes them new by including rare first-person accounts collected from scattered primary sources (she studied Gaelic for the purpose).

Remarkable Trees of the World
by Thomas Pakenham
(W.W. Norton & Company, 2002; $49.95)

Black Potatoes shares with Bartoletti's other books her warm-hearted indignation at the plight of the poor and the manifold ways in which they are left without egress from misery. She points out that while people were starving in the ditches, ships left Ireland full of grain and livestock. "Famine," she says, "is not about a lack of food; famine is about who has access to food."

Diana Lutz keeps an eye on children's literature for her daughter Emily. She is the editor of Muse, *a science magazine for children.*

For the Coffee Table

There's never a shortage of large-format books to keep the dust off the furniture. Represented here are exceptional picture-book treatments of nature and some glimpses of paradise—both on Earth and above it.

Birds, *by Robert Bateman (Pantheon Books, 2002; $40)* A lifelong birder and renowned wildlife painter assembled this portfolio-cum-field diary to chronicle a worldwide "personal birding odyssey." Bateman's brilliant images (220 new paintings are collected here) portray the birds in their natural postures and settings. Field notes provide factual details along with concise, evocative ruminations on his wanderings.

Coral Reefs: Cities under the Sea, *by Richard C. Murphy (The Darwin Press, 2002; $45)* The lesson here—abundantly illustrated in beautifully clear, color photographs—is that people might make their own communities more sustainable if they imitated the Plato-like republics of coral reefs, where a variety of marine species collectively enhance the survival of the whole. A marine biologist, educator, and photographer, Murphy maintains the useful communitarian analogy throughout eight chapters, whose titles begin with "Power Plants and Farms" and end with "Social Security."

Last Stand: America's Virgin Lands, *text by Barbara Kingsolver; photographs by Annie Griffiths Belt (National Geographic Society, 2002; $40)* Remnants of virgin land, surviving piecemeal and scattered across nearly four million square miles of U.S. territory, are the subject of this highly stylized picture book. Color photographs and hand-colored black-and-white prints create images as rich with nuance as the pristine landscapes themselves, and novelist Kingsolver contributes a moving "swan song" for these "lost corners" of wild grandeur.

Glimpses of Paradise: The Marvel of Massed Animals, *by Fred Bruemmer (Firefly Books, 2002; $40)* "But here and there, for a variety of reasons, some animal species still exist in huge numbers and convey . . . a vision of Eden," Bruemmer writes. To prove it, he traveled the globe to record forty-three species that herd for safety, congregate for feeding or breeding, or lay their eggs en masse. His stunning images of multiplicity are accompanied by solo and small-group shots that capture the animals' behavior in their wild environments.

Oceans, *edited by Sue Hostetler (Rizzoli, 2002; $39.95)* Eighty masters of the art of photography present flawless, mainly black-and-white images of oceans and seascapes. Evocative and provocative, the publication coincides with a traveling exhibition and auction of limited-edition prints in support of the Natural Resources Defense Council.

Planet Earth, *edited by the German Aerospace Center (Knopf, 2002; $40)* "The beauty of these photos," writes art critic Robert Hughes in his superb introduction, "is only an accident," because what we're seeing is actually information—satellite data radioed to Earth and reassembled electronically. Most of the images have been assembled not from visible light but from nonvisible radiation. The gorgeous, sometimes eerie results are reproduced uncaptioned on text-free pages and are keyed to an index that identifies their geographical source.

—MICHEL DEMATTEIS

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Universe by Number

Can cosmology be as easy as one, two, three?

By Charles Liu

The cosmos is a cluttered place. Stars dot the night sky in every direction—hardly surprising, given the hundreds of billions of stars in our galaxy alone. If our own solar neighborhood is any guide, each star among those billions could host a handful of major planets, dozens of moons, millions of asteroids and other minor planets, and billions (if not trillions) of icy comets. Now throw into the center of the galaxy a supermassive black hole two and a half million times the mass of the Sun, add a few billion Suns' worth of free-floating interstellar gas and a few trillion Suns' worth of unseen dark matter, and you get the approximate contents of a single galaxy, our own Milky Way. Finally, multiply that by a hundred billion or so—the number of galaxies between us and our cosmic horizon—and you have the number of objects in the visible universe. It truly boggles the mind.

That sheer quantity alone poses a serious dilemma for us astronomers. As eager as we may be to study every single thing out there, assigning ourselves such a task would be like asking an entomologist to get personally acquainted with every insect on Earth. The numbers leave us no choice but to pick and choose our targets, and then to classify and categorize them: planets into gas giants and terrestrials; galaxies into spirals, ellipticals, and irregulars; and so on. Most of what we understand about the cosmos begins with organizing what we observe into families; all of us, scientists or not, classify things in order to transform raw information into knowledge. But how do astronomers deal with the vast majority of objects in astronomical images—the foreground stars, the background galaxies—when we know almost nothing about the objects but their position and apparent brightness? What can we do with them to learn something about the universe?

Here's a start: we can count them.

The **"deep field,"** a long-exposure image made by the Hubble Space Telescope, shows that even what was thought to be an "empty" part of the sky is dotted with galaxies, some more than 12 billion years old.

Simple addition goes a long way in astronomy. That is particularly true in cosmology, the often difficult pursuit of knowledge about the universe as a whole. In the 1920s Edwin Hubble showed that the Milky Way was just one of a vast number of galaxies scattered throughout the universe. At about the same time, inspired by the idea put forth in Einstein's general theory of relativity that space itself is curved, an international community of physicists and astronomers such as Alexander Friedmann, Georges Lemaître, Willem de Sitter, and Albert Einstein proposed various models of the shape of the universe. Because galaxies are the glowing tracers of matter in the universe, it made sense to map the number and brightness of galaxies all across the sky. The maps could then be compared with the predictions of the models to see which model was not ruled out.

Eight decades have passed, and we astronomers are still at it. But along the way we've managed to shed some light, not just on cosmic geometry but also on cosmic evolution. These insights aren't exactly a bonus; they're a product of scientific necessity resulting from the realization that counting galaxies has two major complications.

First, we are embedded in the curved space that Einstein first described; we look out at a vast universe along sight lines distorted by the very galaxies we are trying to observe. Imagine drawing

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Designed by a vision expert, this technology helps to enhance the eye's ability to work tirelessly for hours while reading, or at a workstation, by imitating the beneficial wavelengths of natural daylight. OTT-LITE® VisionSaver™ technology, which can reduce eye strain caused by glare, is based on a scientific understanding of the eyes. The results are a new ease in reading, a reduction in eyestrain, and colors and words that jump off the screen. Vision-Saver™ lamps give off extremely low heat and are almost glare-free, resulting in reduced distortion, increased contrast and visual clarity that is significantly greater than typical cool white lamps. The 10,000-hour bulb uses very low energy while it gives an amazing optical experience.

The technology that lets you see with startling clarity. Dr. John Nash Ott, a world-renowned scientist, developed the first OTT-LITE® over forty years ago. Dr. Ott spent over forty years researching sunlight and its effect on people, plants and animals. This led to his discovery of OTT-LITE® Natural Light Supplements™—the closest thing to natural daylight. While no light perfectly duplicates sunlight, OTT-LITE® lamps are the next best thing to natural sunlight. The OTT-LITE® lamp has naturally balanced wavelengths in much the same way as sunlight, bringing the benefits of sunlight indoors without heat and glare.

See better...with less eyestrain

Dr. John Nash Ott, a scientist with more than forty years experience with lighting technology, developed the first OTT-LITE®. His Natural Light Products utilize a rare earth phosphor blend technology that makes it possible to see almost as clearly and accurately indoors as you do outside under natural light. The result is reduced glare with the OTT-LITE® VisionSaver™ Floor Lamp.

ENJOY THE BENEFITS OF NATURAL SUNSHINE WITH THE FLICK OF A SWITCH

- *Superior contrast lets you see details with startling clarity*
- *See colors true-to-life*
- *Almost glare-free to reduce eyestrain*
- *Provides sharp visibility*
- *Flexible gooseneck design*
- *10,000 hour bulb*
- *Low energy usage*
- *Produces low heat*

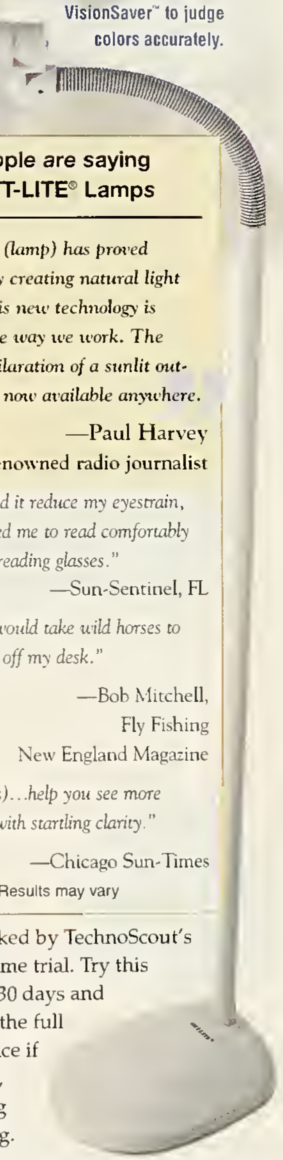
OTT-LITE® Natural Light Supplements™—the first lights that simulate the visible wavelengths of sunlight.

Dr. Ott's Natural Light Products utilize a rare earth phosphor blend technology that makes it possible to see almost as clearly and accurately indoors as you do outside under natural light. Practically glare and heat-free, this lamp will change the way you look at your work. These lights also bring the light of a sunny spring day all year long to any room.

A superior optical experience. This new technology has revolutionized the way we see colors and details. With the OTT-LITE® VisionSaver™ Floor Lamp, you'll be able to read, work and study indoors with all the clarity and accuracy of being outside on a beautiful spring day! Anyone from hobby or reading enthusiasts, students to computer users and senior citizens can enjoy the amazing benefits of this technology.

Try the ultimate lighting technology. The OTT-LITE® VisionSaver™ Floor Lamp provides a difference your eyes can truly feel. The special formulation that brings the feeling of a sunny spring day indoors all year long, is one you'll truly be thankful for. The OTT-LITE® VisionSaver™ Floor Lamp is backed by TechnoScout's exclusive home trial. Try this product for 30 days and return it for the full purchase price if not satisfied, less shipping and handling.

Artists, graphic designers, and photographers use VisionSaver™ to judge colors accurately.



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OTT-LITE (lamp) has proved itself that by creating natural light indoors...this new technology is changing the way we work. The natural exhilaration of a sunlit outdoors day is now available anywhere.

—Paul Harvey
World renowned radio journalist

"Not only did it reduce my eyestrain, it also allowed me to read comfortably without my reading glasses."

—Sun-Sentinel, FL

"Wow...It would take wild horses to pry this light off my desk."

—Bob Mitchell,
Fly Fishing
New England Magazine

"The lamp(s)...help you see more clearly and with startling clarity."

—Chicago Sun-Times

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a fine grid of dots on a rubber sheet. Now stretch the sheet tightly against a table, then a saddle, then a beach ball. An ant clinging to the middle of the sheet, aware only of the sheet's two-dimensional surface, would see the dots spaced differently in each case. We earthlings are in the same predicament as the ant, except that our "curved sheet" has three dimensions instead of two. Taking the galactic census of the entire universe therefore requires that we take curvature into account, or we'll misinterpret what we see.

Second, when we look outward into space, we also look backward in time. The observable universe is about 13 billion years old, which we know because its edge is 13 billion light-years away. By definition, then, every single galaxy in the universe must be younger than 13 billion years of age. Pictures of the universe thus combine past with present. Infant galaxies growing rapidly, adolescents forming new stars at a furious rate, adults making stars gently and steadily—they're all in the mix, all at different distances, and all with different histories of birth and growth.

It gets worse. We also have to take account of a number of other processes, such as galaxy clustering and galaxy merging, surface brightness, and the obscuring power of dust. All of these processes can change with time, drastically increasing or decreasing the number of galaxies we see. It all adds up to a huge mess of cosmic change, collectively called galaxy evolution. Ignoring this factor would completely confound any interpretation of galaxy counts.

To deal with the complications of spatial curvature and galaxy evolution, cosmology-by-galaxy-counts proceeds in stages. First we count the galaxies. Then—just as our predecessors did—we make models of the universe by positing various shapes and evolutionary rates for it, predicting the galaxy counts we would get for each model. Finally, we compare the data with the predictions and tweak the models until they match. The more galaxies we count, the more accurate—and complex—the models get.

Astronomers are creating "kitchen-sink" models—throwing everything in—to make an accurate reconstruction of the universe.

The Subaru Telescope in Hawaii made this deep-field image of a small patch of the northern sky.

One of the latest entries in the model-universe competition was recently published by Masahiro Nagashima of the National Astronomical Observatory of Japan and his collaborators. Their model is "semi-analytic"—part complex equations, part raw computer simulation—and packed with an assortment of computational knobs and switches. With it, Nagashima and his colleagues can take into account the rate of star formation, the size of newborn galaxies, the effects of dust, and a laundry list of other variables, to predict for any given cosmic geometry the average number of galaxies in any patch of sky. (Some astrophysicists wryly call such omnibus constructions kitchen-sink models, since you can throw in just about everything.)

Nagashima chose to test the predictions of the model against three "deep fields"—composite images of a single part of the sky. Usually taken over several days and nights, and combining exposures made with red, green, and blue filters, these images show, in exquisite detail, extremely distant and faint galaxies. Two of the images were made with the Hubble Space Telescope; one exposure lasted 141 hours, the other, 118 hours [*see image on page 74*]. The third image was a twenty-two-hour exposure with the 8.2-meter (323-inch) Subaru Telescope on Mauna Kea, Hawaii [*see image at left*]. According to Nagashima, the best match between the model and the deep-field images suggests that the universe will expand forever, never collapsing back upon itself, and that its expansion may even be accelerating. The result confirms other research—in microwave astronomy, for instance, and in surveys of distant supernovas—that indicates that an unseen dark energy pervades the universe, inexorably pushing the galaxies apart.

As you might expect, though, Nagashima's work also conflicts with the results of some other previous studies. But what gives it special weight is that the model matches not just the deep-field images but also images made across the spectrum, from ultraviolet to visible to infrared. Even so, Nagashima's model can't reproduce all the galaxy counts unless even more parameters are added and adjusted. The search for the true shape of the universe goes on, one galaxy at a time.

Charles Liu is an astrophysicist at the Hayden Planetarium and a research scientist at Barnard College in New York City.

By Joe Rao

Mercury spends much of December in the evening sky, slowly moving away from the Sun. It arrives at its greatest eastern elongation on the 26th, 20 degrees from the Sun's glare. Despite that separation the view is a limited one, because the planet sets about fifteen minutes before the end of evening twilight.

Mercury is barely visible after sunset on New Year's Day; you will probably need binoculars to catch it. The planet passes inferior conjunction on January 11, then rises above the dawn horizon by the 18th. In the last ten days of January it begins its best morning apparition until September 2003.

Seeing **Venus** is a good reason to get up early in December; it shines before sunrise like a modern-day Christmas star. The planet crossed between the Earth and the Sun in November and is now climbing to glory in the southeast. Venus is always bright, but this December both its altitude and its brilliance are exceptional.

By late December the lamplike "morning star" comes up about four hours before the Sun. Its ascent culminates about 28 degrees above the horizon on December 1, and the maximum altitude increases to about 32 degrees by midmonth. From the 3rd until the 9th Venus shines as bright as the planet ever gets, at magnitude –4.7. On snowy ground, Venus-light might be bright enough for surrounding features to cast Venus-shadows.

In January the planet continues to draw all wakeful eyes to the southeastern sky before dawn. Viewed from the northern midlatitudes, Venus rises within a half hour of 4 A.M. local time throughout the winter and spring—nearly two hours before dawn's first light in January. It reaches its greatest western elongation from the Sun, 47 degrees, on January 11; a few days later a telescope will show that the planet's disk appears exactly half lit.

Mars rises at about 3:30 A.M. throughout December. On the 6th it comes to within about 1.5 degrees of the dazzling Venus, which shines 363 times brighter than Mars.

In January Mars and Venus continue rising together, but somewhat earlier, about four hours before the Sun. Although still 179 million miles from Earth at midmonth and relatively faint beside Venus, Mars is hardly boring. Moving from Libra into Scorpius on the 20th, Mars buzzes past the arc of three stars known as the Crown of the Scorpion. It passes just south of the double star Graffias on the morning of January 22.

Jupiter rises in the east-northeast just after 9:30 P.M. local time on December 1, and then about four minutes earlier with each passing night (it's up at 7:30 P.M. by the end of the month). On December 4 it halts its normal eastward drift among the stars, stopping in the constellation Leo and reversing course toward the west, back into Cancer (the shift is called retrograde motion).

By the beginning of January the planet reaches a good altitude for telescope viewing—nearly 30 degrees above the horizon—by about 10 P.M. local time; its ever-earlier rising pushes back that time each day until, by month's end, the planet reaches the same viewing altitude by 7:45 P.M.

Saturn-watchers in December will enjoy their finest month in three decades. The planet attains opposition to the Sun on the 17th: it rises as the Sun sets, reaches its highest point in the southern sky at midnight, and sets as the Sun rises. It shines as bright as it ever does, at magnitude –0.5; only two stars, Sirius and Canopus, are brighter. The planet's rings are tipped more than 26.5 degrees to our line of sight: a certain delight for anyone lucky enough to be favored with a telescope for the holidays.

In January Saturn dims only slightly. It's already well up in the east at sundown, and it sets in the west-northwest an hour or two before sunrise.

The **Moon** is new at 2:34 A.M. on December 4. It reaches first quarter at 10:49 A.M. on the 11th, full at 2:10 P.M. on the 19th, and last quarter at 7:31 P.M. on December 26. In January the Moon is new at 3:22 P.M. on the 2nd. It reaches first quarter at 8:14 A.M. on the 10th, full at 5:47 A.M. on the 18th, and last quarter at 3:33 A.M. on the 25th.

A total eclipse of the **Sun** takes place on December 4. The Moon's dark umbral shadow follows a narrow path beginning at local sunrise over the South Atlantic, crosses southern Africa and the Indian Ocean, and ends at local sunset over southern Australia. Totality lasts between fifty and ninety seconds in parts of Africa and roughly thirty seconds near local sunset in parts of southern Australia.

The Geminid meteors, which seem to emanate from the star Castor in Gemini, reach their peak early on a Saturday morning, December 14. It's one of the best meteor displays of the year and is easy to see after the bright waxing gibbous Moon sets at about 2 A.M. A Geminid meteor should burst across the sky, on average, about once a minute.

The **solstice** takes place at 8:14 P.M., December 21.

The **Earth** reaches perihelion, its closest approach to the Sun, on the night of January 3–4. Our favorite star is just 91,405,304 miles away.

Unless otherwise noted, all times are given in Eastern Standard Time.

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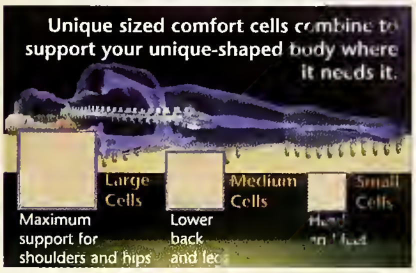

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Walking Sewers

By Ted Steinberg

When Europeans visualized American cities in the nineteenth century, it was not Indians or buffaloes but pigs that came to mind. "I have not yet found any city, county, or town where I have not seen these lovable animals wandering about peacefully in huge herds," wrote Ole Munch Ræder, a Norwegian lawyer, during a visit to America in 1847. Swine, he observed, kept the streets clean by "eating up all kinds of refuse. And then, when these walking sewers are properly filled up they are butchered and provide a real treat for the dinner-table."

Working-class women, who depended on pigs to supply food for the table, allowed them to scavenge the urban commons for garbage. Thus city pigs converted people's waste into protein for the working poor. But a food source to some proved a nuisance to others. By 1849 so many pigs were wandering the streets of Little Rock, Arkansas, that according to one newspaper, they had come "to dispute the side walks with *other persons* [emphasis in the original]." The creatures were not the sedate porkers one encounters today in children's zoos; they were wild animals that copulated in public and had the annoying habit of defecating on people. Worse, they injured and occasionally killed children.

The authorities in New York City had sought to ban swine from the streets as early as the 1810s. Public outcry led to the repeal of that ordinance. But Mayor Cadwallader Colden stood firm against the pigs. "Why, gentlemen!" he remonstrated in 1819, "must we feed the poor at the expense of human flesh?" Eliminate the urban commons, he argued, and the poor would be forced to find jobs to pay for food, instead of taking their meals at the expense of the city's more refined residents. As for the role of swine in street cleaning, Colden intoned, "I think our corporation will not employ brutal agency for that object when men can be got to do it."

In 1821 city authorities went to war against the pigs, taking many into custody when Irish and black women banded together to defend the animals. Other significant pig-related conflicts erupted in 1825, 1826, 1830, and 1832. The fatal blow to the urban commons came in 1849. Cholera broke out in New York, and health officials linked the outbreak to the city's filthy conditions. No animal symbolized dirt more clearly than the pig. Police, armed with clubs, drove thousands of swine from the dwellings of the poor, banishing them uptown. By 1860 the area below 86th Street had been secured as a pig-free zone. And by the last decade of the nineteenth century, the urban commons—a surrogate for the open range in the South and West—had vanished from the scene in cities throughout America. The urban pig was ultimately exiled to the farmyard, where, to this day, it perpetuates for people the division between the country and the city.

Rounding up the pigs, from *Frank Leslie's Illustrated Newspaper,* August 13, 1859

Ted Steinberg is a professor of history and law at Case Western Reserve University in Cleveland, Ohio. This essay is adapted from his book Down to Earth: Nature's Role in American History, *which was published this past May by Oxford University Press.*