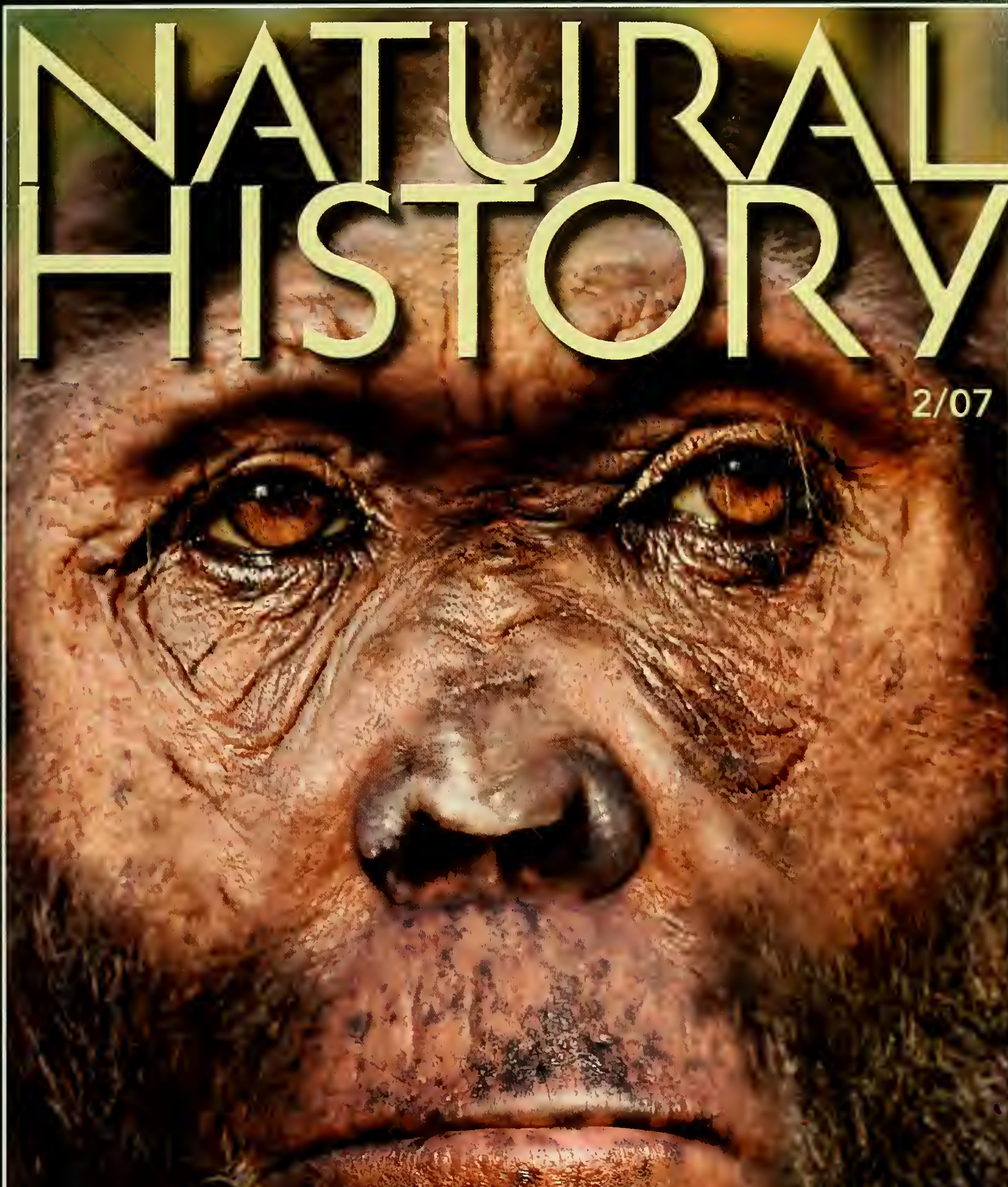
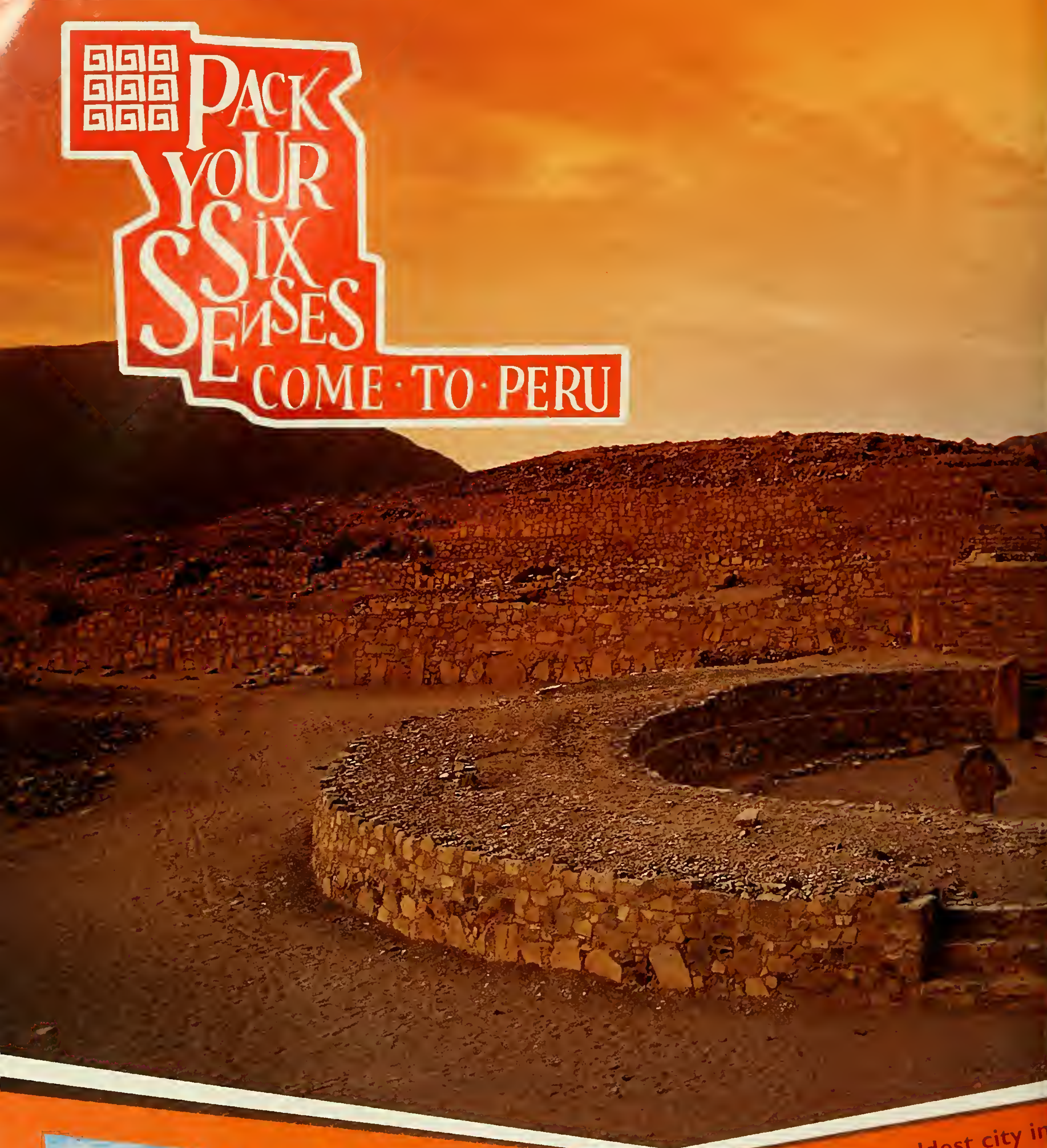
NATURAL HISTORY

2/07



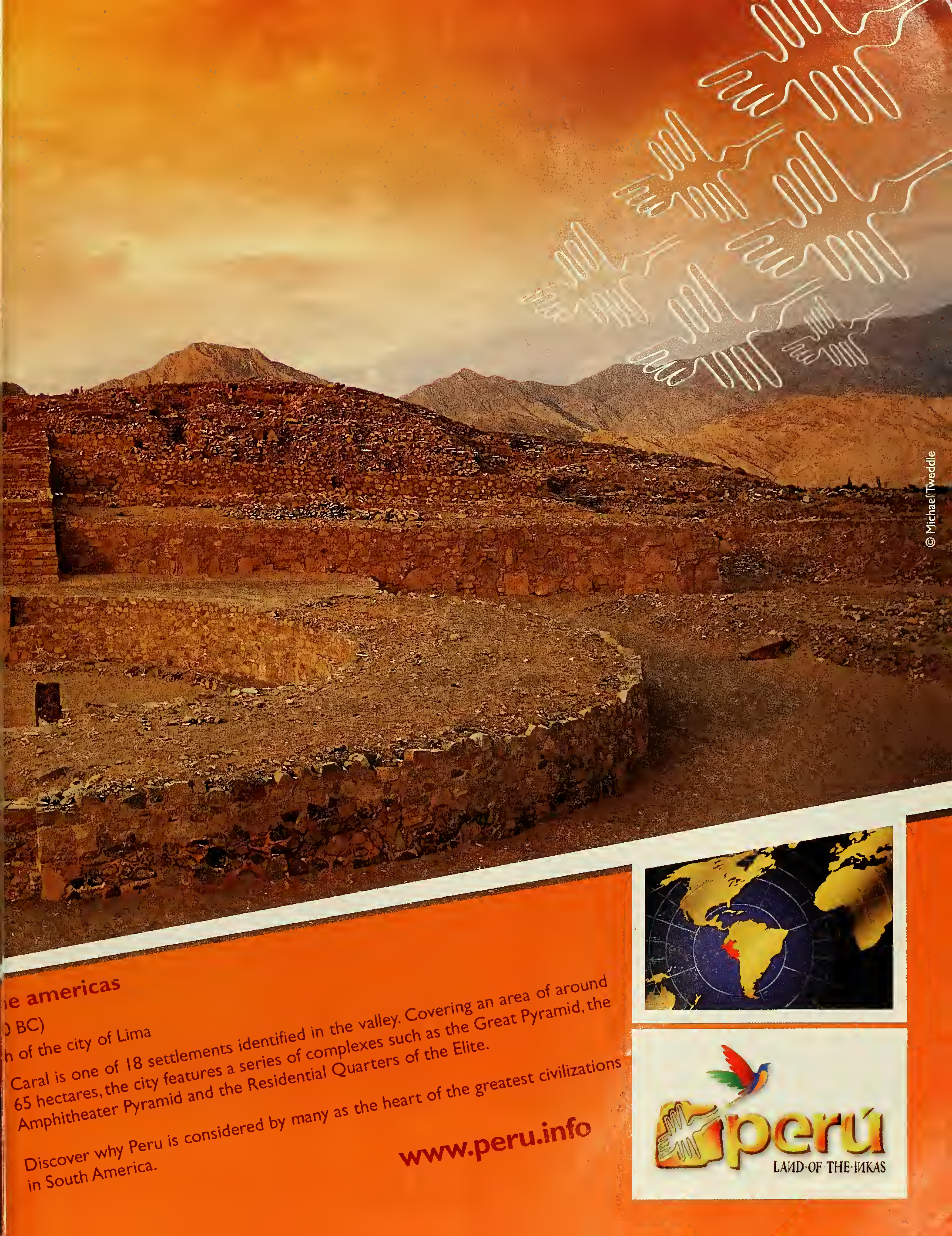
NEW FACES OF THE HUMAN PAST



Caral: The oldest city in

Era: Late Archaic Period (3000-

Location: Supe Valley, 158 km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) BC)
h of the city of Lima
Caral is one of 18 settlements identified in the valley. Covering an area of around 65 hectares, the city features a series of complexes such as the Great Pyramid, the Amphitheater Pyramid and the Residential Quarters of the Elite.
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NATURAL HISTORY

FEBRUARY 2007 VOLUME 116 NUMBER 1

FEATURES

ON THE COVER: The hominid species *Homo rudolfensis* lived in East Africa between 1.8 and 1.9 million years ago. Illustration by Viktor Deak

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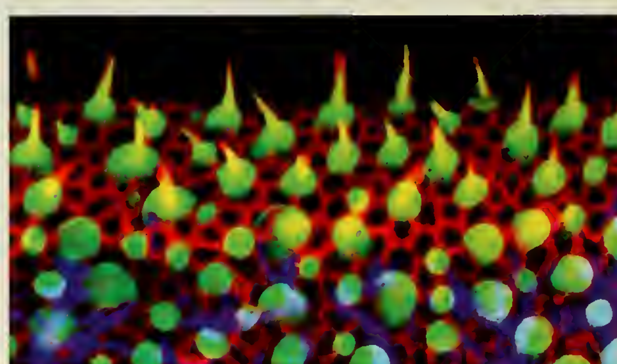

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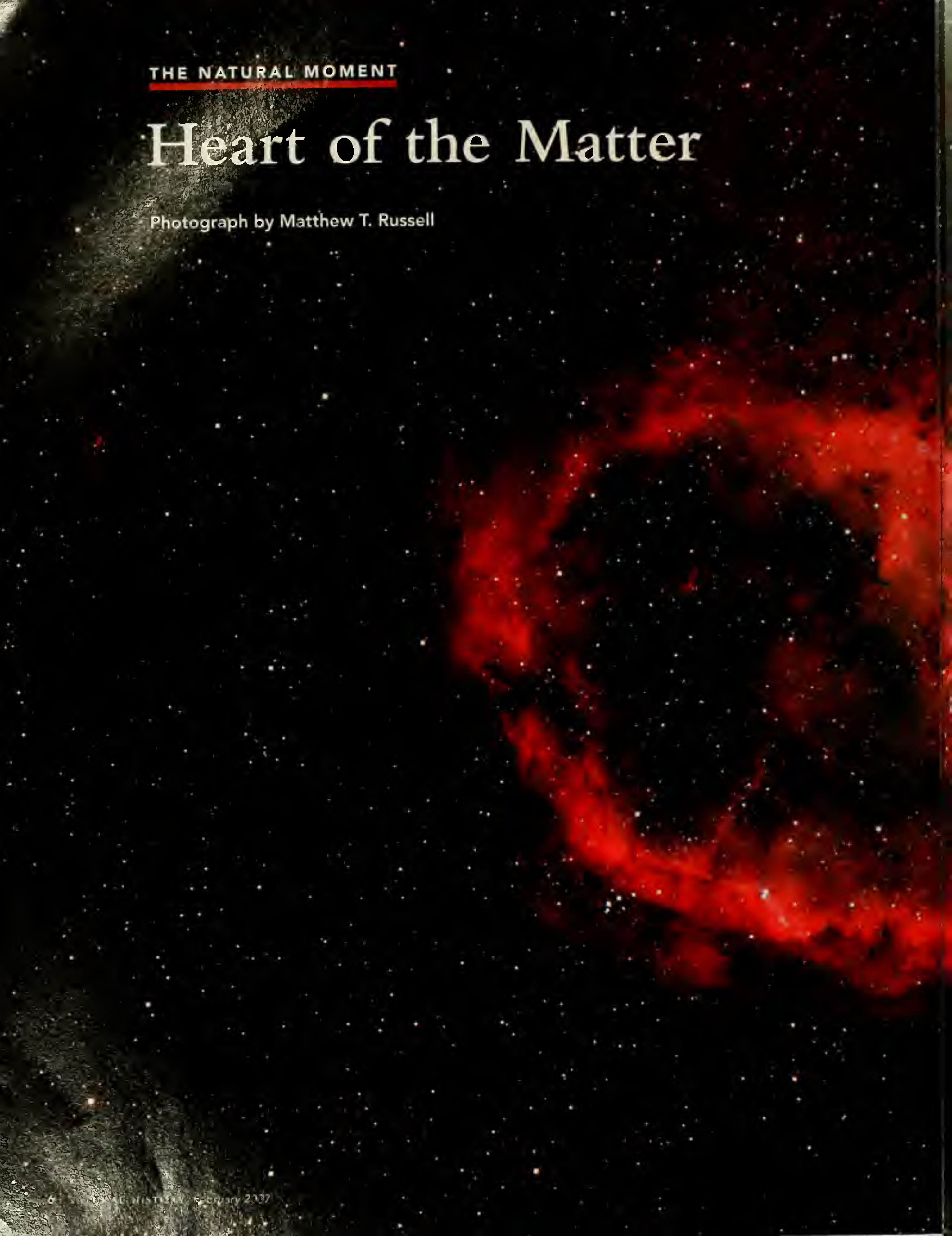
THE NATURAL MOMENT

Heart of the Matter

Photograph by Matthew T. Russell



◄ *See preceding two pages*

Revealing your heart to someone takes time. In the case of IC 1805—a hot cloud of gas near the constellation Cassiopeia—the revelation has taken 7,500 years. That's how long light from the cloud must travel through space to reach Earth. But close observers of the sky will find the long-distance relationship rewarding: through even a small telescope, the light from IC 1805 makes the pattern that inspired the cloud's common name, the Heart Nebula.

The Heart Nebula owes its color, size, and heart shape chiefly to a group of young, energetic stars clustered together in the nebula's center. The hot young stars emit ultraviolet radiation that, in turn, excites the gas around them. Most of the excited gas particles are hydrogen ions, so when those ions "relax" and recombine with free electrons, they throw off their extra energy as deep red light.

Photographer Matthew T. Russell caught the nebula on a charge-coupled device rigged to a four-inch refracting telescope this past September, from his personal observatory in Black Forest, Colorado. He tracked the patch of sky to make a five-and-a-half-hour exposure of the nebula, using four color filters to separate and recreate the nebula's colors.

As telescopes of Hubble-like proportion compete in a kind of technological arms race in space programs around the globe, Russell's photograph proves that the backyard telescope still has amazing potential, too. After all, who said you have to be big to capture a heart? —*Erin Espelie*

Hominid Time Machine

The year is 3.2 million B.C., the light is flattering, and for once, Og's face isn't covered with blood, grime, and the infected bites of tsetse flies. Doesn't someone have a digital camera? Regretfully, no. And no one, to my knowledge, has unearthed a pinhole image from that luminous day, inadvertently recorded for posterity on some nearby photosensitive rock.

So we're stuck. If today's descendants of Og and his tribe—us—want pictures of our distant ancestors for the mantel, we have to make 'em ourselves. Fortunately, the project is intriguing enough to attract institutional support and inspire such long-term organizational discipline that the most talented scientists and artists in the world find their way into the field. Meet Gary J. Sawyer *(near right)*, Viktor Deak *(far right)*, and their friends.

Sawyer is a physical anthropologist at the American Museum of Natural History in New York City; Deak is a paleoartist with that rare kind of virtuosity that can blow you away. Richard Milner and Ian Tattersall tell the story of their collaboration, and the history of their predecessors, in the text that accompanies the extraordinary images you'll find in "Faces of the Human Past" (page 22).

Yet isn't it presumptuous to suppose that an artist can envision such a distant past? Deak is explicit about his assumptions. With fossils from just one side of a face, his renderings are bilaterally symmetric. The underlying facial muscles lie at carefully calculated points along the anatomical path between contemporary primates and humans. Many of Deak's subjects look healthy, well fed, uninjured—artistic license, one might think—but he points out that modern gorillas are quite careful about their appearance. Even hair has an empirical basis: its thickness and coarseness reflect assessments of diet, activity level, and the role of sexual selection. The computer has become a powerful tool: in Photoshop, Deak can borrow what he wants from scores of images of contemporary primates, cutting and pasting so profligately that a single final image may be made up of 250 digital "layers" and consume a gigabyte on his hard drive.

• • •

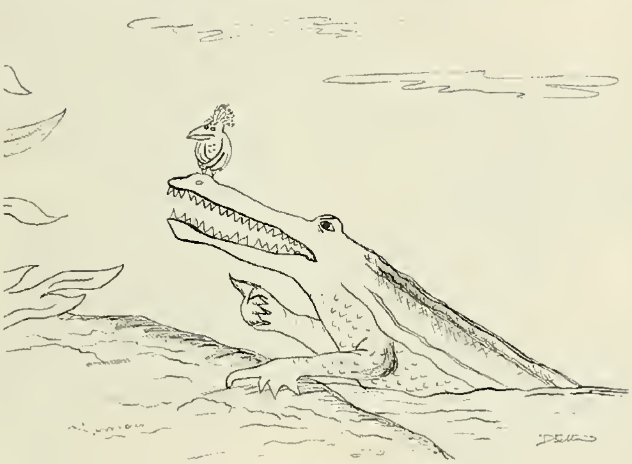
Even though my editorial colleagues and I are "ink-stained wretches," devoted to *Natural History* as a print magazine, we understand that many readers today are informed and entertained through many other media. So won't you please write and tell me what you'd most like to see us add to our Web site? Take a look at the current site (www.naturalhistorymag.com) and then send your thoughts and suggestions to me by e-mail at nhmag@naturalhistorymag.com, or by mail at: *Natural History* Web Site, 36 West 25th Street, fifth floor, New York, NY 10010. —PETER BROWN

Darwin's Progress

I was somewhat startled by Laurence A. Marschall's statement, in his review of *Darwinism and Its Discontents* [10/06], that "nothing about the process of natural selection guarantees that things must get better with time." That may be true in some narrow, technical sense, but I am puzzled how anyone can examine the history of life on Earth and not notice the persistent drive toward complexity, culminating in human consciousness.
Dwight Brown
Kerrville, Texas

LAURENCE A. MARSCHALL REPLIES: Dwight Brown concedes that the undirected character of natural selection may be true in a technical sense, but he misses the point that the technical details of evolution are precisely what natural selection is about. The forces that determine the proliferation of one genotype over another are those of random mutation and population statistics, not a natural or supernatural tendency to culminate in complex creatures like us.

There is, to be sure, a superficial appearance of progress, as Mr. Brown notes. Statistically, that is not surprising: complex creatures are more likely to appear late in the evolutionary sequence rather than early. But does that imply that we should single out those complex creatures as some end product? Far more new species of bacteria and viruses have evolved in the past week, it is safe to say, than all the hominid species that have ever evolved. Does that imply evolution aims to produce bacteria? Hardly.



"You're the dinosaur, not me."

Elephant's Thermostat

I must quibble with the illustration on pages 54 and 55 of John Tyler Bonner's article, "Matters of Size" [11/06]. The gazelle-size elephant wouldn't be able to maintain body temperature without some fur. Likewise, it would lose too much heat through radiation from those big floppy ears. Conversely, the giant elephant would overheat without a better means of dissipating heat. As the text of the article makes clear, there are many effects of scaling beyond just the mechanical strength to support the body.
Jonathan Turetsky, D.VM.
East Hampton, New York

JOHN TYLER BONNER REPLIES: Jonathan Turetsky is not quite on the mark, because the metabolic rate of the small hypothetical elephant would be much greater than that of the larger ones, which would help compensate for the problems he raises. But the point of that figure was simply to show that in a larger quadruped the legs must be thicker to support the increase in weight.

Light on the Dark

In "Times of Our Lives" [11/06], Robert L. Jaffe states that "like a sales tax, the dark energy is a fixed percentage of the newly created volume of space." implying (at least to a novice like me) that some sort of continuous creation is going on. Otherwise, it would seem that the "new" dark energy must have existed somewhere else in the universe, and just have been transferred to the new location. Please set me straight.
Fletcher Downey
Grass Valley, California

In his breathtaking article Robert Jaffe talks about a shift between matter and dark energy. Why should there be such a shift, and where is it originating from?
Lika L. Levi
Scarsdale, New York

ROBERT L. JAFFE REPLIES: No one can stand outside our universe and watch it expand in three dimensions, but perhaps Fletcher Downey will find its two-dimensional analog helpful. Our universe is like the (two-dimensional) surface of a balloon as it is blown up. The galaxies, like spots inked on the surface of the balloon, are flying apart from one another and, as the balloon expands, new space is created. Furthermore, just as energy is stored in the taut surface of the expanding balloon, dark energy is also built up in the new space created by the expanding universe.

The "shift" that Lika L. Levi mentions comes about because the amount of matter in the universe is fixed, but the amount of dark energy grows as the universe expands. In fact, dark energy helps drive the expansion to go faster, so more dark energy causes more expansion, and in turn even more dark energy. The positive feedback makes the expansion of the universe rapid indeed once dark energy dominates: eventually it will cause the universe to "inflate" in much the same way that it did in the early "inflationary" era.

Taking Turns

Donald Goldsmith ["Turn, Turn, Turn," 12/06–1/07] describes three periodic motions of Earth: a daily rotation, a yearly revolution, and the 25,785-year precession of the rotation axis. There are two additional periodic motions—the

(Continued on page 12)

CONTRIBUTORS

An astrophotographer who works out of his own personal observatory in Black Forest, Colorado, **MATTHEW T. RUSSELL** ("The Natural Moment," page 6) gathers light from distant objects in the universe for several hours (if not multiple nights) to expose a single photograph. His images have been featured widely in publications such as *Astronomy* magazine and a recently released book by the late Carl Sagan, *The Varieties of Scientific Experience: A Personal View of the Search for God* (Penguin Press, 2006). Check out www.telescopes.cc for more of Russell's photographs of the night sky.

Milner

Tattersall

RICHARD MILNER and **IAN TATTERSALL** ("Faces of the Human Past," page 22) have been closely following the reconstructions of early hominids by Gary J. Sawyer and Viktor Deak, some of which will appear in a new hall of human origins that opens this month at the American Museum of Natural History in New York City. The reconstructions also appear in the book *The Last Human: A Guide to Twenty-two Species of Extinct Humans,* which is being published this month by Yale University Press, and from which the photographs that accompany this article have been selected. Milner is an associate in anthropology at the American Museum, and a contributing editor at this magazine. His book *Darwin's Universe* will be published this year by the University of California Press. Tattersall, a curator in the division of anthropology at the American Museum, oversaw the installation of the museum's Hall of Human Biology and Evolution in 1993 and has been co-curator of its newly updated successor. A frequent contributor to *Natural History,* Tattersall is the author of several books, most recently, with Rob DeSalle, *Human Origins: What Bones and Genomes Tell Us about Ourselves,* which will be published this month by Texas A&M University Press.

Growing up in Victoria, British Columbia, in a family fond of sailing, **JENNIFER A. MATHER** ("Eight Arms, With Attitude," page 30) was often on or near the ocean. Originally fascinated by shore animals, she eventually came to study one of the full-time inhabitants of the sea, the octopus. A primary focus of her research is comparative cognition, the patterns and "specialties of thinking" in many different animals. Collaborating with Roland C. Anderson of the Seattle Aquarium, she conducted the laboratory studies she describes in these pages. Mather is a professor of psychology at the University of Lethbridge in Alberta.

As an undergraduate, **LINDA S. RAYOR** ("Family Ties," page 38) landed her first paying job observing how mother macaques interact with their offspring. Little did she realize at the time that her own research would explore similar interactions—mother-young behavior that helps structure social organizations—but in quite different creatures: the amblypygids, or whip spiders, that she describes in her article (and displays above), as well as ground squirrels, huntsman spiders, and prairie dogs. Rayor is at work on a book with a colleague, Cole Gilbert, and a photographer, Joseph Warfel, on spider behavior. She is a senior research associate in the entomology department at Cornell University in Ithaca, New York.

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(Continued from page 9)

Milankovitch cycles—one associated with a change in the Earth's tilt, with a period of 40,000 years, and another associated with a change in the eccentricity of Earth's orbit around the Sun, with a period of 100,000 years. The latter motion has had the biggest impact on Earth's climate, resulting in a 100,000-year cycle of ice ages and warming periods.
Matthew Brzostowski
Houston, Texas

Could Donald Goldsmith explain why precession doesn't affect when in the year the seasons occur? From the diagram on page 22 it would appear that the time of year that winter and summer occur should switch every 13,000 years.
Elliot Ofsowitz
Sarasota, Florida

DONALD GOLDSMITH REPLIES: Matthew Brzostowski is correct that in addition to the slow wobble of its rotation axis, the Earth has an even slower cycle of change in the amount by which its rotation axis tilts from being perpendicular to its orbital plane, and another slow cyclical change in the elongation ("eccentricity") of its orbit. Those cycles, often collectively referred to as the Milankovitch cycles, are worthy of examination in a future article.

The answer to Elliot Ofsowitz's question depends on the difference between the tropical and sidereal years. The tropical year is the time interval from one vernal equinox to the next. Precession affects that interval, but, by definition, the seasons must always occur at the same times of the tropical year, because the vernal equinox always marks the beginning of spring in the Northern Hemisphere. The sidereal year is the time for Earth to complete an orbit with the respect to the so-called fixed stars. Hence it determines which stars (and constellations) appear in the sky in various months. Precession leads to a repetitive cycle in the night sky, with respect to the seasons of the tropical year.

DMZ Paradox

I found Mary Mycio's essay "Chernobyl Paradox" [4/06] fascinating reading, all the more so because I had just returned from a trip to South Korea and the Demilitarized Zone (DMZ) that separates South and North Korea. With nothing except watchtowers along the 2.5-mile-wide strip that divides the entire peninsula, fauna and flora thrive there. If the two countries become peacefully united, one hopes the area could be left as a nature preserve.
Howard S. Edelstein
New York, New York

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Cloudmakers

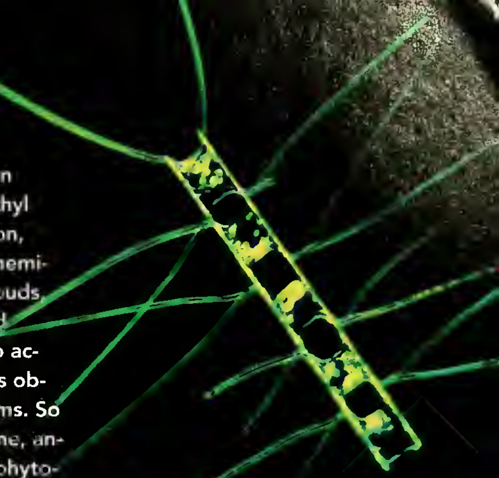
Phytoplankton—single-cell marine organisms—may be microscopic, but they can also play a sizable role in regulating the Earth's climate. A recent study of their chemical emissions could change climate forecasts, though whether for better or worse remains unknown.

The chemical emissions form airborne particles around which water droplets grow, giving rise to clouds. Warmth causes phytoplankton to multiply, but the clouds they make filter the Sun's rays, cooling the Earth's surface. The system has been known for two decades.

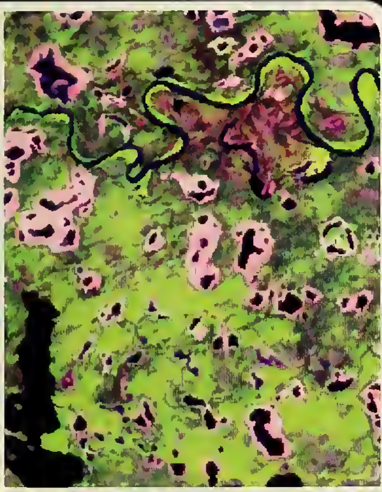
Two atmospheric scientists, Nicholas Meskhidze, now at North Carolina State University in Raleigh, and Athanasios Nenes of the Georgia Institute of Technology in Atlanta, studied satellite images of an immense, periodic bloom of phytoplankton in a remote area of the Southern Ocean. Sure enough, when the bloom waxed, the clouds overhead became bigger, denser, and more opaque to solar energy than when the bloom waned.

But Meskhidze and Nenes discovered a gap in that tidy logic when they ran a computer simulation of the Southern Ocean system. The dimethyl sulfide from phytoplankton, long thought to be the chemical responsible for the clouds, couldn't consistently yield enough water droplets to account for the extra clouds observed during large blooms. So the team plugged isoprene, another chemical made by phytoplankton, into the model—and out popped the extra clouds.

If confirmed at sea, that chemical shake-up will force climate models to replace some dimethyl sulfide with isoprene, a chemical whose properties may change climate forecasts in unforeseen ways. What's more, how phytoplankton will respond to global warming remains unknown. If they flourish, more clouds may put some brakes on the warming. If their populations crash, fewer clouds may accelerate the warming instead. And phytoplankton also affect climate by absorbing carbon dioxide, a major greenhouse gas. Never underestimate the power of the very small! *(Science)* —Rebecca Kessler



Chaetoceros sp., a marine phytoplankter, magnified 1,600×



False-color satellite image of Alaskan lakes was made in 2001. The 1952 lakeshores (pink overlay) show what has been lost.

Out to Dry

Lakes in Alaska are vanishing, and the most probable culprit is—you guessed it—global warming. A trio of ecologists led by Brian Riordan at the University of Alaska Fairbanks analyzed aerial images from the past half-century to track changes in the surface areas of the lakes in nine regions throughout the state.

The investigators spatially aligned digitized aerial photographs from the 1950s, infrared aerial photographs taken between 1978 and 1982, and digital satellite images taken between 1999 and 2002, then manually outlined each lake in the images. The result is a meticulous inventory of more than 10,000 lakes. The investigators then estimated the change in the number of lakes and the area of their surface waters. They also compiled meteorological data for each of the nine regions.

Since the 1950s, they discovered, the total surface area of the lake water in eight of the nine study regions shrank by 4 to 31 percent. What's more, the total number of lakes in all nine regions declined by 5 to 54 percent. And mean annual temperatures increased significantly.

The shrinkage could be caused by any of several effects of rising temperatures, the ecologists argue: increased water loss through evaporation, increased transpiration by nearby vegetation during the longer, warmer growing seasons, or increased drainage into the surrounding soil as the permafrost thaws. In any case, the phenomenon may be a first sign of more widespread changes to come. *(Journal of Geophysical Research)* —Graciela Flores

Bug Life

How will insects, the most abundant animals on Earth, respond to a warmer climate? The answer lies in a basic tenet of biology: at higher temperatures, biochemical reactions happen faster. The principle is particularly relevant for insects and other ectothermic organisms, whose body temperatures depend on the environment.

Consequently, some biologists argue that "warmer is better": species adapted to warmth should always out-reproduce their cold-adapted cousins. Those biologists reason that biological processes—locomotion, metabolism, reproduction, and the like—in organisms from cold regions inevitably run more slowly than in their counterparts from warmer climes. But other investigators counter that natural selection can enable cold-adapted organisms to achieve rates of reproduction and other processes that match those of warm-adapted species.

To probe the issue in insects, Melanie R. Frazier, her graduate adviser, Raymond B. Huey, an evolutionary physiologist at the University of Washington in Seattle, and a colleague compiled data on rates of population growth in sixty-five insect species. The team discovered that at their optimal temperatures, species from warm regions tend to be more prolific than species from cold regions. The results support the "warmer is better" hypothesis.

The results also highlight a largely unforeseen consequence of global warming: an overabundance of insects. Frazier estimates, for instance, that a warming of just two Fahrenheit degrees would nearly double the number of offspring from a single whitefly *(Bemisia argentifolia)*, a crop pest that already produces 1.3 million offspring in a three-month period.

Of course, not all insect species will adapt to warmer temperatures. Some will disappear and others will move to cooler regions. But perhaps, as in B movies, the ones that remain will indeed take over the world. *(The American Naturalist)* —G.F.

But Did They Do It?

When early modern humans spread through Europe some 35,000 years ago, they almost surely met Neanderthals. But did members of the two groups mate and procreate before the Neanderthals died out? The question has spurred debate since soon after the first Neanderthal fossil was unearthed in 1856. A number of anthropologists think the two groups were similar enough biologically, and perhaps even behaviorally, cognitively, and socially, that sexual encounters—and the offspring thereof—were inevitable. Others, however, contend that the two groups' genes never mingled. A flurry of new discoveries in the fossil and genetic records strengthens both sides of the argument, leaving the central question unanswered.

New evidence that interbreeding took place comes from Bruce T. Lahn, a geneticist at the University of Chicago, and several colleagues. Writing in the journal *PNAS,* they report tracing the history of an allele, or version, of a gene that regulates brain size, and discovering that it originated in archaic hominids some 1.1 million years ago. That was around the time the lineage leading to modern humans branched off, sans allele. The allele later appeared in the modern human genome around 37,000 years ago. Lahn proposes that the allele was introduced to the modern human genome through interbreeding—perhaps even a single one-night stand—between a Neanderthal or other archaic hominid and an early modern human.

Erik Trinkaus, an anthropologist at Washington University in St. Louis, Missouri, and two colleagues recently examined 31,000-year-old modern-human bone fragments from Romania. As with other remains he has studied from the same period, Trinkaus writes in *PNAS* that the bones exhibit a mixture of modern human and Neanderthal traits. The latter include a distinctive bulge in the back of the skull, characteristic muscle-attachment points on the lower jaw, and shoulder blades that lack adaptations for throwing. Because not all of his samples share the same Neanderthal-like traits, Trinkaus argues that early modern humans, which formed the larger population, gradually absorbed the Neanderthals, begetting hybrids along the way.

Two recent studies of the Neanderthal genome, by contrast, suggest that the two groups are unlikely to have interbred. Both are based on genetic material initially isolated from a 38,000-year-old Neanderthal femur by Svante Pääbo, a paleogeneticist at the Max Planck Institute in Leipzig, Germany, and his colleagues. Pääbo's team, writing in *Nature,* and another group led by Edward M. Rubin, a geneticist at the Joint Genome Institute in Walnut Creek, California, writing in *Science,* independently compared portions of the Neanderthal genome to our own and to that of chimpanzees. Both teams concluded that even though the modern human and Neanderthal genomes are more than 99.5 percent identical, the two groups diverged around 400,000 years ago, and interbred little, if ever, during the intervening years.

Although no signs of interbreeding or the allele studied by Lahn have yet surfaced in the Neanderthal genome studies, investigators can't rule out the theory that early modern humans and Neanderthals produced offspring until the Neanderthal genetic blueprint is completed, probably in late 2008. Even then, however, the genome of a single Neanderthal won't tell the whole story about interactions between the two groups.

"The debate," says Osbjorn M. Pearson, an anthropologist at the University of New Mexico in Albuquerque, "is as alive as ever."

—*Corey Binns*

The Beast of Kings

Two medieval lions have lurked unnoticed in the Natural History Museum in London for decades. Their skulls, along with those of a leopard and nineteen dogs, were discovered during a 1937 archaeological excavation of the Tower of London. But their significance has only now been made clear. Radiocarbon dating by Hannah O'Regan, an archaeologist at Liverpool John Moores University in England, and two colleagues shows that the two lions are the only big cats ever unearthed that date to medieval Britain.

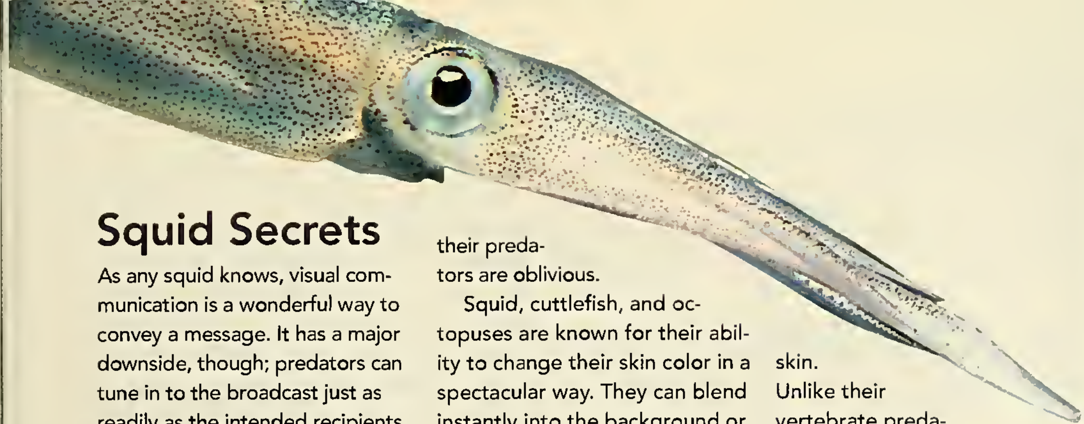
Skull of a lion kept in London's Royal Menagerie in medieval times

The lions, which lived between the thirteenth and fifteenth centuries, and the more-recent leopard (alive sometime between 1440 and 1625) were part of the Royal Menagerie established in London by King John, who reigned from 1199 to 1216. A section of the Tower of London called the Lion Tower housed an array of exotic creatures that, despite their rarity and connotation of royal power, were sometimes the star attractions in blood sports, such as baiting by dogs. Records from the mid-sixteenth century indicate that the Tower's animals weren't exactly housed in luxurious conditions, either: they lived in cages so cramped they had little room to turn around. In 1831 the last surviving inmates were moved to the newly established London Zoo, and the Lion Tower was demolished two decades later. After they died, the bodies of the lions, leopard, and dogs appear to have been unceremoniously dumped in the Tower of London's moat. *(International Journal of Osteoarchaeology)*

—*Nick W. Atkinson*

Silent Alarm

It pays for lovelorn male *túngara* frogs to listen while they call for mates in the dangerous jungle twilight. A sudden silence that interrupts the chirping, chucking, trilling, and whining of a frog chorus might herald the arrival of an unwelcome

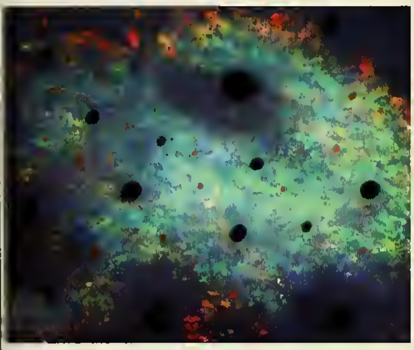


Squid Secrets

As any squid knows, visual communication is a wonderful way to convey a message. It has a major downside, though; predators can tune in to the broadcast just as readily as the intended recipients (other squid) can. A recent study by Lydia M. Mäthger and Roger T. Hanlon, both biologists at the Marine Biological Laboratory in Woods Hole, Massachusetts, suggests that squid—and most likely their close relatives, cuttlefish and octopuses—have evolved a secret communication channel to which their predators are oblivious.

Squid, cuttlefish, and octopuses are known for their ability to change their skin color in a spectacular way. They can blend instantly into the background or produce a startling array of patterns and hues to express their physiological or motivational state [see *"Eight Arms, With Attitude," by Jennifer Mather, page 30*]. The secret to the show is the two distinct layers of cephalopod skin: The inner layer of iridophore cells is both iridescent and reflects polarized light. The outer layer is made up of pigmented organs, or chromatophores, which expand or contract to help change the color or pattern of the skin.

Cuttlefish, octopuses, and squid have a visual system to match the complexity of their skin. Unlike their vertebrate predators, they can detect differences in polarized light. Mäthger and Hanlon discovered that the two skin layers work independently, and that by taking advantage of the reflective properties of the iridophores, squid may be able to communicate with other squid via polarized light. At the same time, the squid can camouflage themselves from predators by altering the color pattern in the chromatophore layer, through which polarized light travels freely. What happens among squid stays among squid! *(Biology Letters)* —*N.W.A.*



Squid skin (left, magnified 9×) has an inner layer that is iridescent and transmits polarized light through dark, overlying camouflage spots. Common squid is pictured at top.

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bat, snake, or other predator. A study by Steven M. Phelps, a zoologist at the University of Florida in Gainesville, and two colleagues now suggests that male túngaras *(Physalaemus pustulosus)* don't listen just for their own species' refrain, they eavesdrop on other species, too.

To determine how much attention túngara frogs pay to the calls of their own and other species, Phelps's team fooled captive male túngaras into thinking they were under attack. The team played a túngara chorus, then interrupted it while mimicking the appearance of an aerial predator (they slid a plastic plate along an overhead wire). After a brief pause, they presented the túngaras with one of four stimuli: the recorded call of a single frog of one of three species or silence (as a control). Then they measured how quickly and vigorously the túngaras resumed calling.

The investigators discovered that male túngaras pay nearly as much attention to the calls of *Leptodactylus labialis* frogs as they do to those of their own species. What was important about *L. labialis* was its geographically overlapping range, not the sound of its calls: the túngaras all but ignored a closely related species, *P. enesefae*, whose calls are similar to their own, but whose range does not overlap. Phelps surmises that túngaras attend to species with overlapping ranges because they share the same dangers of predation.

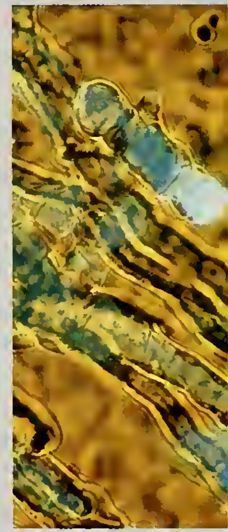
By eavesdropping on the calls of other frog species, túngaras can maximize both survival and reproduction: they enhance their predator early-warning system while reducing their time spent in silence. After all, the jungle rewards with mates or punishes with death in an instant. *(Behavioral Ecology)* —*N.W.A.*

Male túngara frog sings for a sweetheart.

Vitriphagy

Microorganisms can live in the most extreme environments, feed on a host of seemingly inedible materials, and thrive on improbable sources of energy. Can they possibly still surprise us? Try this: they feed on glass inside submarine volcanoes.

Recently Hubert Staudigel, a marine volcanologist at the Scripps Institution of Oceanography in La Jolla, California, and four colleagues published a comprehensive paper augmenting the evidence that distinctive pitting in underwater volcanic glass from around the world is of biological origin. The evidence includes telltale microscopic textures in the glass, such as spiral tunnels and branching tunnels, which are hallmarks of microbial activity. The paper also points to the presence of carbon isotopes characteristic of life, as well as microbial DNA, in the tunnels. The microorganisms apparently dissolve the glass with acid.



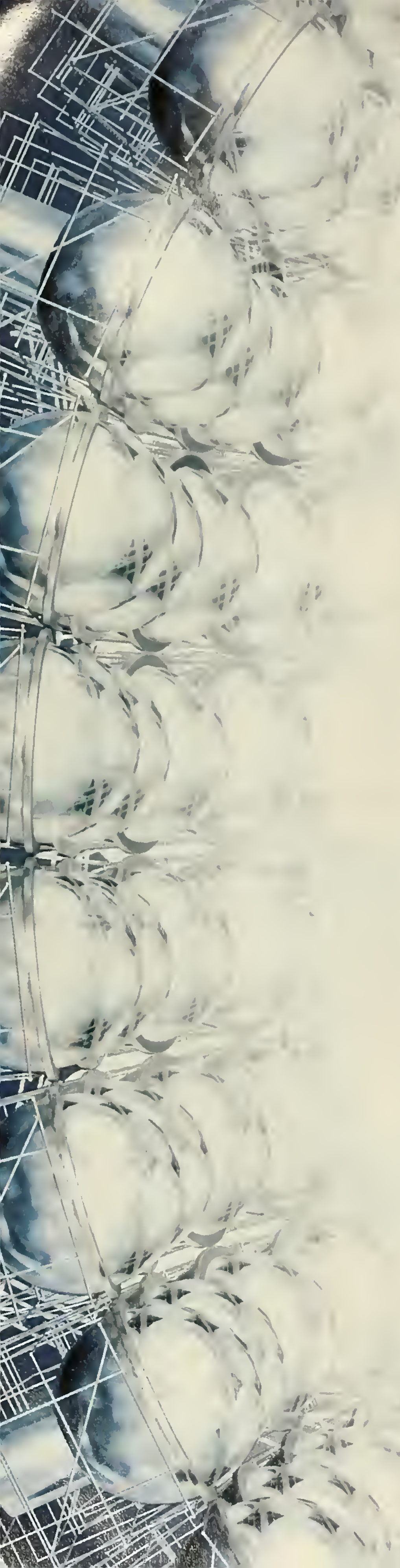
Volcanic glass altered by microorganisms, magnified 2,500×

The evidence for glass alteration by microorganisms occurs throughout the uppermost thousand feet of oceanic crust, suggesting that the process may be playing an important role in cycling elements between seawater and the seafloor. And because volcanic glass dates to 3.5 billion years ago, the authors argue, it might be just the place to look back in time for the most ancient forms of life. *(GSA Today)* —*G.F.*

Little Neutral Ones

In John Updike's memorable description, "The earth is just a silly ball/To them, through which they simply pass."

By Neil deGrasse Tyson



You'd never know it, but 6 trillion subatomic particles pass through every square inch of your body every second at nearly the speed of light. Most are leftovers from the big bang, but others arrive fresh from their superhigh-energy origins near black holes, deep inside gamma-ray bursts and supernovas, and within the core of our Sun. They zip across space, pass through your flesh and bones as though you didn't exist, and continue heedlessly on their way.

Before these particles were actually discovered, the Austrian physicist Wolfgang Pauli hypothesized their existence. In a letter to his colleagues, written in December 1930 and addressed to "Dear Radioactive Ladies and Gentlemen" (yes, that's physics humor), Pauli proposed an electrically neutral particle that he called a neutron. It was, he admitted, "a desperate remedy to save . . . the law of conservation of energy"—a law that, to the surprise of his colleagues, appeared to be failing on the subatomic level.

Two years later the English physicist James Chadwick discovered a relatively massive neutral particle residing contentedly in the atomic nucleus. Soon the name "neutron" was bestowed on it. But that nuclear neutron was not Pauli's; his hypothetical savior had to be much less massive. A year later the Italian physicist Enrico Fermi named Pauli's still-undiscovered particle the neutrino, Italian for "little neutral one."

Photomultiplier tubes catch the flash of blue light generated by a neutrino interacting with an atom in a detector deep underground.

Along with the photon, the electron, and the less-familiar quark, the neutrino lays claim to being one of the fundamental, indivisible building blocks of nature. Pauli had tactfully remarked in his 1930 letter that if such a particle existed, physicists should already have seen one. Not long afterward he confessed, in a candid assessment of what he had wrought, "I have done a terrible thing. I have postulated a particle that cannot be detected."

But it could be. Indeed, it was. Just after the Second World War two American physicists, Clyde L. Cowan Jr. and Frederick Reines, realized that the place to search would be a nuclear reactor, where, as in a nuclear bomb, disruptive changes to atomic nuclei lead to the prodigious emission of neutrinos. So they looked in the Savannah River Plant, a just-finished underground fission reactor near Aiken, South Carolina, built to produce tritium and plutonium for the Cold War nuclear arsenal of the United States. The physicists' first task was to find a way to capture these most antisocial of particles. Their second task was to disentangle the properties, behavior, and effects of the neutrino from those of all other subatomic particles liberated by their experiment. In 1956, based on their detection of a unique particle "signature," they announced the discovery of the neutrino.

Pauli proposed his new particle because of his confidence in the laws of conservation, which are among the most highly tested and fertile ideas in science. "Conservation," to a physicist, does not refer to recycling or to safeguarding endangered habitats. It's the shorthand way to say that certain properties of nature remain unchanged during a controlled experiment, no matter what you do to it, no matter what anybody else does to it, and no matter what nature does to itself. Conserved properties include momentum, the total quantity of mass and energy, and the net electric charge. Run the experiment, and when you're done, the stuff you take out of the box must be the same as the stuff you put into the box—for all properties described by the laws of conservation.

Take momentum, which is motion coupled with direction. Imagine twin ice skaters standing still and facing each other, palms touching. This two-skater system has zero momentum, and since it's resting on slippery ice, it has only negligible attachment to Earth. If the twin skaters—two objects with the same mass—push away from each other, they will glide apart in opposite directions at the same speed. The momentum of one skater cancels that of the other, leaving the system as it started, with a net momentum of zero.

Arithmetically, momentum is just mass times velocity, so various kinds of pairs can still cancel. For example, if one skater has twice the mass of the other, the chubbier one will glide away at half the speed of the thinner one, again leaving the system's total momentum at zero. Rockets do much the same thing. Spent fuel spews out the back while the body recoils forward, leaving the momentum of the entire system unchanged from its prelaunch repose on the launch pad.

Even when rocket engines are anchored to the ground while fired (which is what goes on at testing facilities), something's got to give. Typically, the rockets are mounted horizontally and connected securely to Earth by cement piers. When the high-velocity exhaust blasts out the nozzles, it's planet Earth that recoils, ever so slightly, in the opposite direction. So a lazy but perverse engineer could point all the world's test rockets due east—in the direction of Earth's spin—and ignite them, just to shorten the workday.

The conservation of total mass and energy has illustrious roots. Before Einstein proposed his most famous equation, mass-energy conservation was instead the conservation of mass and, separately, the conservation of energy. The universe was endowed with a certain amount of each, presumed from the experiments of the day to be changeless. But at the turn of the twentieth century, the discoveries of radioactivity and other bizarre phenomena within the atom indicated that mass could become energy, and energy could become mass. The conversion recipe was none other than $E = mc^2$.

Another conserved quantity is electric charge. Protons carry a unit of positive charge, electrons carry the same amount of negative charge, and neutrons carry no charge at all. Charge conservation requires that at no time during an experiment is the net charge anything other than what you started with. And that's as true for particle accelerators on Earth as for supernova explosions in distant galaxies.

Armed with the conservation laws of momentum, mass-energy, and electric charge, you're more or less where Pauli was in 1930. Back then, life was simpler. Particle physicists were not yet talking about quarks, muons, gluons, or Higgs bosons. What they did discuss was a subatomic process called beta decay, in which a proton and an electron spontaneously fly apart, accompanied by unbalanced momentum and a loss of mass-energy. Had the conservation laws lost their grip on nature? Or could the existence of an unforeseen and undiscovered particle resolve the conundrum?

Discoveries in physics often emerge from one's confidence in competing ideas. Rather than dismantle the foundations of physics, Pauli postulated that the escaping proton and electron (both later shown to have come from a decayed neutron) were not the sole products of the decay. His additional

particle was to have no charge, some momentum, and vanishingly small, possibly zero, mass-energy.

Turns out, the key to beta decay was not the neutrino but its antimatter counterpart, the antineutrino. A decaying neutron yields a proton, an electron, and an antineutrino. Under the dictates of additional conservation laws, unknown to Pauli and his contemporaries, that's just what you'd expect. Two of those laws decree that no process can change the net numbers of heavy particles (baryons) and light particles (leptons). If your experiment starts with one baryon (a proton or a neutron), it must end with one baryon. That means a neutron can morph into a proton. And if it starts with zero leptons (an electron or a neutrino), it must end with zero leptons.

Wait a minute. Beta decay starts with zero leptons but ends with two leptons: an electron and an antineutrino.

Not to worry. The antineutrino is not simply a light particle; it's an anti–light particle. So in the particle count, an electron and an antineutrino cancel, resulting in zero net leptons. The laws of conservation triumph yet again.

Pauli died in 1958. Fortunately for him, he lived just long enough to see Cowan and Reines detect his "undetectable" particle. Today neutrinos remain among the most challenging subatomic particles to catch, even though everybody and everything is steeped in trillions of them. Problem is, they interact so rarely with other kinds of matter that you need enormous, clever traps to boost your chances of detecting any at all.

Nearly all the evidence for neutrinos from space comes from detectors buried deep underground, which hold enormous quantities of odd liquids surrounded by unusual hardware. These underground "telescopes" can catch intrepid neutrinos from any direction, even those that have passed all the way through Earth from below. In one detector the neutrinos enter a tank filled with 600 tons of chlorine-laden dry-cleaning fluid. Every so often, in a kind of reverse beta decay, one of the passing neutrinos changes a resident neutron within a chlorine atom into a proton, thereby changing the chlorine to radioactive argon. The presence of an argon atom serves as a tracer of the neutrino's visit. Other creative designs track the flash of blue light emitted by the particle products of neutrino interactions. Those tanks are filled with ultrapure water or a mixture of baby oil and benzene.

My favorite setup, though, is a not-yet-finished neutrino observatory called IceCube. Its "tank" is a cubic kilometer of clear, dense Antarctic ice, in which the investigators will suspend a lattice of sensors, lowered through deep holes melted by a hot-water drill.

Unfortunately, Pauli didn't live long enough to see how populous the particle zoo would become—how many categories and subcategories and families and flavors particle physicists would postulate and discover in the decades that followed his death. Nor could he have imagined that neutrinos themselves would land in the middle of one of the greatest astrophysical conundrums of the twentieth century.

In March 1964, in the journal *Physical Review Letters,* the late American astrophysicist John N. Bahcall published his calculations showing that vast quantities of neutrinos should continually flee the Sun as the nuclear furnace in its core transforms hydrogen into helium. In a tandem paper, Bahcall's friend and colleague Raymond Davis Jr. described an experiment he was building in the disused Homestake Gold Mine in Lead, South Dakota. In search of evidence for solar neutrinos, he would place a tank of chlorine-rich liquid deep belowground. As usual, the encounters between neutrinos and atoms would be exceedingly rare; Bahcall calculated that the experiment should record about ten neutrinos a week. But even those few neutrinos would reveal what was going on in the

Sun's center, thus eliminating the need ever to visit the place.

For years, however, only about three of the ten neutrinos showed up. That gap became the tenacious "solar-neutrino problem." Some physicists copped an attitude, suggesting that astronomers didn't fully understand how the Sun manufactures energy—knowledge that underpins much of modern astrophysics. Shaken but not stirred, Bahcall was so sure the Sun was not misbehaving that he committed much of his career to demonstrating why. Meanwhile, Davis continued to refine his measurements. And the solar-neutrino problem endured.

Normally, physicists hand the laws of physics to astrophysicists, and it's those laws that guide questions and constrain answers. But every now and then, astro folks teach the physics folks a thing or two about how the universe works. Indeed, Bahcall was right all along. The missing neutrinos were there. They just weren't the kind of neutrinos that would turn chlorine into argon. Apparently, without telling anybody, they had left the Sun with one identity—the one the experiment was designed to detect—but reached Earth in a different guise, requiring a different experiment to be detected at all.

Turns out, neutrinos come in three flavors, representing three regimes of energy in the universe. Not that you asked, but they're called the electron neutrino (low energy), the muon neutrino (middle energy), and the tau neutrino (high energy). So if your apparatus is designed to detect electron neutrinos, such as the ones forged in the core of the Sun, then the other neutrinos will pass undetected. Furthermore, if your experiment is designed to detect neutrinos of any regime, but antineutrinos are what come your way, you'll miss them, too. As with so much else in life, you need to know in advance what you're looking for.

But detection is only part of the challenge. Next comes the urge to compile a list of the neutrino's properties, beyond its neutral charge and its elusiveness. How about mass? All attempts to measure this basic property had failed so miserably that, until recently, physicists were uncertain whether the neutrino had any mass at all.

Here's where things get spooky.

According to Einstein's special theory of relativity, an onlooker who views a material object traveling at ever-greater speeds will see the object's mass increase, its time slow down, and its length shorten in the direction of motion. At the speed of light, its mass would become infinite, its time would stop, and its length would shorten to zero—all of which led Einstein to the sensible conclusion that physical objects can never attain light speed. Not only that, the reverse is true as well: if the thing has no mass whatsoever (if it's

a photon, say), it must always travel at the speed of light.

So if the neutrino exists but has no mass, then it must travel at the speed of light. And if it travels at the speed of light, its own passage of time has stopped, leaving it with no internal "clock" to judge how old it is. To an outside observer, the neutrino's identity would forever be what it has ever been.

But if the neutrino has mass, it must travel more slowly than light, and must therefore bear an internal clock that actually ticks—one that recognizes the passage of time. And if the neutrino undergoes the passage of time, as other particles do, then it can transform itself. Unlike the neutron, however, which can decay into fundamental particles, the neutrino is already a fundamental particle. All it can do, then, is transform into another variety of neutrino. So if someone were to build an apparatus that could detect muon neutrinos or tau neutrinos, rather than only the garden-variety electron neutrinos detectable in Davis's setup, maybe all ten of Bahcall's neutrinos would show up.

And that's exactly what's happened.

John Bahcall had proceeded on the perfectly plausible assumption that the Sun's supply of electron neutrinos would simply remain electron neutrinos. But by the time they arrived on Earth, two-thirds of them had changed into muon and tau neutrinos, a process called neutrino oscillation. Imagine that somebody threw you a baseball, but it turned into a football in midflight. If you were looking only for the baseball, the football might pass unnoticed.

Once you know a neutrino can transform itself, you know it has a self-timer. You also know it cannot be traveling at the speed of light, which means it must have mass. As of March 2006, courtesy of a beam of muon neutrinos sent from Illinois to Minnesota, physicists can say with confidence that the mass of the neutrino is no more than 1/2,000,000 the mass of the already tiny electron, itself checking in at about 1/2,000 the mass of the proton.

Knowing that the neutrino can switch identities and has very small (but nonzero) mass, astrophysicists have revisited earlier calculations that assumed a massless neutrino. Their efforts have lengthened the list of cosmic dramas in which the neutrino plays more than a bit part. Astrophysicists have not seen the last of the little neutral ones. For all we know, neutrinos hold the answers to questions already posed, as well as to questions not yet imagined.

Astrophysicist NEIL DEGRASSE TYSON *is the director of the Hayden Planetarium at the American Museum of Natural History. He also hosts the PBS television series NOVA scienceNOW. Tyson's latest book is* Death by Black Hole: And Other Cosmic Quandaries *(W.W. Norton, 2007).*

NATURAL HISTORY
FEBRUARY 2007

Faces of the Human Past

Science and art combine to create a new portrait gallery of our hominid heritage.

By Richard Milner and Ian Tattersall
Illustrations by Viktor Deak and Gary J. Sawyer

Judging from their astonishing paintings and engraved images of animals on the walls of European caves—works that have somehow survived since prehistoric times—people have been making pictures for at least thirty millennia, and probably for a lot longer. In contrast, attempts by scientists and artists of our own day to make credible likenesses of the cave painters and their more remote evolutionary antecedents go back a mere 150 years. In fact, scientific evidence for prehistoric humans was not generally recognized much before then.

One of the earliest published reports was that of the English antiquarian John Frere, who in 1800 presented his *Account of Flint Weapons Discovered at Hoxne in Suffolk*. Workmen digging clay for bricks had come across finely worked flint hand axes in a layer of gravelly soil, sealed beneath a sandy layer sprinkled with mammoth bones. Frere concluded that the tools were "fabricated and used by a people who had not the use of metals. [They lived in] a very remote period indeed; even beyond that of the present world."

Although Frere's discovery went unnoticed until long after his death, further evidence of early humans continued to accumulate. Following the lead of the French prehistorian Jacques Boucher de Perthes, who trained workmen to search for stone hand axes in the 1840s, others began to seek and find quantities of prehistoric stone tools all over Europe. Part of a fossilized Neanderthal skull was discovered in a cave in the Neander Valley, near Düsseldorf, Germany, in

Portrait of a three-year-old female Australopithecus afarensis *(left) is based on a fossil recently unearthed at Dikika, a site in the Afar region of northern Ethiopia. An early bipedal ape that stood three and a half to four and a half feet tall when fully grown, the species was first known from the famous "Lucy" skeleton discovered just six miles from Dikika in 1974. It had a chimpanzee-size brain but humanlike tooth patterns. Lucy lived 3.2 million years ago; the Dikika child dates from 3.3 million years ago. Above: An adult male* A. afarensis *glares at an intruder while taking a cooling dip in a lake. The aquatic setting is based on recent observations of gorillas in the wetlands of the Congo forest, where they like to wade and forage for aquatic plants.*

Dissection in Reverse

To reconstruct an extinct hominid, the collaborating artist and scientist first make a urethane cast of a skull and jaw. In this example, the artist Viktor Deak and the physical anthropologist Gary J. Sawyer base their reconstruction on a 400,000-year-old skull excavated from the Spanish site of Atapuerca, a fossil some have classified as *Homo heidelbergensis*. With data from dissections of present-day animals and humans—which they and others have conducted—they meticulously rebuild layers of muscles, glands, and other tissue onto a cast of the skull, using carefully measured strips of modeling clay. The technique is known as "dissection in reverse."

Cast of the fossil, supplied by the excavators, is the starting point for the reconstruction. A silicone rubber mold is made from it, and a new urethane cast is produced.

Missing sections of the skull are reconstructed out of an epoxy compound, and any distortions are corrected (often by comparing the right and left sides).

Deepest muscle layers are sculpted in clay based on modern primate anatomy. One glass eye is set in position, with its surrounding musculature.

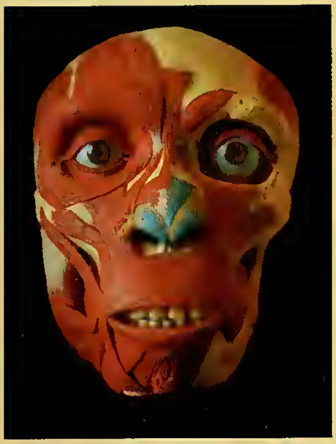
1856, a find that brought the term "caveman" into popular culture.

Beginning in 1858, when rich prehistoric deposits were discovered at Brixham Cave at Torquay, in Devon, England, the archaeologist William Pengelly developed revolutionary new techniques for conducting excavations. His systematic work at Brixham and nearby Kent's Cavern over the next two decades yielded tens of thousands of fossil animal bones and early human artifacts, and established their association in time.

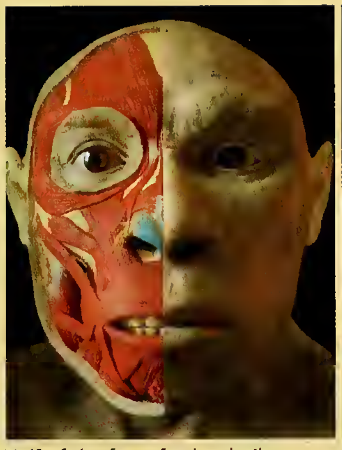
Charles Darwin's book *On the Origin of Species* shook the world in 1859 with its one-two punch: evolution by natural selection, coupled with the immensity of geologic time. The impact was seismic, but even before the book appeared, discoveries that ancient humans had lived with extinct mammoths and rhinoceroses in Britain had caused many to question traditional beliefs about human origins. In 1851 the art critic John Ruskin had lamented in a letter to a friend that his trust in biblical authority was being daily eroded by "those dreadful [geologists'] hammers." "I hear the clink of them at the end of every cadence of the Bible verses," he wrote. Now cavemen began to challenge Adam and Eve as primal ancestors in the popular imagination.

It turned out that some of the ancient "cavemen" were fine artists. In 1879 the first-known painted cave was accidentally discovered at Altamira, Spain; its images of extinct aurochs, bison, and horses stunned both the art and scientific worlds. Only rarely, however, had the ancient artists portrayed

Hominid with large molar teeth, Paranthropus robustus *(left) lived in southern Africa about 1.7 million years ago. Many fossil features, including those of the hip and thigh, attest that it was bipedal, and characteristics of the hands indicate that the animal may have been able to make and use stone tools. It was a member of a diverse group of hominids that disappeared from the fossil record by about a million years ago. Right: Adult males of the species* Ardipithecus ramidus *brandish branches to frighten off a rival band of hominids. The reconstruction is particularly speculative, because the species is still poorly known. Although a remarkably complete skeleton was discovered in Ethiopia in 1994, its condition is delicate, hampering its preparation and scientific description. The fossils date from 4.4 million years ago, making* A. ramidus *one of the earliest hominids discovered so far, but it is not considered ancestral to humans.*



Shape and size of the nose are calculated from surrounding bone attachments, and both eyes are set in place. Sculpting of superficial facial muscles is completed.



Half of the face, further built up to represent fat and other tissue, is covered with clay "skin." Using molds, textures are impressed into the surface.

Silicone rubber mold is made of the entire reconstruction, and a new cast is created in urethane rubber. Skin tones are painted onto the finished cast.

Hairs are individually punched into the skin, and finishing touches are applied. After the reconstruction is photographed, the image can be digitally enhanced.

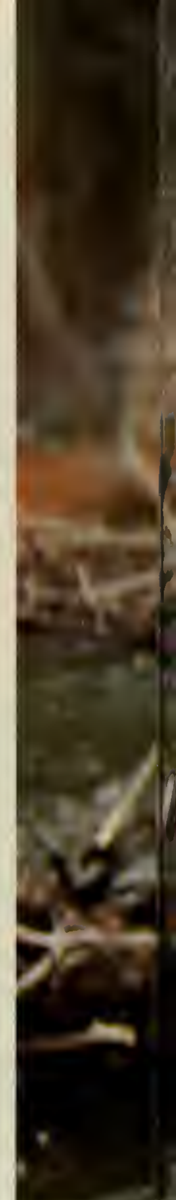
themselves, and never with the sophisticated realism they had applied to other animals. That state of affairs cried out for modern artists to reconstruct the appearance of what became an expanding roster of extinct humans and near-humans. The nascent genre of paleoart, which had originated to visualize dinosaurs and other fossil animals, expanded to portray extinct humans as well.

John Lubbock, Darwin's informal (and only) student, commissioned some of the first paintings in the new genre. The scion of a banking family that owned much of the Kentish countryside surrounding Darwin's home, Lubbock decorated his indulgent father's mansion with a collection of primitive stone tools, ethnographic artifacts, glass-enclosed colonies of social insects, and eighteen watercolor paintings of early humans going about their daily lives. The paintings, which Lubbock sponsored during the 1870s, were the work of Ernest Griset, an outstanding natural-history illustrator whose anthropomorphic animal drawings often lent whimsy to the pages of the magazine *Punch*. Lubbock himself had coined the terms Paleolithic and Neolithic, meaning old and new stone ages, respectively, in his landmark book, *Pre-Historic Times,* which appeared in 1865. The book also includes the earliest printed usage of the word "cave-man."

The undisputed king of the paleoartists was Charles R. Knight (1874–1953), who inspired all who came after him. The imperious paleontologist Henry Fairfield Osborn, president of the American Museum of Natural History in New York City from 1908 until 1933, hired the gifted young painter and teamed him with the museum's best anatomists and paleontologists. Together the teams created the most accurate and realistic reconstructions of ancient animals and early humans and near-humans that had ever been attempted. But Knight also relied on the caveman artists for his portrayals of Ice Age animals. When, in 1927, he visited the French painted caves to see the Ice Age artists' paintings firsthand, he had what he later described as "a distinct feeling of awe and admiration for the skill of the man who had painted and incised their curious outlines thousands of years ago."

One of today's preeminent paleoartists is Jay H. Matternes, based in Fairfax, Virginia, whose paintings are informed by his rich knowledge of primate anatomy and behavior. Knight often prepared for his painting of animals and cavemen by creating sculptures as reference points, carrying them onto the roof of his New York City studio at various times of day to observe where the shadows fell. Matternes has adopted the same technique. "Making a preliminary sculpture, even a quick one, to study light and shadow is a device frequently used by artists, and I have used it often," he writes.

One of the latest fruits of the vigorous tradition in paleoart is the creative collaboration between the physical anthropologist Gary J. Sawyer of the American Museum and the paleoartist Viktor Deak. (A selection of their depictions of our early relatives accompanies this article.) In their collaboration



Paranthropus boisei was a hominid with huge molars backed by powerful jaw muscles, inspiring the nickname "Nutcracker man" when the paleoanthropologist Mary Leakey discovered the first cranium of the species at Olduvai Gorge, Tanzania, in 1959. *P. boisei,* which dates from 1.8 million years ago, may have made some of the earliest crude stone tools, also found at Olduvai, but the fossils and tools are not firmly linked. Additional finds of *P. boisei* fossils have come from deposits near Kenya's Lake Turkana, which have also yielded early bones of the genus *Homo,* showing that the two hominids may have coexisted at the same time and place.

H. georgicus is named for fossils discovered at Dmanisi, a 1.8-million-year-old Georgian site in the lower Caucusus Mountains. The five crania and four jawbones unearthed there since 1991 represent the earliest firm evidence of a hominid that lived outside Africa. Its brain was small (between 600 and 700 cubic centimeters) compared to that of modern humans (which averages 1,350 cubic centimeters). The fossils were discovered in association with crude stone choppers and scrapers.

Sawyer and Deak also make sculptural busts of the ancient hominids, reflecting their knowledge of anatomy as well as clues from muscle attachments that occur in the fossil bones. Superficial features of hair and skin are partly a matter of guesswork, based on the appearance of modern humans and apes. Deak then photographs the busts, and may finally retouch the images digitally on a computer. [*See "Dissection in Reverse," pages 24 and 25*]

Both Sawyer and Deak had a childhood obsession with prehistoric humans and near-humans. Sawyer, a New Jersey native, was inspired by Knight's classic murals of dinosaurs, mammoths, and cavemen at the American Museum. Deak grew up in a leafy, suburban Connecticut town that may seem an unlikely place to dream about living the life of Neanderthals. In 1991, however, at age fourteen, he viewed a *National Geographic* television program in a science class, which showed how the paleo-artist John Gurche sculpted a reconstruction of the hominid *Australopithecus afarensis.* "I was bitten by the bug," Deak recalls. "I knew immediately that I wanted to do what he did. . . . I see myself in these people, living thousands of years ago. I'm haunted by going back in time."

As the young Deak sketched fantasies of the remote past, he did not yet realize that he would need a scientific accomplice to discipline and focus his talents. When he was twenty-six, however,

Adolescent H. ergaster *searches through swamp grass for food. The reconstruction is based on the well-preserved skeleton, found in northern Kenya, of a nine-year-old male. Known as "Nariokotome boy" (or "Turkana boy"), this individual lived 1.6 million years ago. He was of slender build with essentially modern-human proportions; when mature, he would have stood about six feet tall. Some consider* H. ergaster *the earliest fossil hominid that can properly be called human.*

he met Sawyer, who was looking at the time for an artist to work with him on reconstructions of early humans. Their partnership exemplifies a long tradition of cross-fertilization between knowledge and skill, observation and vision.

In Darwin's day, people asked, "Where is the missing link?" Today, as previously unknown varieties of humans and near-humans continue to be identified, keeping up with the pace of discovery is a continual challenge. There are so many "missing links" that paleoanthropologists don't know what to do with them all. In place of the lineal tree trunk familiar to paleoartists until the mid-1960s, paleoanthropologists have since adopted a complex branching bush that reflects the fact that several kinds of humans lived on Earth at the same time and in some of the same places.

Many more species and fossils are known today than ever before, and new polyester resins, rubbers, and plastics give the paleoartist finer tools that make it possible to render ever greater accuracy of form. Furthermore, today's paleoanthropologists can borrow the computer techniques of forensic medicine for analyzing data, creating sections of fossils through virtually any plane, or restoring the original shape of skulls that have been crushed or distorted by geological pressures. Texture, hair color, and skin are still matters of artistic interpretation, though work with ancient DNA may eventually shed light on those areas, too.

The best artist-scientist teams attempt to keep their imaginations in check, and treat the emerging likeness of a prehistoric face as a puzzle to be solved, according to strict rules of the game. As Gurche puts it, referring to an 8-million-year-old fossil ape discovered in Greece in 1990:

> The final form of the animal is often a surprise—I try not to let any preconceptions guide me. I didn't expect *Ouranopithecus* to look as gorilla-like as it does, for example, but when I followed the process I've developed from great-ape facial dissection, that's just the way it came out.

We humans seem incapable of gazing, Hamlet-like, at a bit of skull or jawbone without trying to conjure up an image of how its owner appeared in life—and how similar or different was the appearance of its face from our own. Some of the homes of royal or wealthy European families house impressive galleries of ancestral portraits that go back ten or twenty generations, but most of us count ourselves fortunate to have a faded photo of our great-grandparents. And yet, in each generation, a few talented anthropologists, anatomists, and paleoartists—eternally optimistic—combine their skills in the attempt to show us all what our ancestors looked like, a hundred thousand generations ago. □

The images by Viktor Deak and Gary J. Sawyer that accompany this essay are used with the kind permission of Nevraumont Publishing Company, from the forthcoming book, The Last Human: A Guide to Twenty-two Species of Extinct Humans, *created by G. J. Sawyer and Viktor Deak, and produced by Nevraumont Publishing Company, with a text by Esteban Sarmiento, G.J. Sawyer, and Richard Milner and contributions by Donald C. Johanson, Meave Leakey, and Ian Tattersall. The book is being published this month by Yale University Press. Many of the portraits have also been incorporated in the new hall of human origins at the American Museum of Natural History in New York City, scheduled to open to the public this February.*

Reconstruction of a Neanderthal (H. neanderthalensis) *is based on a 50,000-year-old skull found at La Ferrassie, a rockshelter in the Dordogne region of France. The site yielded the intentionally buried remains of eight individuals. Although Neanderthals had brains as large as those of modern humans* (H. sapiens), *many scholars believe the two lineages parted ways more than 500,000 years ago.*

Eight Arms, With Attitude

Octopuses count playfulness, personality, and practical intelligence among their leading character traits.

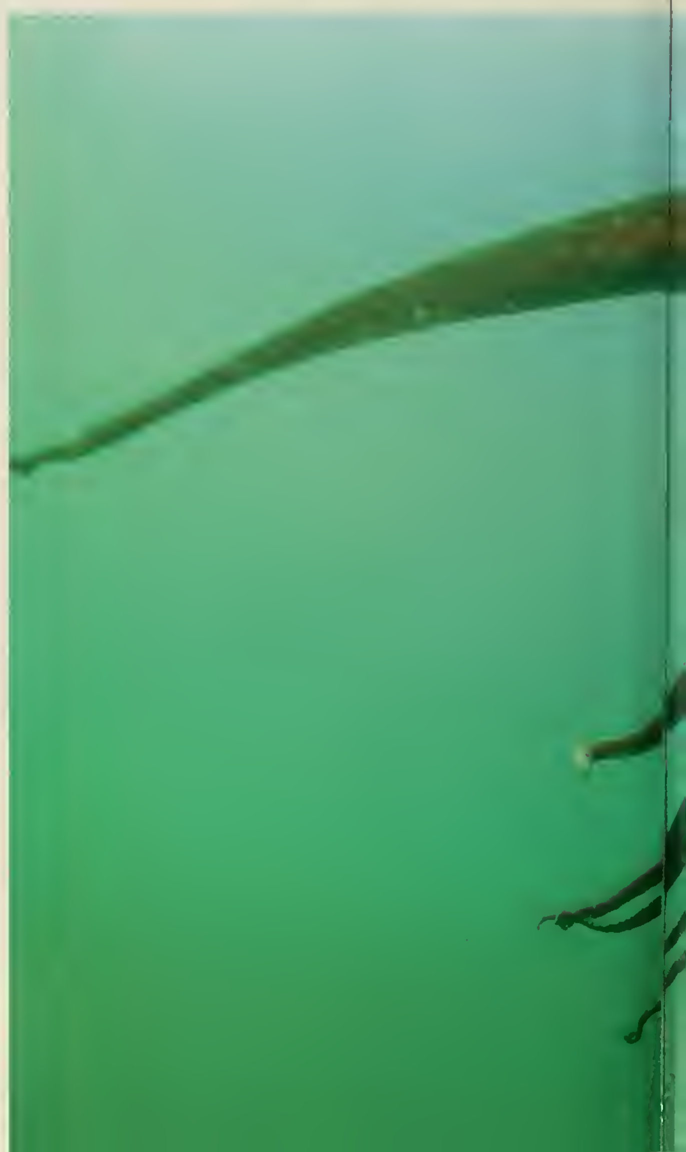
By Jennifer A. Mather

Twenty-five years ago, when I started my fieldwork on the behavior of juvenile common octopuses in the azure waters of Bermuda, I expected all my subjects to be much the same. I assumed their activities would be fairly limited; individuals would hunt, rest, and avoid predators, all in roughly the same way. In fact, I learned, their behavior is quite complex and variable. I watched as they carefully chose rocky crevices for their dens and blockaded the entrances with piles of rocks. I observed them navigate complicated routes across the sea bottom to and from their hunting grounds. But I was most intrigued to discover that individual octopuses are very different from one another.

I could swear, for instance, that octopus number 45 never left its crevice—except that the discarded shells of clams, crabs, and snails kept appearing in front of the crevice. It must have been making secret hunting forays when my back was turned. By contrast, octopus number 26 was anything but shy. One afternoon I watched it as I floated in the shallow Bermuda water, hanging on to a rocky outcrop. The little octopus peered back at me from inside its den for some time, then suddenly jetted three or four feet directly toward me and landed on my dive glove. After about a minute of exploring, it must have decided the glove didn't taste good, and slowly jetted back home. I was hooked.

Around the same time, Roland C. Anderson, a marine biologist at the Seattle Aquarium who has since become my frequent collaborator, noticed that aquarium workers gave names to only three kinds of animals in their care: seals, sea otters, and giant Pacific octopuses. The workers named the octopuses for their distinctive behaviors. Leisure Suit Larry, for instance, was all arms. He touched and groped his keepers so often that had he been a person, he would have been cited for inappropriate behavior. Emily Dickinson, by contrast, hid permanently behind the artificial backdrop of her display tank, so retiring that eventually she had to be replaced by a more active octopus for aquarium visitors to watch. Then there was Lucretia McEvil, whose caretakers were afraid to approach her, and who ripped up the interior of her tank. All those "characters" set me to thinking about whether octopuses might just have something like human personality.

Twenty-five years ago it was hard to know what

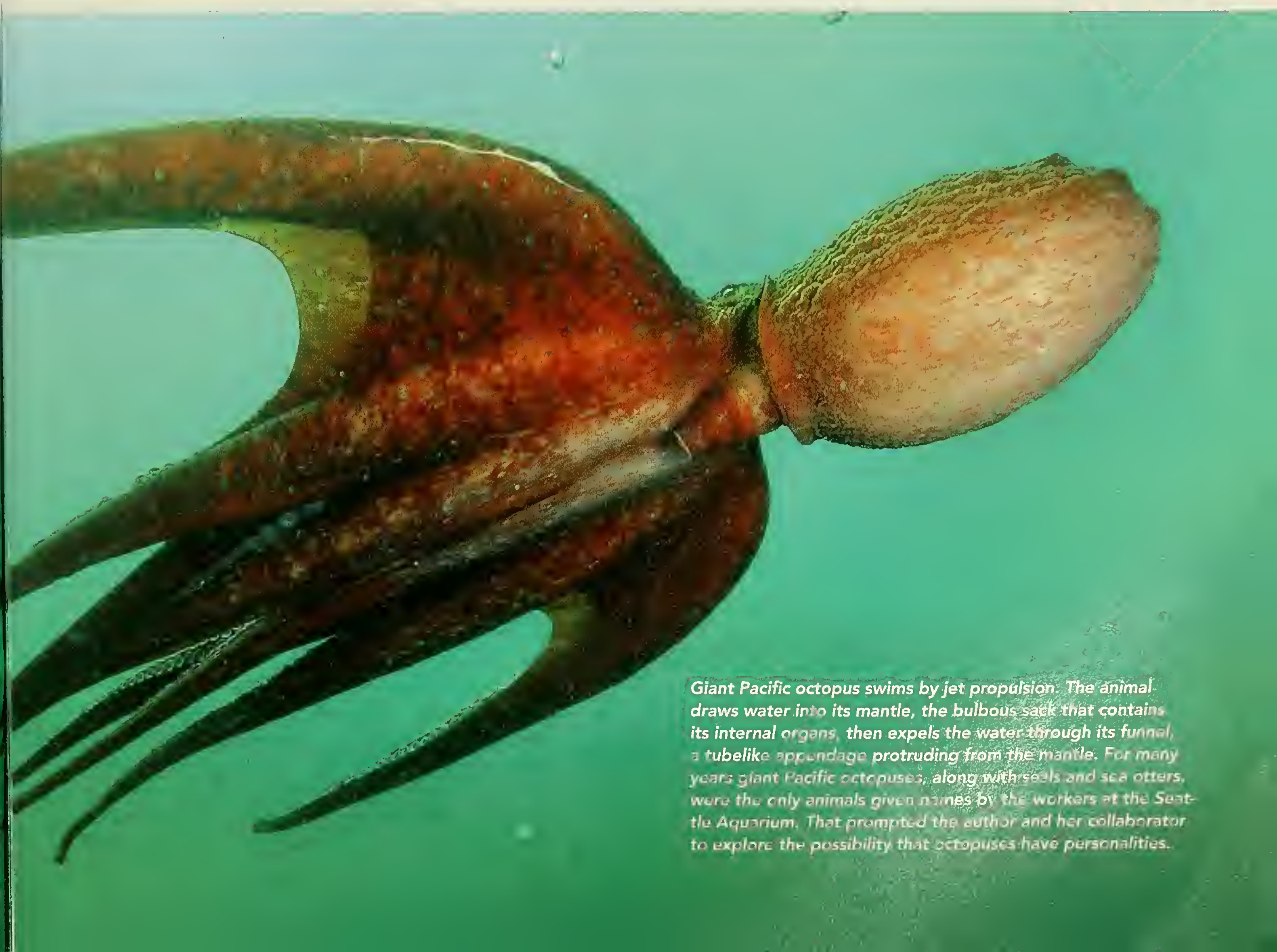


to expect of octopus behavior: the creatures had seldom been studied, and when they had, it was mostly in captivity. Furthermore, they are invertebrate mollusks, and so they are evolutionarily distant from vertebrates; it would have been hard to justify extrapolating the significance of their activities from the well-studied behaviors of mammals and birds.

Most mollusks are clams or snails that hide within hard shells and have little brainpower. But cuttlefish, octopuses, and squid (which along with nautiluses make up the cephalopod mollusks) are nothing like their shell-bound relatives. Evolution led them to lose their protective shells, but what they gained was far more interesting: dexterous, sucker-lined arms; ever-changing camouflage skin; complex eyes; and remarkably well-developed brains and nervous systems. The 289 known species of octopus range in size from the one-ounce Atlantic pygmy octopus, *Octopus joubini,* to the giant Pacific octopus, *Enteroctopus dofleini,* which can weigh more than a hundred pounds. They are all ocean-dwellers, and, though the group is distributed from the poles to the tropics, octopuses are reclusive beasts; individuals are hard to find, let alone study.

The intelligence of octopuses has long been noted, and to some extent studied. But in recent years, research by myself and others into their personalities, play, and problem-solving skills has both added to and elaborated the list of their remarkable attributes. They turn out to be uncannily familiar creatures, not nearly as unlike you and me as one might expect—given their startlingly different physiques and the 1.2 billion years of evolution that separate us from these eight-armed marvels of the sea.

Personality is hard to define, but one can begin to describe it as a unique pattern of individual behavior that remains consistent over time and in a variety of circumstances. I've adopted the model that developmental psychologists have applied to study the behavior of children. Psychologists begin with the idea of "temperament," or behavioral tendencies genetically pro-



Giant Pacific octopus swims by jet propulsion. The animal draws water into its mantle, the bulbous sack that contains its internal organs, then expels the water through its funnel, a tubelike appendage protruding from the mantle. For many years giant Pacific octopuses, along with seals and sea otters, were the only animals given names by the workers at the Seattle Aquarium. That prompted the author and her collaborator to explore the possibility that octopuses have personalities.

grammed before birth. After birth the environment shapes an individual's temperament to give rise to an adult personality.

Many people assume that only human beings have personalities. Yet in the past fifteen years or so a number of investigators have reported evidence of personality in animals as diverse as guppies, hyenas, and rhesus monkeys. To pin down what can be a notoriously slippery concept, they have identified a number of personality traits, or "dimensions,"

Eye-to-eye with a common octopus, the camera records a view that few fish would survive. The octopus eye (circle with dark slit at top of the image), like that of other cephalopods, is a remarkable example of convergent evolution; it has many of the same parts as the vertebrate eye, including a cornea, iris, lens, and retina, despite more than 1.2 billion years of independent evolution.

such as activity, aggression, curiosity, and sociability. Many animals, including people, can be rated along each of those dimensions, and an individual's rating along one dimension can vary more or less independently of its ratings along the others.

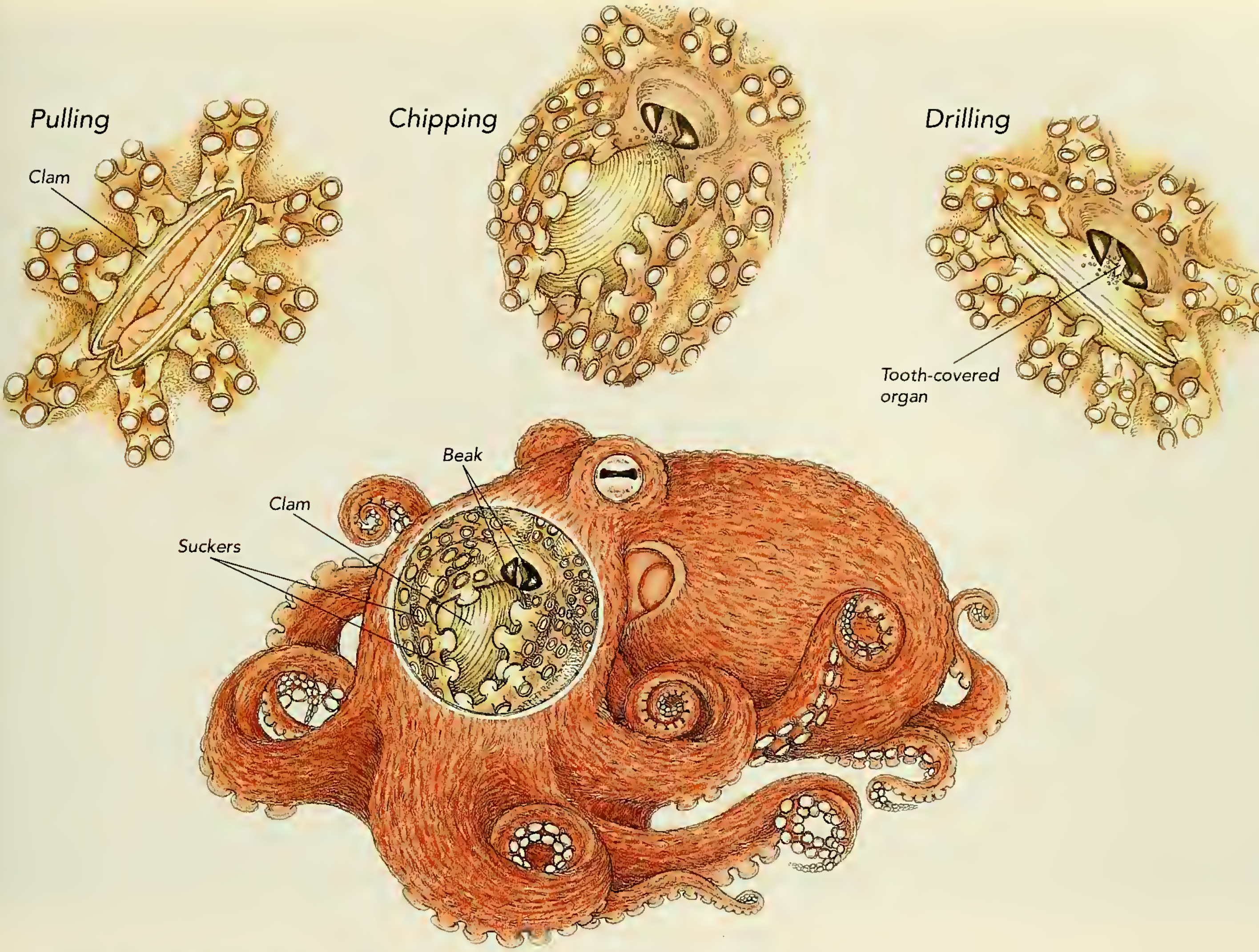
Could a combination of differences in genes and life experience—personality—have made individual octopuses behave so differently from one another? Our experiences led Anderson and me to think so. We didn't expect to discover a sociability dimension because octopuses lead solitary lives, but we thought we might find differences along such dimensions as activity or aggression.

We gave "personality tests" to forty-four red octopuses *(Octopus rubescens)*, natives of the West Coast of North America that weigh as much as a pound. We exposed each animal to three test conditions, seven times each, during a two-week period. We measured and recorded their responses when we opened the tank lid, when we touched them with a brush, and when we fed them a crab. The brush prompted the greatest variety of responses. Some octopuses grabbed it, stood their ground, and inflated their mantle to look bigger. Others jetted to the opposite end of the tank, leaving a cloud of obscuring dark ink in their wake. Individuals gave the same responses to the tests even after being exposed to them several times.

In all, the forty-four octopuses responded to the three tests with nineteen distinct behaviors. Statistical analysis enabled us to group the nineteen behaviors and place them along three personality dimensions: activity (how much the octopus moved around), reactivity (how strongly it reacted to the stimuli), and avoidance (how much it kept out of our way). An octopus could vary on all three dimensions independently. For example, among highly avoidant octopuses, which tended to remain in their dens during testing, some were extremely reactive, shrinking at the first sign of the brush. Others were not reactive at all, practically ignoring the brush. (By extension, Leisure Suit Larry, the touchy-feely giant Pacific octopus, would have rated high on activity and low on avoidance.)

So do octopuses have personality? Our answer is a qualified "yes." Because we didn't try to change their personalities by manipulating their experiences, we couldn't rule out the possibility that their behavioral variations might have been genetically preprogrammed. But given the octopus's legendary intelligence, behavioral flexibility, and learning ability, such preprogramming seems unlikely.

How much of the behavioral differences among individual octopuses is inherited, and how much is learned? For his master's thesis, David L. Sinn, now a zoologist at the University of Tasmania in Hobart, raised laboratory-born California two-spot octopuses *(Octopus bimaculoides)* in small isolation chambers and gave juveniles the same three tests Anderson and I gave our red octopuses. The genetic effects were clear. Octopuses that shared at least a mother (female octopuses mate several times with any available male, so paternity was all but impossible to determine) reacted to the three



Cutaway view of a giant Pacific octopus (above) shows how it manipulates a clam it is about to eat. Octopuses have several techniques for breaking into clam shells. They can pull the shell halves apart with their arms and suckers (top left). They can chip with their beaks (top middle). Or they can drill a hole by alternately secreting acid and scraping with a tooth-covered organ in the mouth (top right). If an octopus drills or chips, it secretes a paralytic toxin into the shell to weaken the muscles holding the shell halves together. Octopuses are excellent problem-solvers: which technique an octopus chooses depends on the species of clam, the thickness of the shell, and the strength of the clam's muscles.

tests more similarly than octopuses from different broods. Intriguingly, Sinn also discovered that as the animals matured, their responses to the tests changed in a predictable way.

Sinn did not raise his subjects to maturity, so no one knows whether youthful experiences might have added a layer to the octopuses' temperaments to yield true adult personalities. It's too bad—it would be fascinating to know whether octopuses' differing experiences when young would result in differing adult personalities. Was Lucretia McEvil's destructiveness, for instance, the result of a "bad childhood"?

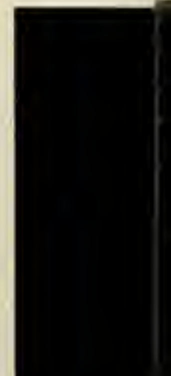
Another question about octopus personality is whether it has evolutionary benefits or drawbacks. The only scientific clue comes from Sinn's doctoral work, which showed that squid, too, vary along the personality dimensions of avoidance, activity, and reactivity. Shy female southern bobtail squid, Sinn found, mate with males that are shy, bold, or anything in between along the avoidance dimension. But bold females tend to reject shy males. Score one for the survival of the boldest. Sinn also found, however, that shy females are more successful than bold females at hatching their broods of eggs. No obvious pattern emerges, but personality clearly does affect survival and reproductive fitness.

Evidence for the octopus's intelligence begins with its anatomy. Intelligent animals typically have large brains, and octopuses' brains are large for their body size compared to those of other animals—larger than fishes' brains and, proportionally, as large as those of some birds and perhaps some mammals. Moreover, three-fifths of an octopus's neurons aren't even in its brain. Instead, they are divided among its eight arms to coordinate the arms' remarkable flexibility. The big brain itself is mostly dedicated to learning, planning, and coordinating actions with stimuli.

Broadly defined, intelligence is the measure of an animal's ability to acquire information from its environment and to change its behavior in response—in short, to learn. The octopus's behavioral repertoire has few fixed, preprogrammed responses, and it can respond to a given stimulus in a great variety of ways; those are both hallmarks of intelligence and learning. The sea slug, by contrast, has only a limited palette of reflexive responses, no matter what the stimulus. In one particularly vivid demonstration, published in 1970, the biologist William R.A. Muntz showed that octopuses could learn to tell complex visual figures apart by forming a new rule for each for each new set of figures. He concluded that octopuses aren't merely able to learn; they can also learn what to learn.

Anderson and I became interested in how octopuses apply their intelligence to predation. After capturing a clam, an octopus must break through the hard shell to get to the meat inside. To do so, it can deploy a veritable built-in Swiss Army knife of tools [*see illustration on preceding page*]. It can pull the shell's halves apart with its arms and suckers, chip at the shell's edge with its beak, or drill a tiny hole in the shell by alternately secreting acid to dissolve it and scraping at it with one of two tooth-covered organs in its mouth. (Which of the two organs it uses remains subject to debate.) If the octopus breaches the shell by chipping or drilling, it secretes a paralytic toxin into the clam's muscles so that it can more easily pull the shell halves apart—and then it's dinnertime.

We discovered that giant Pacific octopuses apply differing techniques to various clam species: they break fragile mussel shells, probably while pulling on them; they pull apart the stronger Manila clams; and they drill or chip at the strongest clams, the littlenecks. We placed individuals of each species on a device of our own design (which we darkly called the "clam rack"), and measured how much force it took to overcome the clam's muscles and pull the shell halves apart. Intriguingly, octopuses ate plenty of weak-muscled mussels when they had to open dinner by themselves, but they gobbled up littleneck clams—all but ignoring the mussels—when we offered all three species on the half shell. Maybe the mussels were less tasty but easier to get at than the littlenecks.



Octopuses conduct the business of breaking into clams with the clams near their mouths, which are under their arms and so out of sight. There they dexterously manipulate the clams into position by touch. To pull clam shells apart, an octopus holds it with the umbo (the bump near the shell's hinge) toward its mouth. But if it chooses to chip at the shells' edge, it moves the clam's "sides," where the muscle insertions are, toward its mouth. And when it drills, it turns the broad side of the shell toward its mouth.

Giant pacific octopuses usually drill through the center of a clam's shell into its heart. But they must learn where to drill the holes. Anderson found that juveniles drill their first few holes randomly on the shell, but they soon master the art of drilling near the heart or the muscles that hold the shell halves together. Either place is a good target for injecting paralytic toxin.

We were curious about what octopuses would do with artificially strong Manila clams, whose shells they usually just pull apart. We gave each octopus Manila clams held together with strong wire. The octopuses simply switched tactics to drilling or chipping, thereby confirming the numerous studies such as Muntz's that had shown they are good problem-solvers. They can weigh effort against food reward, flexibly switch penetration tactics, and orient the clam to penetrate its shell most effectively—all good uses of intelligence, indeed.

After investigating a few octopus problem-solving skills, Anderson and I turned our attention to two less-studied categories of behavior that are also linked to intelligence: exploration and play. Philosophers and psychologists have debated for centuries about the nature of play, where it comes from, and what purpose it serves. When animals play with objects, their explorations move from "What does this object do?" to "What can I do with this object?"

Gordon M. Burghardt, a biologist at the University of Tennessee in Knoxville, recently offered a clear and useful definition of play in healthy animals. Play, he writes, is made up of voluntary, incomplete, repeated fragments of activity that have no obvious purpose, and which are often exaggerated and out of normal context. Some scholars still maintain that people are the only animals that truly

Giant Pacific octopus feeds on a dead spiny dogfish. Octopuses can instantaneously change color and texture, often to camouflage themselves. Giant Pacific octopuses can change from a "relaxed" rusty red to gray, pale beige, coral, orange, red, or any mottled variation in between. Certain colors may indicate an octopus's internal state: the scarlet color of the octopus shown here could indicate stress, possibly triggered by the camera's flash. Or it could be a simple, automatic reaction to the burst of light.

play. But dog owners know that when their companion lowers its front end and raises its hind end, tail wagging, it has no purpose but to communicate that the next set of interactions should be just for fun. Crows slip down a playground slide over and over, or grasp a clothesline in their claws and spin round and round like a pinwheel, calling "Wheee" the whole time. Those behaviors clearly conform to Burghardt's definition, and other examples are documented in many animals, including dolphins, lab rats, and river otters.

Would an octopus play if given the chance? We decided to find out. Animals are more likely to play when they are satiated and secure, without any threat from predators. An aquarium tank is such an environment. There we presented eight well-fed giant Pacific octopuses with plastic pill bottles containing enough water that they floated at the surface of the tank. The octopuses followed a fairly predictable behavioral sequence. First, they grasped a pill bottle with one or more of their arms and explored it with their suckers. Then they pulled it to their mouths, and sometimes bit it with their parrotlike beaks. Gradually, both within each trial, and by the end of all ten trials, most of them lost interest in the bottle.

But two of the octopuses independently did something very different in the later trials. Like most aquariums, their tanks had water-circulation systems; water entered the tank at one end and exited at the other. While sitting near the outflow, each animal released the bottle it had been holding and jetted water through its funnel, sending the bottle against the gentle current to the inflow end of its tank. (A funnel is a tubelike appendage that an octopus uses for breathing and for jetting through the water [*see photograph on pages 30–31*].) When the bottles returned on the current, the octopuses jetted them upstream again, repeating the process more than twenty times. Anderson, who had been skeptical that octopuses play, phoned me excitedly after watching the first playful octopus and said, "It's like she's bouncing a ball!"

In vertebrates, some kinds of play have benefits as well as simply being fun. They strengthen and define social relationships, as in the roughhousing of canines. Or they give young animals the chance to hone fragmentary actions into polished sequences, as when a kitten plays with a mouse to "practice"

Play in octopuses has been documented experimentally, but remains controversial. After investigating and habituating to blocks for several days, common octopuses engaged in play or playlike behavior, passing the blocks from arm to arm, towing the blocks, or repeatedly pushing and pulling them back and forth. The octopus pictured here exploring a block with her mouth was among the most playful in the experiment. In another experiment, giant Pacific octopuses sent buoyant pill bottles circling repeatedly around their tanks.

capturing prey in the future. Skeptics often dismiss play by nonhuman animals as functional, and thus in violation of Burghardt's definition that it have no obvious purpose.

But octopuses don't have social relationships—they're solitary creatures, except when they mate. And as for the argument that only the young play because only they need to practice their skills, Michael J. Kuba, a former graduate student of mine now at Hebrew University in Jerusalem, recently showed that adult common octopuses also engage in playlike behavior. They passed a plastic block from arm to arm or pulled it along when they swam just as often as the young did. Still, in our view, octopus play is neither as extensive as it is in mammals, nor as potentially adaptive. It may simply be a sign of an active mind at work.

Octopuses have personalities. They learn. They solve problems. They play. Does all that add up to a simple form of consciousness? The suggestion is even more contentious than the ideas that octopuse s play or have personalities. Just defining consciousness is tricky; one general definition is that an animal with primary consciousness—a dog, for instance—is aware of the complexity of a given circumstance as well as its role there and its decision-making options. Higher-order consciousness has more stringent criteria: using language, being able to report on the content of one's thoughts, being able to think about thinking. Only people and perhaps chimpanzees exhibit that exalted form of consciousness.

But how could one tell whether octopuses have some form of primary consciousness? Some theorists say it is enough to show complex and flexible behavior, such as the octopus's clam-opening tactics. Others say an animal must be able to shift its attention from one set of stimuli to another, making decisions in rapidly changing conditions. Octopuses meet that criterion in their varied responses to a predator: they can flash unpredictable changes in pattern and color, jet off in an unexpected direction to escape, or squirt out ink to form a smoke screen.

Still other theorists argue that conscious animals build a complex, multidimensional set of internal impressions about the world on the basis of their sensory perceptions. For example, the human mind constructs a three-dimensional image of objects from the two-dimensional array of stimuli that arrive at the retina. Additional study of how octopuses analyze visual shapes might show whether they meet that criterion, too. Or perhaps a conscious animal must have a concept of self. What do octopuses see when they look in a mirror? Answering that question will be our next research project.

It will be hard to say for sure whether octopuses possess consciousness in some simple form. But from what biologists already know about them, there's no denying they are some smart suckers. □

Family Ties

Unexpected social behavior in an improbable arachnid, the whip spider

By Linda S. Rayor

If you're a fan of the Harry Potter films, you've seen an amblypygid. The most recent cinematic installment of the series, *Harry Potter and the Goblet of Fire*, showed an improbable creature with a flat body, spiny "arms," and incredibly long, flailing "whips" that was ultimately killed in a class demonstration of the Avada Kedavra curse. (In the book, a spider was sacrificed.) Most viewers probably assumed the creature was a figment of the director's imagination. Not so. In fact, with minimal digitization and color enhancement, an amblypygid stole the scene.

Amblypygids—commonly called whip spiders or tailless whip scorpions—are neither spiders nor scorpions. Nevertheless, as their appearance suggests, they are arachnids. Spiders and uropygids (also called vinegaroons) are their closest relatives; other arachnids, including harvestmen, pseudoscorpions, scorpions, and solfugids (also known as wind scorpions) share similar characteristics. Like them, amblypygids have eight legs, two main body parts (an abdomen and a combined head and thorax known as a cephalothorax), and a pair of spiky appendages known as pedipalps or simply palps—situated on either side of their mouthparts [*see upper photograph on page 40*].

Add up those discordant parts, include their first pair of legs, or "whips," and amblypygids seem rather improbable. As it turns out, their behavior might also strike some as strange. My research suggests that the animals, long thought to be solitary and aggressive to members of the same species, are surprisingly social. Mothers and siblings remain in close, interactive groups for almost a year before the young reach sexual maturity. If my recent studies are any indication, the creatures warrant more attention than a cameo appearance on the big screen.

The first amblypygid I ever encountered in the wild loomed over me while I was visiting an outhouse in Costa Rica. The creatures often slip their flat bodies into

such places, where they can hide in narrow crevices during the day. At night they emerge to hunt, often on the trunks of trees or inside caves—or, as in my case, on an outhouse wall. A total of 136 species occur worldwide, primarily in the tropics, throughout Africa, India, Latin America, and Southeast Asia. They range in body length from an eighth of an inch to one and three-quarters inches. *Phrynus marginemaculatus,* a Florida native the size of a dime, and the slightly larger *Phrynus fuscimanus,* an inhabitant of the desert regions of Arizona, are the only amblypygids indigenous to the United States.

An amblypygid's palps—the wide "arms" near their mouth—are long, covered in spines, and tipped with small stilettos. The palps can reach out to grab like a hand or to stab their arthropod prey like a talon. In many amblypygid species the adult males sport considerably longer palps than the females do. The male palps are often deployed in intense male-male contests, in which each male strikes rapidly at his opponent with open palps. Such a battle may be a

Newly-hatched whip spiders (Phrynus parvulus) *cling to their mother's back in Costa Rica. They stay aboard and remain largely immobile for about a week after they hatch. If they happen to drop off, though, they do not survive, and their mom—about an inch long—may even eat them.*

Female Heterophrynus, *pictured here among leaf litter in southern Guyana, displays her palps, or "arms" near her mouth, with spines about a quarter of an inch long. Palps are formidable weapons for stabbing prey and fighting other whip spiders of both sexes.*

way of assessing the size of competitors [*see lower photograph on this page*].

All aspects of an amblypygid's life center on the use of their delicate first pair of legs, which put the *whip* in the name *whip spider*. The whips are not used for walking; rather, they are covered with fine chemosensory and mechanosensory hairs that function much like an insect's antennae. The sensory hairs on the whips can distinguish a multitude of airborne odors—a rare ability in arachnids—or detect mechanical changes through touch or air currents. The whips are incredibly flexible and may be three to four times the length of the walking legs—as long as three feet in the larger species. Each whip comes with as many as 148 joints, which enables the animals to delicately explore 360 degrees around their bodies. It's no wonder the whips are constantly sweeping and probing their environment.

When something interesting comes along, the whips move accordingly. For example, my students and I have shown that if prey or, alternatively, a sibling, approaches from one side, the near-side whip moves faster than the far-side whip. A hunting amblypygid may even reach around a corner with its whip and gently touch potential prey, such as a cricket, so that it is led, unaware of the danger, toward the hunter. That keen technique is evidence that amblypygids may be among the smartest arachnids. Nicholas J. Strausfeld, a neuroanatomist at the University of Arizona in Tucson, demonstrated that amblypygids have the largest mushroom body—an area of the brain associated with spatial memory and learning—of any of the arachnids.

Although they are fearsome predators, amblypygids are also solicitous lovers. Males court potential mates by stroking the females repeatedly with their whips. Sometimes the male vibrates his own palps or gently nibbles on one of the palps of his mate. Even when not actively courting, a couple interacts intensely for several weeks, typically facing each other or sitting close together for the entire courtship period [*see upper photograph on page 43*].

The male amblypygid does not have a sex organ like a penis that can deliver sperm directly and internally to the female. Instead, he secretes a small white stalk and deposits a protein-covered sperm package into the stalk's clasps; the entire structure is known as a spermatophore. The upright stalk is glued to the surface of the tree or rock where the couple has been courting. The male hopes to entice the female to take up the sperm package. Each time she does, a spermatophore stalk is left behind, and so by counting stalks, one can tally the number of times a couple has mated. I have counted more than nine stalks left by a single male during a two-week period when his mate was receptive.

Following courtship, the male and female move

*Two males (*P. parvulus*) grapple for territorial supremacy on a tree in the lowland forests of Costa Rica.*

apart and seemingly have little more to do with each other. The female deposits her eggs in a brood pouch on her abdomen. After roughly ninety days for smaller species and 120 days for larger ones, the eggs hatch; even the shorter gestation time is surprisingly long for an arachnid. Like young scorpions, vinegaroons, and wolf spiders, newly hatched amblypygids climb onto their mother's back for about a week [*see photograph on pages 38–39*]. During that stage, they do not eat. Their hard exoskeletons do not sclerotize, or darken and harden, and so they remain a vivid lime green until they molt, climb off their mothers back, and begin catching prey for themselves.

The traditional thinking has been that amblypygids lead entirely solitary lives. In fact, when I first began my research on them, I was told that a mother would kill her own young if they remained with her after the first week. So, given the reputation of adult amblypygids for aggression, imagine my surprise when I first observed their social interactions. Now my students and I, working with captive mother-offspring groups, have shown that the animals lead highly complex social lives.

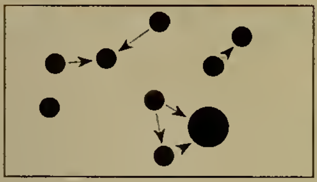
One morning, as I watched a *P. marginemaculatus* mother with her three-week-old young, I observed an amazing sight: The mother walked directly over to a group of ten closely grouped offspring and gently stroked them with her whips. The young moved to surround and orient to her and stroked her in return, touching her whips, palps, and legs. Over a period of about four minutes, the mother made individual contact with seven out of the ten youngsters. Although the young had initially been sitting close together, slowly waving their whips, their whip movements quickened once their mother joined the group, so that most of the youngsters touched each other while she was with them.

Then the mother left the group of ten, and walked directly to a separate group of youngsters. She stroked them—and, as with the first group, they stroked her in turn—for about thirty seconds. Finally, she visited a third group and repeated the interaction for several minutes, before returning to sit in the middle of the first group. In each case, the young oriented towards their mother and stroked her palps, whips, and legs with their whips. What amazed me about those interactions was that they appeared to indicate social bonding between a mother and her offspring.

After watching that mother-offspring behavior in amazement, I set out to discover just how social the creatures might be. In the past five years my students and I have quantitatively documented extensive social interactions in captive populations between mothers and offspring, and among siblings, in two amblypygid species: the Floridian *P. marginemaculatus* and the much larger *Damon diadema*, from Tanzania. The results are changing the view of amblypygids as solitary animals.

Mother Damon diadema *(right) circles a thin "whip," or modified leg, to stroke one of her young (left). The youngster is about four months old and measures three-eighths of an inch long. A second youngster is under the mother's left palp.*

Why is this finding so exciting? Among arachnids, maternal care (or, in the case of some harvestmen species, paternal care) for the eggs and the newly emerged offspring is not uncommon. Yet arachnid social behavior, beyond the transient parental care of newborns, is extremely rare. Less than 0.1 percent of the almost 93,000 known arachnid species live in interactive social groups for extended periods. Along with the two amblypygid species I have studied—in which mothers and their offspring may remain together for nearly a year—only fifty-three



Family portrait of D. diadema includes an adult female (with a sheen because she has recently molted) and eight of her twenty-two offspring. Each animal is touching another, being touched, or has just been touched by a relative's whip. In the schematic diagram at left, each arrow points from the animal touching with its whip to the animal being touched. The young are about eight months old and will continue to interact peacefully with their mother and one another for three or four more months.

spider species, eleven scorpion species, three pseudoscorpion species, and seven spider-mite species have been observed to live in social groups.

Sociality is broadly defined to include interactive groups whose members tolerate one another and associate beyond early development. The sociality of some groups is short-lived: in some spider groups the siblings remain together for a couple of instars after eating their mother, and young scorpions remain with their mother for part of their development. At the other end of the social spectrum are the complex societies of the highly social cobweb-weaving spiders, *Anelosimus eximius*, of Central and South America. They maintain group nurseries for their young in massive webs that house thousands of individuals.

For arachnids, the benefits of being social include having others help capture large prey, sharing prey once it is caught, and cooperatively constructing a retreat (which may be webs, burrows, or silk-covered lairs). Furthermore, the longer the youngsters have to grow and become better predators before becoming independent adults, the better their survival. Some investigators have suggested that unlike the eusocial insects—ants, termites, many wasps, and some bees—which work together to increase the reproductive output of the colony, the few arachnid societies function primarily to increase the foraging success of the group's members.

In spite of the potential benefits of cooperation, mutual tolerance by arachnids of the same species is very rare. Why hasn't sociality evolved more often among them? Probably because most arachnids are predators that not only compete for prey but also can prey on each other. For example, the longer offspring remain with their mother, the greater their predatory capabilities and the greater their need for prey. As the young mature, the balance between cooperation and conflict, which is inherent in all social groups, becomes ever more precarious. By studying the rare arachnid species that live in amicable social family groups, biologists can pose ecological and evolutionary questions about the costs and benefits of group living.

Amblypygid social groups share many, though not all, traits of other groups of social arachnids. My students and I have observed seventeen *D. diadema* family groups for a year or more in captivity. In each one, the mother amblypygid and her offspring have been peaceful and interactive. Their social relations are consistently friendly, with little aggression until the young begin to reach sexual maturity, at about twelve to fourteen months.

As they reach sexual maturity, however, the siblings become aggressive toward each other. My students and I find young adults with missing whips, damaged legs, or emaciated bodies (the last because the victims are forced to hide from aggressive males). At this age individuals are sometimes cannibalized, something we never see in younger animals. In the wild, the family groups would clearly disperse by the time the offspring are sexually mature. In some groups, the mother continues to interact with her youngsters throughout their development; in others, she leaves the group before she molts or mates again. It is the siblings that form the strongest social bonds [*see photograph on opposite page*].

The most obvious social trait in *D. diadema* is that the members of a family group stay close together, constantly touching and exploring each other and their surroundings with their whips. Typically, they form loosely connected groups, within which between three and twenty animals are in constant contact with some other family members. As the youngsters grow older and larger, they space themselves progressively farther apart, but remain within easy reach, separated by less than a whip length. Although there are always a few youngsters that move away from the group, most of them stay closely associated with other family members until sexual maturity. There is remarkably little aggression among the immature siblings. In a testy exchange, one youngster might open its palps or chase its sibling briefly, but we have seen none of the grappling or standoffs with wide-open palps and flicking whips that so characterize adult male conflicts.

Cannibalism, always a risk among arthropod predators, is extremely rare in the family groups. In contrast, when adult *Damon* are kept together, even in huge cages with plenty of food, they spread themselves as far apart as they can (unless they happen to be courting), and cannibalism is common. My student Rachel E. Walsh has shown that when seven- to nine-month-old *D. diadema* are briefly removed from their families, then either reintroduced to their own group or placed within an unfamiliar group of the same age, they are more aggressive to the unfamiliar animals than to their own family members. Since all the animals in Walsh's experiment were immature, their aggression did not escalate to the dramatic levels seen in the battles between unfamiliar adults, but it was much testier than that among typical siblings. Walsh has also demonstrated that the adolescents can distinguish their mother from an unfamiliar adult female by smell alone.

Upper photograph: Damon whip spiders are pictured in courtship. Lower photograph: Female D. annulatipes *from South Africa, when turned on her back, exposes a brood pouch. Dozens of young will soon hatch and climb onto her back.*

I am not entirely sure *why* the young amblypygids want to stay in close contact with other individuals, but they clearly do! If a clutch of young *D. diadema* are removed from a familiar cage and scattered inside a large, unfamiliar one, they gather back together within minutes. Do the amblypygids congregate into groups because certain areas of the cages—the tight spaces, such as where cork bark touches the glass walls of the cages—are more attractive than others? My student Lisa A. Taylor and I tested that hypothesis by putting family groups on more uniform "bark"—otherwise known as plywood—that we installed around the walls of the cage, equidistant from the glass. When we observed where individuals distributed themselves, we were rather surprised that both species gathered together in small groups on the plywood, but that the location of the gatherings changed daily. Individuals were less interested in certain spots in the cage than in simply associating with others in their group.

Another common benefit of group living is that it affords some protection from predators. Group members can take turns as lookouts, warn their neighbors of impending danger, or help defend against incursions by outsiders. Amblypygids must be preyed upon by other animals (and not only by the desperately greedy people on the television show *Fear Factor*), but surprisingly few reports have surfaced of the capture of amblypygids by other animals in the wild. Only a scorpion in Costa Rica and an Amazonian monkey, the golden backed uakari, have been observed eating amblypygids.

Response to the risk of predation is hard to test realistically in the laboratory. We found, however, that when we disturbed *D. diadema* families, the youngsters moved closer to their mother or siblings, or even scurried under their mother. As the young became adolescents, though, they were less likely to respond to a threat by gathering closer together. Most of the time, the adolescents as well as their mother just scuttled rapidly away from a threat. But every once in a while a mother threatened us. On several occasions an adult female with seven-month-old offspring tried to defend her young with an effective threat display. Each time she raised her body high above the bark, opened her palps widely, and slowly stalked toward us. The display made her look even larger and more threatening. Once she tried to stab me with the stiletto-sharp tip of her palps. Believe me, I backed off as fast as I could!

Freshly-molted male whip spider (D. diadema) *leaves behind an old, dark exoskeleton. After a day, the animal's white exterior will darken and harden. Throughout their lives whip spiders molt in order to grow or rejuvenate.*

I mentioned earlier that group living often helps facilitate the capturing and sharing of large prey. Among spiders, pseudoscorpions, and scorpions, prey sharing is one of the major benefits of social living. Immature animals, in particular, have the advantage of getting much larger prey than they could capture by themselves. I am a behavioral ecologist who believes that amblypygids should rightfully be considered part of the pantheon of social arthropods, but I can't defend my position by claiming that amblypygids share prey or cooperate in prey capture. On rare occasions, we have seen siblings or mothers and their young briefly share prey, but the behavior has seemed incidental, rather than reflective of cooperation or even mutual tolerance. More commonly, hungry group members try to steal prey from one another—a rather comical effort, because the thief often returns to the center of the group to eat its ill-gotten gains, only to have the meal stolen once again.

Another important difference between amblypygids and most other social arachnids is that the amblypygids construct no communal retreat. They cannot produce silk, so webs are not an option. Nor do they dig burrows. But perhaps they have no need to collaborate on a retreat. Amblypygids are so thin they can fit into narrow spaces where they are safe from predators and from the elements. Groups of young siblings often pack into tight spaces, leaving only their whips waving at the entrance.

In fact, young amblypygids are remarkably hard to see. Even after years of observing them, I rarely locate the youngsters right away. Instead, I tend to glimpse first the white "elbows" on their whips, next the movement of the waving whips, and only then do I recognize that six or ten fingernail-size youngsters are right before my eyes. Their camouflage probably explains why social behavior in amblypygid families in the wild has not yet been explored. An adult female can be relatively easy to find when she is foraging alone at night, but her nearby offspring may be virtually invisible if the light is dim and the background is at all complex.

Yet as people look carefully for young amblypygids in the field, I predict biologists will discover more of these fascinating animals living in family groups. They may be peculiar looking—even off-putting to some—yet I cannot help but be charmed by their peaceful family dynamics where siblings entwine whips and explore their surroundings together. One must admit that in their mastery of social grace, they are incredibly alluring. □

Ozark Mushrooms

Bedecked with resilient plants, an Arkansas cliff top overlooks fantastic formations known as pedestal rocks.

By Robert H. Mohlenbrock

Carved by wind, rain, and frost, a pedestal rock rises twenty-five feet high.

The Ozark Mountains are centered in Missouri, but they extend into northwestern Arkansas, where they fall largely within the Ozark National Forest. The Arkansas Ozarks are a rugged region of high peaks, steep cliffs, ravines, and various unusual rock formations. Some of the most intriguing formations are part of a rocky escarpment along the upper reaches of the Illinois Bayou River drainage. Many, known as pedestal rocks, are shaped like giant mushrooms, with an enlarged top supported by a narrow shaft. Others are blocks pierced by "windows" or weathered into natural arches. You can enjoy all those forms—along with panoramic views—in the Pedestal Rocks Scenic Area of the forest's Bayou Ranger District.

The Ozarks originated some 300 million years ago when the region uplifted to form a large dome, the Ozark Plateau. Since that time the elements have ceaselessly eroded the plateau. The oldest rocks, exposed near its center in eastern Missouri, include granite and volcanic rock. In Arkansas, however, the exposed rocks are younger, sedimentary layers of limestone, sandstone, and shale, originally deposited by rivers and shallow sea waters. At Pedestal Rocks, the exposed deposits are of sandstone. The unusual rock formations result when sections of sandstone begin to separate from the edge of the cliff and are shaped by the combined action of wind, water, and frost.

From a parking lot and picnic area

HABITATS

Dry woods Oaks and hickories are the dominant trees; the most prevalent of their species are chestnut oak, northern red oak, red hickory, shagbark hickory, and white oak. Among the other major tree species are black cherry, black gum, black walnut, eastern witch hazel, flowering dogwood, red maple, shortleaf pine, slippery elm, and white ash. Shrubs are relatively sparse. They include dwarf sumac, hop tree, shrubby Saint-John's-wort, and smooth sumac. Woody vines, by contrast, are common, and include fox grape, poison ivy, four kinds of prickly greenbriers, summer grape, and Virginia creeper.

Among the nonwoody species are Indian physic, rough-leaved goldenrod, two skullcaps, spreading sunflower, Sullivant's coneflower, five kinds of tick trefoils, white avens, white lettuce, and white-leaved mountain mint.

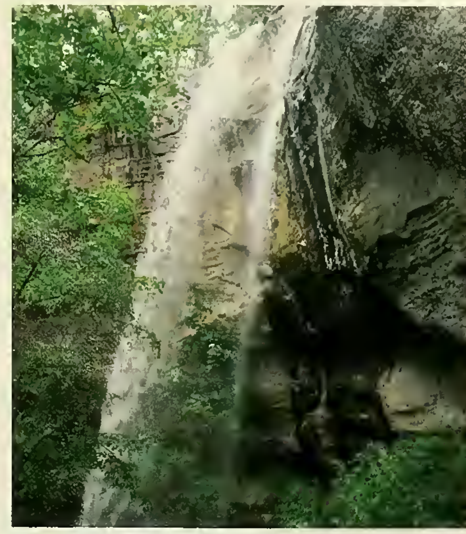
Rocky rim and exposed bluff The gnarled trees are black hickory, blackjack oak, eastern red cedar, post oak, scarlet oak, and winged elm. Shrubs include dwarf hackberry, farkleberry, and lowbush blueberry, all with leathery leaves. Wildflowers with very small leaves include along Arkansas State Route 16, visitors can follow two trails into the scenic area. The Pedestal Rocks loop, a round trip of about two and a quarter miles to the rim of the escarpment, provides a view of the pedestal rocks, which stand below, off the edge of the cliff. Another, shorter loop goes to King's Bluff, a flat, rocky expanse, also along the rim of the escarpment, that after a rain becomes the top of a hundred-foot waterfall. Both trails pass through typical Ozark upland forest. The vegetation is diverse, despite the fairly dry and hot conditions that prevail in the summer.

All along the rim there are plenty of open stretches of what looks like bare rock, though on close inspection the surface often proves to be covered with a thin layer of lichens. Interspersed among those bleak areas are microhabitats more hospitable to vegetation. Rainwater flowing to the rim in rivulets from the upland woods has carved narrow channels where soil has accumulated. Periodically replenished by rain, the channels usually remain wet and muddy throughout the summer, enabling several fern and wildflower species to grow as high as three feet.

VISITOR INFORMATION
Bayou Ranger District
Ozark–St. Francis National Forest
12000 State Route 27
Hector, AR 72843
470-284-3150
www.fs.fed.us/oonf/ozark/recreation/pedestal_rocks.html

Other plants survive in slight depressions where soil has accumulated. After a heavy rain, water stands in the depressions for a while, creating mini-wetlands, some just two or three feet across. Although the water may eventually be lost to evaporation or seepage, some of the species that grow here also occur in more substantial wetlands along streams and around ponds. Such cliff-top depressions are also the exclusive home for limestone quillwort, a spore-producing species related to the ferns. It's a plant you would have to search out between mid-March and mid-June, because after that, its leaves wither away. It is easy to pass by, in any case, because it looks like a small tuft of grass about six inches tall.

I must admit a special fascination for plants that can survive on rock surfaces that are practically bare and exposed to intense, direct sunlight. Depending on the kind of rock (as well as on regional terminology), such habitats may be known by such terms as barrens, glades, or pavements. In spite of the paucity of soil, several tree species have gained a tenuous foothold, often getting moisture



Cascade at King's Bluff, in early-spring flow

and anchorage by sending roots deep into fissures. Among them are blackjack oak and post oak, whose leathery leaves, covered by a thin coating of wax, reduce water loss. Because of the harsh conditions, however, such trees are usually small and gnarly.

Other plants have adapted with small or even threadlike leaves, which expose little surface to the sun's rays. Leaf surfaces may be covered with scales or hairs. Succulent leaves store water for later use in extremely dry conditions. In the prickly pear, a cactus, the leaves have evolved into spines, and water is stored instead in the fleshy stems.

Then there are the so-called spring ephemerals, plants that simply beat the heat and drought by germinating during March, flowering and going to seed during April and early May, and drying up by the end of May.

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nits-and-lice, pineweed, and pinweed. Thread-leaved sundrops, a kind of evening primrose, has, well, threadlike leaves. The leaves of a few plants, such as rushfoil, have a scaly surface, whereas those of goat's-rue are hairy. Prickly pear stores water in its fleshy stems; plants with succulent leaves include fame flower, Illinois agave, and widow's-cross.

Spring ephemerals include three kinds of bluet, a delicate grass known as six-weeks fescue, and yellow star grass. Hairy lip fern and rock spikemoss are tiny spore-producing plants that simply dry out and curl up during drought, but a summer rain is all it takes to revive them.

Small depressions in the rock surface Dwarf Saint-John's-wort, rough buttonweed, three small sedges, and small-flowered bittercress are among the wetland plants. Limestone quillwort also grows here.

Blufftop channels Christmas fern, Ohio spiderwort, polypody fern, slender mountain mint, toad rush, winged crown-beard, and woodland oatgrass are among the species that grow in the moist soil.

By Laurence A. Marschall

George Tooker, Sleepers II, 1959

The Family That Couldn't Sleep: A Medical Mystery
by D.T. Max
Random House; $25.95

Among the manifold ways we may depart this mortal coil, none are more terrifying than those that involve the slow disintegration of the central nervous system. So first, a warning: do not read this book—or even this review—unless you are absolutely immune to suggestion and hypochondria. Otherwise, journalist D.T. Max may scare you sleepless with tales of innocent people whose bizarre symptoms slowly turn horrific.

Do you perspire profusely and have trouble getting a good night's sleep? Have your pupils shrunk to the size of the dot over this "i"? Those are signs of fatal familial insomnia (FFI), a hereditary malady so rare that it afflicts only forty families worldwide. Do you stumble from time to time? Do your arms cross uncontrollably whenever you turn your head? Those difficulties may signal Gerstmann-Sträussler-Scheinker disease, first recognized in a twenty-six-year-old Viennese woman in 1928, and now diagnosed in one in a hundred million people worldwide. Do you smack your lips reflexively when you are tickled under the chin? Sheep do, when they contract a degenerative brain disease called scrapie. No cases of sheep-to-human transmission are known, but after eating contaminated beef, more than 150 people have died of the bovine variant of scrapie, bovine spongiform encephalopathy, or "mad cow disease," a degenerative brain disorder called in humans "variant Creutzfeldt-Jakob disease."

What all those maladies have in common is that they are caused by prions, abnormal forms of small proteins that quite normally occur in animal and human cells. Prions do not reproduce like bacteria or viruses, but under certain conditions they can propagate uncontrollably, the way a slight crack in a windshield can turn into a web of fissures across the entire pane.

Since the outbreak of mad-cow disease in Britain in the 1980s, and the consequent destruction of millions of cattle, prion diseases have generated almost as much public fear as urban terrorism. Prions seem impervious to antibiotics; they survive boiling, ultraviolet radiation, and soaking in formaldehyde. They can remain dormant in the body for years, making it possible for prion infections to become epidemic long before symptoms are apparent. And they are invariably fatal. The only upside of prion diseases, if you can call it that, is that they are hard to catch and extremely rare.

Max is the latest of many excellent writers who have reported on prions, but his book is probably the most gripping and sympathetic. He himself suffers from a rare neuromuscular (nonprion) disease. Throughout his story of prions, he threads the saga of an Italian family plagued by FFI, perhaps the most gruesome prion disorder of them all: it leaves cognition intact while the victim, unable to eat or sleep, twitches uncontrollably until the end. Doctors have only recently identified the cause of the debility, which has carried away generations of uncles, cousins, and parents. One hopes that, before another generation has passed, science will find a cure, not just a reason, for their affliction.

Richter's Scale: Measure of an Earthquake, Measure of a Man
by Susan Elizabeth Hough
Princeton University Press; $27.95

For more than forty years, from 1927 until his formal retirement in 1970, Charlie Richter was an employee of the Seismological Laboratory, long a part of Caltech, in Pasadena, not far from his childhood home in Los Angeles. His work, for the most part, was routine: compiling and analyzing records from a network of earthquake detectors scattered around the area. Off-hours, he lived in a modest house with his wife and a few pets, enjoyed music, and belonged to a local book group. When time permitted, he would hike alone in the mountains. But apart from that, he shunned travel, seldom venturing out of the country—or out of the state, for that matter. Not the kind of life, one would imagine, to merit a 300-page biography.

Yet Charles Francis Richter was, and is, perhaps the most famous seismologist of our time, a man whose name is mentioned in news reports every time a large quake hits. The first thing an inquiring public wants to know is: How strong? The expected answer is one measured by Richter's scale of magnitudes, even though its scientific usefulness has largely been superseded by more modern standards.

The real Charles Richter, fellow seismologist Susan Hough would have us understand, was neither drudge nor genius, but a complex and gifted man who made fundamental contributions to his field. She is also at pains to recount her subject's highly unconventional personal life. Hough bases her profile on public documents; interviews with surviving family, colleagues, and acquaintances; and most of all, a wealth of personal papers. Richter, you see, left seemingly everything he ever wrote to the Caltech archives—perhaps in anticipation that one day a biographer would tackle the task of putting his life in order.

Charles Richter, circa 1952

No one can quibble with Hough's assessment that the intensely private seismologist was a most unusual man. In appearance, he was the quintessential nerd—bespectacled, babyface smile, and hair flying in all directions. True to stereotype, he kept detailed records of all the *Star Trek* episodes he watched. But Richter was much stranger than stereotype. For

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most of their lives he and his wife were active nudists, sunning themselves at various "naturist" camps around the Golden State. He was the author of several unpublished novels, as well as painfully self-referential poetry, some of it published—reams of verse, from which, thankfully, Hough quotes with restraint. Judging from some of his poems and letters, he may have carried on several extramarital affairs.

As a scientist, though, Richter earns Hough's admiration. According to his colleagues, he was a veritable encyclopedia of information about earthquakes, and a tireless advocate for improving building designs in quake-prone areas.

But Hough has a harder time coming to terms with Richter's quirky personality. She strongly suggests that Richter suffered from Asperger's syndrome, a mild form of autism, which could account for both his ability to concentrate on details and his difficulty in connecting with people. Of course, it's always dangerous to psychoanalyze from a distance. But the famous earthquake expert, she surmises, was a man equipped "with a three-hundred-horsepower engine and a transmission that slipped madly between gears," who followed his own peculiar highway through life's unsteady terrain.

Human Anatomy: From the Renaissance to the Digital Age
by Benjamin A. Rifkin and Michael J. Ackerman, with biographies by Judith Folkenberg
Abrams, New York; $29.95

In medicine, as in many other professions, the distinction between science and art is a contemporary idea, dating to no earlier than the 1800s. That observation is particularly relevant to the history of anatomy, the focus of this magnificent collection of classic reproductions from the holdings of the National Library of Medicine in Bethesda, Maryland, and the Thomas Fisher Rare Book Library at the University of Toronto. Furthermore, the images have been annotated by a team of modern-day specialists: an art historian (Rifkin), a biomedical engineer and pioneer in bioinformatics (Ackerman), and a writer/book artist (Folkenberg).

Contrast the pictures on display here with the ones in any surgical manual of recent vintage, depicting exposed or disembodied organs and tissues against a featureless background. In the florid engravings of earlier centuries, the central figures often appear as elements of larger naturalistic or formal compositions. In Andreas Vesalius's landmark text on the human body, *De humani corporis fabrica libri septem*, published in 1543, a skinned cadaver vogues against the background of an Italian village; a skeleton in Charles Estienne's 1545 dissection manual stands contemplatively before a bucolic lake, holding out its detached mandible for inspection; a disembodied arm in Govard Bidloo's 1690 album of anatomy rests

on a table as matter-of-factly as a bowl of fruit in a still life.

To modern eyes, those settings seem distracting. And at times they are unsettling, particularly when the bellies of pregnant women are drawn as if cut open, to show the form and position of the fetus, or when mouths are incised and spread to illustrate the structure of the lips, tongue, and teeth. The most bizarre, hands down, are engravings from the *Thesaurus anatomicus primus* (1701–1716) of Frederik Ruysch, an anatomy professor from Amsterdam. They are a partial catalog of his personal cabinet of curiosities, a collection of preserved body parts, bones, and fetuses that represented not only abnormalities and rarities of the natural world, but also the grotesque imagination of Ruysch himself. Some of them show tableaus created with fetal skeletons, posed amidst surrealistic landscapes constructed of stuffed birds, bovine tracheas, and kidney stones.

In spite of their conflation of art and science, early anatomy texts required the collaboration of specialists: master surgeons whose skill with scalpel and dye highlighted organs of interest; artists who could sketch faster than cadavers decay; and engravers who could render not just form, but texture and contrast.

Engraving artfully drapes the muscles and tendons of a forearm and hand (from the 1690 edition of Ontleding des menschelyken lichaams [Anatomy of the Human Body], *by Govard Bidloo).*

In the twenty-first century, online databases such as the Visible Human Project (www.nlm.nih.gov/research/visible) make it possible to view anatomy from any angle, distance, or functional perspective with a precision the earlier masters could not hope to achieve. CAT scans and MRIs can render the particular internal structure of any individual on demand. Still, the pioneering works showcased here stand as elegant testimonials to how far science has come, and how long art endures.

LAURENCE A. MARSCHALL, author of The Supernova Story, *is W.K.T. Sahm Professor of Physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

Not Seeing Is Believing

The existence of dark matter is confirmed—again.

By Charles Liu

Dark matter is everywhere. According to current theory, it permeates our solar neighborhood, surrounds our Milky Way, and envelops every other substantial collection of matter in the universe. It's so dilute that astronomers can't even detect its presence in our solar system, yet on scales of millions of light-years, it's the dominant source of gravity in the cosmos. What's more, it's not made up of the same stuff we're made of—electrons, neutrons, and protons. And, true to its name, it's dark: Not only does it give off no visible light, but it's also dark across the entire electromagnetic spectrum. No gamma rays, no X-rays, no waves of ultraviolet, infrared, microwave, or radio frequency issue forth from dark matter anywhere.

Aftermath of the collision of two galaxy clusters is shown in this composite of X-ray, optical, and gravitational-lensing images of the object 1E 0657–56. The two colliding galaxy clusters (each white or orange speck in the two purple patches is a galaxy) have passed through each other; hot gas (pink) that was once part of each cluster was slowed by the collision and now lags behind its former cluster. The purple overlay indicates higher distortion by gravitational lensing, hence greater mass. It shows that mass is concentrated in the two galaxy clusters, even though the hot gas far outweighs the galaxies' combined luminous mass, confirming that each cluster is permeated and surrounded by a huge amount of unseen, cosmological dark matter.

So what *is* dark matter? Astrophysicists still don't know, but its existence has been tested again and again in the past few decades, and has been confirmed in various ways by a number of investigators. Yet despite all the tests and confirmations, plenty of people remain skeptical. Could another explanation be consistent with the observations?

The question, of course, is specific to astrophysics, but that *kind* of question would be familiar to investigators in virtually any scientific discipline. Whenever an accepted scientific theory can't explain a set of observations, scientists have three options: discard the theory and propose a new one; expand the theory to account for the anomalous data; or propose an alternate explanation for the observations that shows how the theory remains sound. That, by the way, raises a fundamental difference between science and nonscience: no scientific knowledge is so sacred that it can't be tested, challenged, and ultimately superseded.

Here's another fundamental difference between science and nonscience. No matter which of the three options they choose, scientists must push the new or revised ideas to their logical conclusions, deriving new predictions from them and testing the predictions repeatedly with new experiments and observations. A proposed but untested explanation is not a scientific explanation at all. It remains hypothetical—maybe an educated guess, possibly even a correct guess, but a guess nonetheless.

So it is with the theory of dark matter. A few scientists have supported an alternate explanation for the observations that dark matter is supposed to explain. Their idea is that Newton's second law of motion needs to be subtly modified. If its correctness could be confirmed, many observations that seem to point to dark matter could be explained in terms of ordinary matter alone.

Mind you, these "modified force" guys are part of only a small dissenting minority on the dark-matter issue. Yet dismissing their ideas would hardly be scientific, either. The scientifically right thing to do is to conduct experiments or make observations that clearly distinguish between a modified-force law and a preponderance of dark matter. Recently, a team at the University of Arizona led by Douglas Clowe, now of Ohio University in Athens, made just such an observation.

How much testing must be done before a hypothesis becomes established scientific knowledge, or else is discarded? It depends. If an idea is revolutionary, it must be confirmed often and in many independent ways before it is accepted. A classic example is the history of the theory of gravity. In the seventeenth century, Newton's theory explained the orbits of the planets around the Sun. The theory was revolutionary, but it was repeatedly confirmed.

But Newton's theory of gravity was eventually supplanted by an upgrade, as it were. Einstein's theory of gravity—general relativity—added the critical idea that space-time curves. General relativity, however, was nothing more than an elegant hypothesis until 1919, when observations of the apparent positions of stars during a solar eclipse confirmed one of its major predictions—that matter can bend space-time.

Less than two decades later, general relativity appeared subject to its own apparent anomalies. In the 1930s the American astronomer Fritz Zwicky measured the speeds of galaxies in a cluster in the direction of the constellation Coma Berenices as they orbited their common center of gravity. To his great surprise, he found that the typical speed of the orbiting galaxies was about 2 million miles an hour! At those speeds, so many galaxies would have escaped the cluster's collective gravitational pull so quickly that the cluster could never have formed in the first place. And yet, there it was, hale and hearty—in direct observational contradiction to Einstein's established theory of gravity.

Like all good scientists, Zwicky had to choose: new theory, revised theory, or same theory with alternate explanation? Zwicky chose door number three—and came to an astounding conclusion: a vast amount of invisible, or "dark," matter must be lurking in the Coma cluster, far outweighing the combined mass of the galaxies in the cluster. Only such dark matter could provide the gravitational "glue" necessary to hold the cluster together.

The recent work of Clowe and his collaborators centers on an object far more distant and complex than the target of Zwicky's studies. Designated 1E 0657–56, the object, about 3 billion light-years from Earth, is actually a merger of two galaxy clusters that looks like a gargantuan, asymmetric dumbbell [*see image on opposite page*]. Each cluster, or "knob" of the dumbbell, is actually made up of hundreds of galaxies, and the two clusters are more than 2 million light-years apart. (By comparison, our entire solar system, out to the orbit of Pluto, is about 0.001 light-year across.)

The clusters appear to have passed through each other after a head-on collision that began some 100 million years ago. Traveling like two schools of cosmic fish, the galaxies in the clusters flew right by one another at millions of miles an hour. But the diffuse, ionized gas that permeated the space between the galaxies didn't pass through quite as cleanly. Instead, the gas clouds dragged behind, billowing like two giant jellyfish in the space between the clusters. All that gas is more than twice as massive as the star-laden galaxies, based on estimates of its density and its volume from X-ray images. The result is that even though the galaxies are concentrated in the clusters at either end, the ordinary matter is concentrated near the center of the dumbbell, in the form of lingering ionized gas. So if there were no dark matter in the dumbbell, its gravity should be strongest in its central region and weaker at each end.

Clowe and his colleagues were able to measure how gravity varies across the entire dumbbell by charting how it acts as a gravitational lens: how the images of distant galaxies behind 1E 0657–56 are bent or distorted because of the space-time curvature in its vicinity—as the light passes through its various parts. The resulting gravitational-lensing map showed clearly that most of the mass of 1E 0657–56 is concentrated around the galaxy clusters—not in the center, where the gas remains, even though the hot gas far outweighs the combined stellar mass of the two clusters.

A modified-force law simply can't explain that observation. Something around and within the two clusters of galaxies, other than ordinary matter, is generating most of the gravitational pull in the system.

What could this something be? Lots and lots of dark matter remains the best answer.

So once again, and in a new and unambiguous way, the reality of dark matter has been confirmed. Has that finally put the controversy to rest? Can we astronomers at last take its existence as truth?

Um, no and yes. No, because both as a scientific community and as individual scientists, we should never reject the possibility—however remote—that we are wrong. Yes, because with so many lines of overwhelming evidence in its favor, it would be silly to pretend otherwise.

Yet we'll also keep on testing our theories of dark matter at our laboratories and observatories. That's a good thing; it's precisely the kind of skepticism that elevates real scientific theory above the realm of mere hypothesis. And it's also the only way, after all, that we're ever going to get to the bottom of the great mystery of what dark matter really is.

Charles Liu is a professor of astrophysics at the City University of New York and an associate with the American Museum of Natural History.

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By Joe Rao

February begins with Mercury in prime position for evening viewing. When darkness falls on the 1st, the innermost planet glows low in the west-southwest at magnitude −0.9 and sets about eighty minutes after the Sun. From the 1st through the 11th, Mercury will be within ten degrees and to the lower right of brilliant Venus (your clinched fist held at arm's length measures roughly ten degrees against the sky). The two planets appear closest together, approaching within slightly more than six degrees of each other, on the evenings of the 4th and 5th. Then they quickly draw apart.

On the 7th Mercury reaches its greatest eastward elongation, or apparent distance from the Sun, moving eighteen degrees east of the Sun. That delays the planet from setting until evening twilight comes to an end. As Mercury descends in the western sky, it lies almost directly above the part of the horizon where the Sun had set earlier. For observers at forty degrees north latitude, Mercury is also near its maximum altitude, eight degrees above the horizon at midtwilight (forty-five minutes after sunset)—the second-highest evening altitude the planet attains in 2007. The planet fades quickly thereafter by a factor of almost five in brightness, from magnitude −0.2 on the 9th to +1.5 by the 15th. Thereafter it becomes lost from view on its way to inferior conjunction with the Sun on the 23rd. Through a telescope, Mercury appears at midmonth as a rapidly thinning crescent.

Venus is likely to be the first "star" you see through the twilight after sunset; look for it in the west-southwest. With each passing week Venus moves higher and grows brighter. But it still isn't much to look at in a telescope, appearing as just a tiny, slightly gibbous ball. Observers can see nearly all of its illuminated face because it is now on the far side of the Sun as viewed from the Earth. On the evening of the 19th a slender crescent Moon, about two and a half days past new, rides well above Venus.

Mars rises just after dawn throughout the winter and much of the spring. Although it shines at magnitude +1.3, the Red Planet's low altitude in a brightening sky makes it a challenge to see, even for observers with binoculars.

Jupiter rises well after midnight and shines brightly in the southeast to south-southeast in the dawn twilight. At daybreak—an excellent time for observing Jupiter telescopically—the planet is higher in the sky than it has been since late last summer. The noble planet shines at about magnitude −2, as it creeps eastward through the feet of the constellation Ophiuchus, the serpent holder, and away from the bright star Antares, situated below and to the right of the planet.

Saturn reaches opposition to the Sun on the 10th. Thus it is visible all night long, shining as a bright (zero-magnitude), yellowish-white interloper in the constellation Leo, the lion, just to the west of the easily recognizable "sickle" of stars. It is now at its brightest and (for observers with a telescope) biggest. The rings, which have been tilting increasingly edge-on since 2003, are still inclined at about a fourteen-degree angle toward Earth, making for a grand sight even in a small telescope. Take note of Saturn's position relative to the full Moon on the evening of the 2nd; the Ringed Planet is the bright "star" above and to our satellite's right.

The Moon is full on the 2nd at 12:45 A.M. It wanes to last quarter on the 10th at 4:51 A.M., and to new on the 17th at 11:14 A.M. The Moon waxes to first quarter on the 24th at 2:56 A.M.

Unless otherwise noted, all times are eastern standard time.

FYI READER SERVICE

ADVENTURE TRAVEL/ TOURS

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Travel on the 104-passenger, zodiac-equipped *M/S Explorer* and discover the art, culture and wildlife of Arctic Canada and Greenland with our team of artists, scientists, and culturalists.

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Small group travel in the Andes, Amazon, Galapagos, Patagonia, Antarctica, and Central America. Expert local guides lead our cultural and ecological explorations and naturalist cruises.

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Small ship cruise and adventure travel experts. Explore nature up close and in style aboard luxury yachts, small ships and wilderness lodges. Our experienced staff knows the best ships and trips for every ability and budget.

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Award-winning Jungle Lodge in the Tamshiyacu-Tahuayo Reserve, shown to have the greatest diversity of mammals in all of the Amazon.

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Join an AMNH Expedition and experience first hand the world's greatest wildlife areas, archeological sites and cultural treasures in the company of AMNH scientists and researchers.

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Custom nature and soft adventure travel to Tasmania and Australia. Personal and small group touring based on your own interests and timetable. Accredited Tasmanian specialists.

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Canodros offers up-scale services in Ecuador with the Galapagos Explorer II and Kapawi. We are committed to providing a memorable and enriching experience of the culture, and natural history.

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Small-group cultural adventures led by world-renowned scholars explore some of the world's most interesting locations.

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Specializing in comprehensive, educationally- oriented, professionally-led natural history tours of the Galapagos Islands. Spend 11 or 15 days touring all the significant outer islands.

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Enjoy the natural wonders of South America on unique custom trips & expedition cruise voyages in the Galapagos Islands. Amazon River tributaries and Patagonia ice fields.

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We specialize in South America, offering exceptional nature and cultural programs to areas where wildlife abounds and indigenous communities are unspoiled. Small groups, customized itineraries, personalized service.

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Tara Tours specialize in travel to Central and South America since 1980. Free brochures and quotes.

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For trips that make a difference to you and to the places we visit. Trek Mountain Gorillas, snorkel on Barrier Reefs, rainforest hikes, whitewater rafting, and more.

15. ZEGRAHM EXPEDITIONS
Offers small-group expeditions to remote locations around the world. Expertly led and staffed, our programs provide the finest adventure travel experience imaginable.

CANADA

16. NEW BRUNSWICK, CANADA
From the world's highest tides in the Bay of Fundy to rivers that reverse their flow. . . there are no small wonders in New Brunswick, CA!

17. NEWFOUNDLAND & LABRADOR, CANADA
Newfoundland and Labrador. We offer our visitors the natural wonders of whales, icebergs and seabirds framed by our dramatic seascape and landscape and unique culture.

18. QUEBEC CITY, CANADA
Discover the magic of North America's most European City! Only 40 minutes from the Old City, go birdwatching, hiking and enjoy yourself. Our waterfalls and our colorful region will charm you!

19. PRINCE EDWARD ISLAND, CANADA
Come experience our unique red cliffs and parabolic sand dunes and hike or bike the Confederation Trail across our Island.

CRUISES

20. NORWEGIAN COASTAL VOYAGE ANTARCTICA CRUISES
Our 19-day voyage to Antarctica gets you closer to the wildlife and spectacular scenery of "The White Continent." Noted lecturers, expedition guides, and PolarCirkel shore excursions make this the journey of a lifetime.

21. NORWEGIAN COASTAL VOYAGE NEW WINTER CRUISES
These cruises feature watercolor painting and photography lessons, a whale-watching "safari", Arctic Spitsbergen, and other unforgettable experiences. Prices start under $1,999.

22. ORIENT LINES
Unique CruiseTours[SM] combine a luxury cruise aboard the elegant *Marco Polo* with included hotel stays and city tours before and/or after your cruise. Enjoy the best of land and sea with the Destination Cruise Specialists!

INTERNATIONAL TRAVEL

23. BELIZE
Catch the Adventure! From rainforest resort to Barrier Reef. Belize is only 2 hours from the USA. Belize. Mother Nature's best kept secret.

24. GUATEMALA
From our archeological skyscrapers to our quaint colonial cities; our Mayan culture to our vast natural resources. Come "Discover" our Mayan Spirit.

25. ICELAND
Where else can you experience an ancient heritage, pristine nature, and modern lifestyle that coexist in harmony? Enjoy yourself in a pure, natural, and unspoiled place—Iceland: The Way Life Should Be.

Of Arms and the Brain

By Robert Anderson

Last summer my son and I went snorkeling in the chilly waters off Catalina Island, along the California coast. As we swam above a kelp forest swaying with the surf, we spotted fish by the hundreds. Then my son pointed excitedly toward a yellowish-brown creature jetting along the rocky bottom. Sliding over some dark green stones, it instantly changed to a matching color, vanishing from sight as if by magic. This master of camouflage, I later learned, was a California two-spot octopus.

Members of the Cephalopoda, the class that includes cuttlefishes, nautiluses, and squids, along with octopuses, can change appearance in seconds. You can watch marine biologist Roger T. Hanlon's clip of the action by going to video.google.com and typing in "chameleon octopus" to access the video. To see a species that does more than just disappear into the background, type "Indonesian mimic octopus." That takes you to a short video of an octopus that mimics any one of three toxic species that occur in its native waters: a lionfish, a sea snake, or a sole.

"The Cephalopod Page" (www.thecephalopodpage.org), maintained by James B. Wood, a research scientist at the Bermuda Institute of Ocean Sciences in St. George's, is a good place to discover what features besides camouflage make cephalopods so fascinating. Near the top of the page, click on the "Lessons" section to select among the modules on cephalopod biology. There you'll find out about the mechanics of quick color changes and the physiology of the cephalopod eye, which is similar to our own. Or click "Cephalopod Articles" on the menu at the top to find more detailed (and marvelous) information: for example, "20,000 Tentacles Under the Sea: Cephalopods in Cinema," by the marine biologist Roland C. Anderson of the Seattle Aquarium, examines the creatures' horror-movie appeal and lists their film credits.

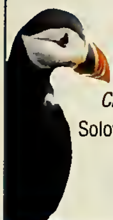
Their fearsome reputation is not entirely unfounded. Recently Japanese investigators, filming nearly 3,000 feet, caught on camera an adult giant squid, with an arm span (tip to tip) of twenty-six feet, in the act of hunting—the first images of an adult both alive and in the deep (go to news.bbc.co.uk/1/hi/sci/tech/4288772.stm and click on the video near the upper right).

Still, their monster image notwithstanding, cephalopods are an important source of the world's protein, as well as a favorite animal in medical research. At the Web page of the National Resource Center for Cephalopods at the University of Texas Medical Branch (www.utmb.edu/nrcc), click on "Cephalopod Literature and Information Resources" and then on "The Peerless Squid" for an overview of how the study of the squid's giant nerve cell, with its readily manipulated pencil-lead-thick axon, has led to key discoveries in neuroscience.

Of all the invertebrates, the giant Pacific octopus is often cited as the most intelligent. David Scheel, a marine biologist at Alaska Pacific University in Anchorage, has a site devoted to the animals (marine.alaskapacific.edu/octopus), which notes that they can reach several hundred pounds and span nearly two dozen feet from arm tip to arm tip. PBS's *Nature* series has the most startling video clip of all—an excerpt from "The Octopus Show" (www.pbs.org/wnet/nature/octopus). The keepers at the Seattle Aquarium kept finding the remains of four-foot-long sharks in their tank for big fish. Nighttime filming caught the culprit red-armed: the giant Pacific octopus they had innocently placed in the enclosure was snacking on the so-called "top" predator.

ROBERT ANDERSON is a freelance science writer living in Los Angeles.

EXPLORER GUIDE



AMNH to Confer Doctoral Degrees

For nearly a century, graduate students have conducted doctoral research at the American Museum of Natural History, but always for a degree at another institution. Until now. The American Museum of Natural History is now the first—and only—American museum to grant its own Ph.D. degree. Under authorization by the New York State Board of Regents, candidates for a doctorate in comparative biology will study and work within the Museum's unparalleled collections and laboratories in the newly established Richard Gilder Graduate School, with its faculty drawn from an internationally recognized staff of curators.

"The Gilder Graduate School, capitalizing on the Museum's unique and unrivaled combination of scientific leadership, world-renowned collections, and active program of field research, will train the next generation of scientists to investigate many of the most pressing issues confronting society in the 21st century," said AMNH President Ellen V. Futter.

D. FINNIN AND C. CHESEK/AMNH

Graduate students pursuing advanced degrees in comparative biology at the Museum will have plenty of paleontology and other specimens at their fingertips in the treasured public galleries as well as in the Museum's collection of more than 30 million specimens.

The new Ph.D. candidates will work in some of the most advanced scientific facilities in the world. Located within the Museum are three molecular laboratories, a powerful parallel computing facility, a frozen tissue collection with a capacity of one million samples, an imaging and microscopy laboratory, more than 30 million specimens and cultural artifacts, and the largest independent natural history library in the Western Hemisphere.

The American Museum of Natural History has long been known for its comprehensive approach to biological studies. Michael J. Novacek, Provost, Senior Vice President, and Curator in the Museum's Division of Paleontology predicted, "Profound biological discoveries will come from examination of myriad species. Here, we link emerging information on genes, form, and species diversity in a way that powerfully informs our understanding of the evolution of life."

The first class of the Gilder Graduate School, a select group of 8 to 10 students, is scheduled to arrive in September 2008.

Four donors have, combined, given more than $50 million to support the new graduate school in endowment, fellowship support, and capital enhancements required to accommodate the new Graduate School: the Gilder Foundation, the Hess Foundation, Inc., an anonymous Museum Trustee, and the City of New York—the Department of Cultural Affairs and the New York City Council.

Podcast News

The next time you assume that teenagers with the tell-tale wires hanging down from their ears are zoning out to the latest band on their iPods, think again. They might just be pondering the legacy of Charles Darwin's voyage on the *Beagle* or learning the secret sticking power of a gecko's toes.

That's because the American Museum of Natural History, in collaboration with Science & the City, the online newsletter of the New York Academy of Sciences, is now posting its world-class educational content in free podcasts.

Podcasting, downloading audio files to a portable player or personal computer, expands the Museum's reach by providing access to lectures, panel discussions, and other educational programs.

Just visit www.amnh.org/podcast, where you will find a list of podcasts by noted scientists and authors on everything from the 1906 San Francisco earthquake to biodiversity in New York City, the thrill of whale watching to what motivates someone to spend their life studying snakes.

I Spy a Butterfly!

WWW.AMNH.ORG

H. DAVIES/AMNH

Julia butterfly *(Dryas iulia)*

Unleash your inner lepidopterist with the Museum's online Butterfly Cam, which is focused on the colorful creatures of the in-house hothouse that is *The Butterfly Conservatory*, on view through May 28, 2007.

To get there, simply click on the exhibition itself at the Museum's home page, www.amnh.org, and follow the prompts to the Butterfly Cams.

As a bonus, you will also find three prerecorded film clips of monarchs and swallowtails enjoying a meal and the amazing spectacle of a zebra longwing emerging from its chrysalis.

Dedicated to Dunham

You dance because you have to.
—Katherine Dunham (1909–2006)

Katherine Dunham sought, in the native dances of the Caribbean, in the pounding rhythms of Africa, the cultural origins for the distinctive form of dance she pioneered. She spent her long life creating art of transcendent power and beauty, coupled with awareness of both racial inequality and ethnic pride.

PHOTOGRAPH BY CARL VAN VECHTEN, MUSEUM OF THE CITY OF NEW YORK

Katherine Dunham in *Cabin in the Sky*, 1940

Dunham was an exceptional and gifted woman—when she died in New York last May at 96, she held a 1936 degree in cultural anthropology from the University of Chicago and scores of honorary doctorates. She founded revolutionary dance troupes, choreographed at the Metropolitan Opera, and performed on Broadway. Her great love for the Haitian people led her to embrace the Vodoun religion and to capture headlines by going on a 47-day hunger strike at age 82 to protest U.S. treatment of Haitian refugees.

"Dedicated to Dunham" is the Museum's tribute to this remarkable woman, a one-day festival on Sunday, February 25, during African-American Heritage Month, celebrated as part of the Museum's Global Weekends programming. From 1:00 to 5:00 p.m., dancers and educators who studied with Dunham and the young stars who are influenced by her extraordinary work will perform, present panels, and screen films about Dunham and her remarkable life.

"I used to want the words 'She tried' on my tombstone," Dunham once said. "Now I want 'She did it.'" Dedicated to Dunham shows that, indeed, she did.

Dedicated to Dunham is coproduced by the American Museum of Natural History; Barbara Horowitz, founder and president of Community Works; and Voza Rivers, executive producer of New Heritage Theatre Group.
Global Weekends are made possible, in part, by The Coca-Cola Company, the City of New York, the New York City Council, and the New York City Department of Cultural Affairs. Additional support has been provided by the May and Samuel Rudin Family Foundation, Inc., the Tolan Family, and the family of Frederick H. Leonhardt.

PEOPLE AT THE AMNH

Leslie Martinez
Coordinator, Sleepover Program

D. FINNIN/AMNH

Every Thursday, when many people race for the door at the end of their workday, Leslie Martinez heads to the Akeley Hall of African Mammals for an evening animal drawing class. "I love it," she says. "It's a way to get to know the dioramas—and the Museum at night."

The Museum at night is Leslie's bailiwick now, as coordinator of the recently revived sleepover program in which 300 8- to 12-year-olds and adult chaperones explore the Museum after hours before setting up camp in the Milstein Hall of Ocean Life. "I only slept for one hour but it was all worth it," she emailed a colleague, exhausted but exhilarated after the first trial run in October. "It was amazing to see children with their favorite stuffed animals getting ready to sleep under the blue whale with their families."

Like so many AMNH employees, Leslie's enthusiasm is heightened by that of her daughter, Whitney, 10. "Whitney grew up here," says Leslie, who started at the Museum in 2001 as a part-time membership assistant while earning her B.A. in history at Baruch College. Whitney is also her best programming adviser. "She tells me what flies, what doesn't."

If there is a downside to her new job, it's turning someone away; for example, "a dinosaur-crazy 5-year-old on his birthday." But if Leslie has her way and the program keeps selling out as it has been, when that little boy turns 8, the sleepovers will still be going strong.

Museum Events
AMERICAN MUSEUM OF NATURAL HISTORY

www.amnh.org

R. MICKENS/AMNH

EXHIBITIONS

Gold
Through August 19, 2007
This glittering exhibition explores the captivating story of the world's most desired metal. Extraordinary geological specimens, cultural objects, and interactive exhibits illuminate gold's timeless allure.

Gold is organized by the American Museum of Natural History, New York (www.amnh.org), in cooperation with The Houston Museum of Natural Science. This exhibition is proudly supported by The Tiffany & Co. Foundation, with additional support from American Express® Gold Card.

The Butterfly Conservatory
Through May 28, 2007
Visitors mingle with live, free-flying butterflies in a tropical environment.

Yellowstone to Yukon
Through February 18, 2007
Spectacular photographs emphasize the diverse flora, fauna, and geology of the Yellowstone to Yukon wildlife corridor.

This exhibition was developed by the American Museum of Natural History's Center for Biodiversity and Conservation in concert with the Yellowstone to Yukon Conservation Initiative and the Wilburforce Foundation and is made possible by their support. Additional generous support provided by the Woodcock Foundation.

GLOBAL WEEKENDS

African-American Heritage Month: Dedicated to Dunham
Sunday, 2/25, 1:00–5:00 p.m.
A day of performances, workshops, and symposia celebrate the life and legacy of anthropologist, dancer, choreographer, and teacher Katherine Dunham. See p. 61.


DAN DEITCH

LECTURE

Death by Black Hole: And Other Cosmic Quandaries
Tuesday, 2/13, 7:00 p.m.
Neil deGrasse Tyson introduces readers to the physics of black holes by explaining just what would happen to your body if you fell into one. He explores these "and other cosmic quandaries" in this entertaining and informative talk.

ADULT WORKSHOP

Bead Workshop by Samuel Thomas
Sunday, 2/18, 12:00 noon–3:00 p.m.
Both East African bead winding and a similar technique used by the Iroquois will be demonstrated in this workshop with Iroquois beading artist Samuel Thomas and Munuve Mutisya, founder and director of the Akamba Peace Museum in Kyanzasu, Kenya.

FAMILY AND CHILDREN'S PROGRAMS

Bones, Brains, and DNA
Saturday, 2/10, 2:00 p.m.
Rob DeSalle and Ian Tattersall have coauthored an engaging illustrated book, *Bones, Brains, and DNA.* DeSalle will examine both paleontological and genetic evidence relevant to human evolution with the help of Museum mice Wallace and Darwin, narrators of the book.

ASTRONOMY PROGRAMS

NEW! Twinkling Stars
Two Tuesdays, 2/6 and 13, 4:00–5:30 p.m. (Ages 4–6, each child with one adult)
Classroom activities and observations in the Hayden Planetarium Space Theater reveal the stars above and the ancient stories and traditions that have followed them through the ages.


NASA AND THE HUBBLE HERITAGE TEAM (AURA/STSCI)

"Light echo" illuminates dust around a supergiant star.

NEW! Frosty Adventures
Sunday, 2/4, 11:00 a.m.–12:30 p.m. (Ages 4–5, each child with one adult) and 1:30–3:00 p.m. (Ages 6–7, each child with one adult)
Imagine what it would be like to live on a planet or moon with temperatures of -400 degrees Fahrenheit. In this workshop, investigate extreme cold in our solar system.

Robots in Space II (Intermediate)
Three Thursdays, 2/1–15, 4:00–5:30 p.m. (Ages 8–10)
Continue your exploration of robotics by designing increasingly complex robots and completing ever more challenging missions.

Dr. Nebula's Laboratory: Life with Lucy
Sunday, 2/18, 2:00 p.m.
What would it be like to live, work, and play with Lucy, a three-million-year-old human ancestor? Come join Dr. Nebula's apprentice, Scooter, as she

ROSE CENTER FOR EARTH AND SPACE

Sets at 6:00 and 7:30 p.m.

Friday, February 2

Arturo O'Farrill Ensemble
The 7:30 set will be broadcast live on WBGO Jazz 88.3FM


JOHN ABBOTT

AMNH

Lucy, an early human ancestor

explores the mystery, myth, and science of our earliest ancestors.

This program is made possible, in part, by an anonymous donor.

AMNH ADVENTURES: WINTER CAMPS
Monday–Friday, 2/19–23, 9:00 a.m.–4:00 p.m.
For further information, please call 212-769-5758.

Destination Space: Astrophysics
(For 2nd and 3rd graders)
Have you ever wondered what it would be like to live, work, and travel in space? Join others who share your interest in astrophysics and learn more about the universe.

Robotics
(For 4th and 5th graders)
Design, build, and program your own robot to explore an unknown planet using Lego Mindstorms robotics kits and computers.

NASA

Astronaut Michael Gernhardt is attached to the space shuttle *Endeavour's* robot arm during a spacewalk.

HAYDEN PLANETARIUM PROGRAMS

TUESDAYS IN THE DOME
Virtual Universe
The Grand Tour
Tuesday, 2/6, 6:30–7:30 p.m.

This Just In...
February's Hot Topics
Tuesday, 2/20, 6:30–7:30 p.m.

Celestial Highlights
Welcome the Lions of March
Tuesday, 2/27, 6:30–7:30 p.m.

LECTURE
The Road to Reality
Monday, 2/5, 6:30–7:30 p.m.
Roger Penrose of Oxford University highlights his account of theoretical physics that does not shirk its mathematical foundations.

HAYDEN PLANETARIUM SHOWS

Cosmic Collisions
Journey into deep space—well beyond the calm face of the night sky—to explore cosmic collisions, hypersonic impacts that drive the dynamic formation of our universe. Narrated by Robert Redford.

Cosmic Collisions was developed in collaboration with the Denver Museum of Nature & Science; GOTO, Inc., Tokyo, Japan; and the Shanghai Science and Technology Museum. Made possible through the generous support of CIT. *Cosmic Collisions* was created by the American Museum of Natural History with the major support and partnership of the National Aeronautics and Space Administration's Science Mission Directorate, Heliophysics Division.

SonicVision
Fridays and Saturdays, 7:30 and 8:30 p.m.
Hypnotic visuals and rhythms take viewers on a ride through fantastical dreamspace.

Presented in association with MTV 2 and in collaboration with renowned artist Moby.

AMNH

Earth's Moon was created by a "cosmic collision."

INFORMATION

Call 212-769-5100 or visit www.amnh.org.

TICKETS AND REGISTRATION

Call 212-769-5200, Monday–Friday, 9:00 a.m.–5:00 p.m., or visit www.amnh.org. A service charge may apply. All programs are subject to change.

AMNH eNotes delivers the latest information on Museum programs and events to you monthly via email. Visit www.amnh.org to sign up today!

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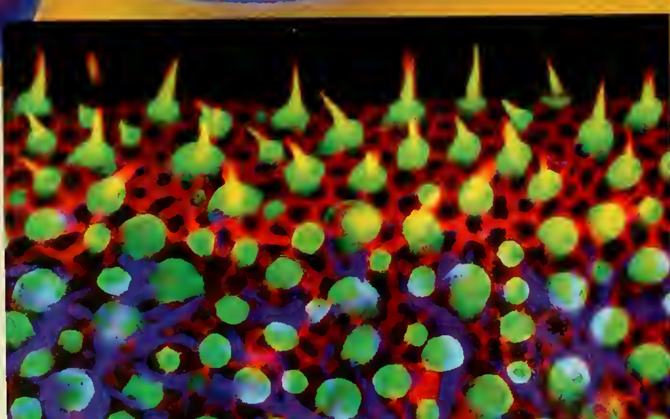
You'll enjoy many valuable benefits, including unlimited free general admission, discounts on programs and in shops, subscriptions to *Natural History* magazine and our Members' newsletter *Rotunda*, and much more!

For further information, call 212-769-5606.

ENDPAPER

Small Is Beautiful

The often uneasy marriage between science and art can be positively blissful when it comes to photomicrography, or photography through a light microscope. Micrographs have become a powerful tool for scientific investigation, but the ones shown here—all honorable mentions in the Olympus BioScapes 2006 Digital Imaging Competition, organized by Olympus America, Inc., of Center Valley, Pennsylvania—reveal the artistic beauty in life's eclectic complexity.



Top: Stamen cells in the small pink flower of a Tradescantia *plant undergo cytoplasmic streaming, the movement of organelles along microfilaments. The "tracks" show the organelles' paths. The image is magnified 700×. Above: Sensory hair cells (green) of a mouse's utricle, an organ of balance in its inner ear, appear in an image magnified 550×. Above middle: Longitudinal section of a rat fetus reveals its humanlike anatomy, including its tongue (blue), heart (green), and liver (right of heart, in blue). The image is magnified 3×. Above right: Cartilage in the ventral fin of a turbot, a flatfish, is shown in an image magnified 100×. Right: Regenerating bag cell neuron, which helps initiate the reproduction of a hermaphroditic sea slug (*Aplysia californica*)*. Thin projections called filopodia (pink), protruding ahead of the leading edge of the neuron (yellow), enable the cell to move. The image is magnified 300×.*