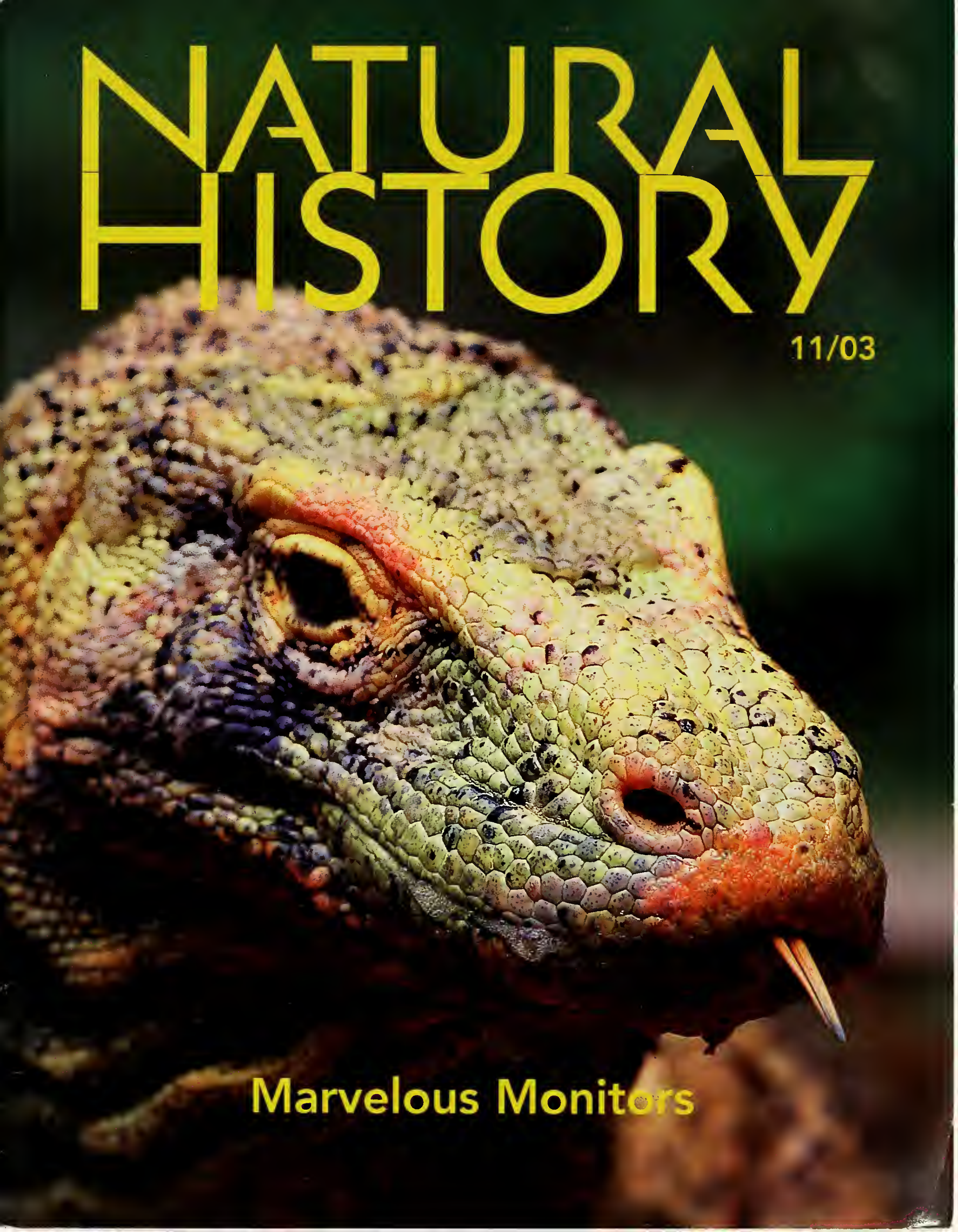
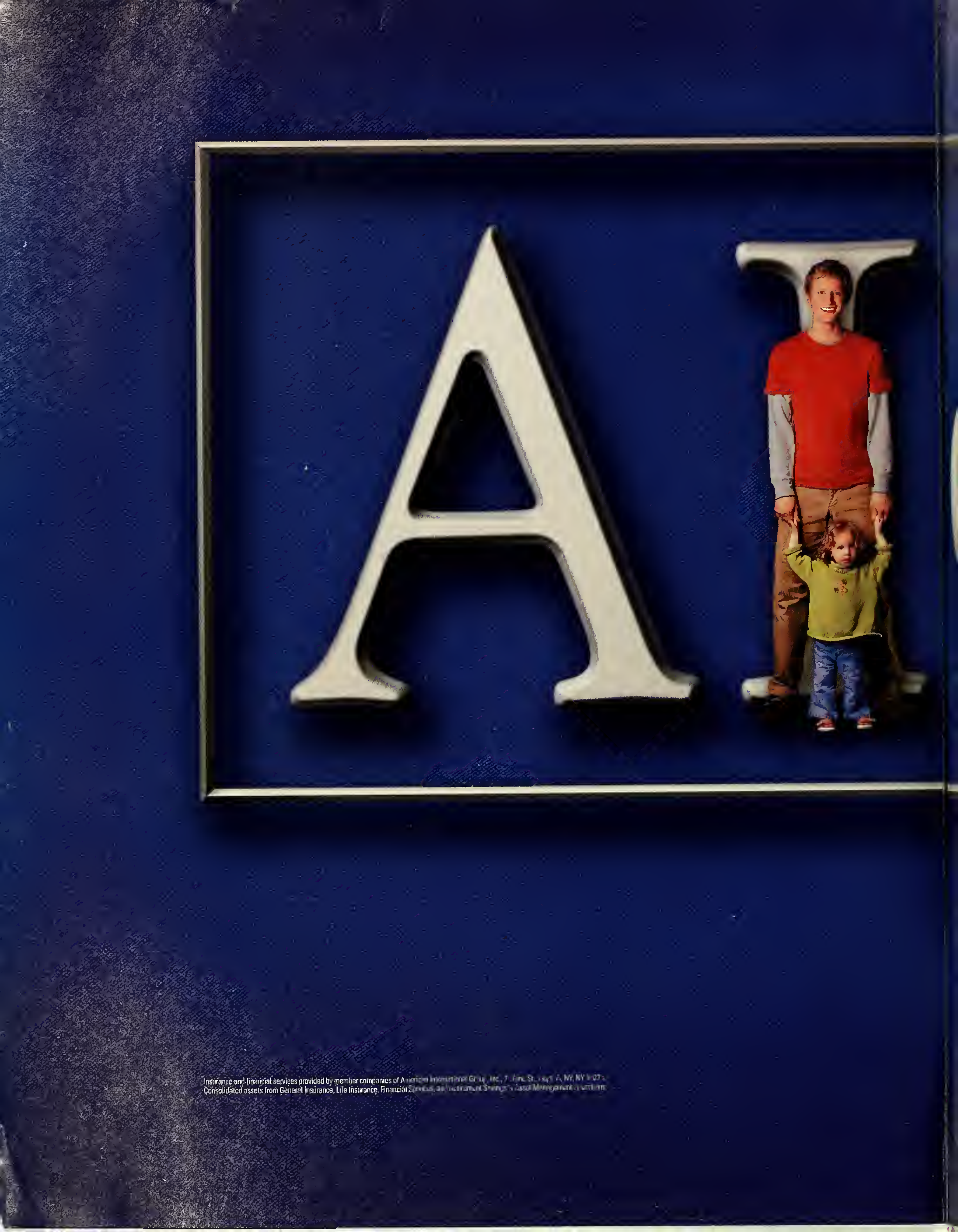
NATURAL HISTORY

11/03



Marvelous Monitors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NATURAL HISTORY

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PAUL SCHMID-HEMPEL

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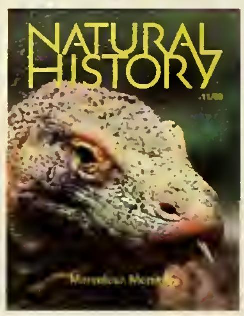

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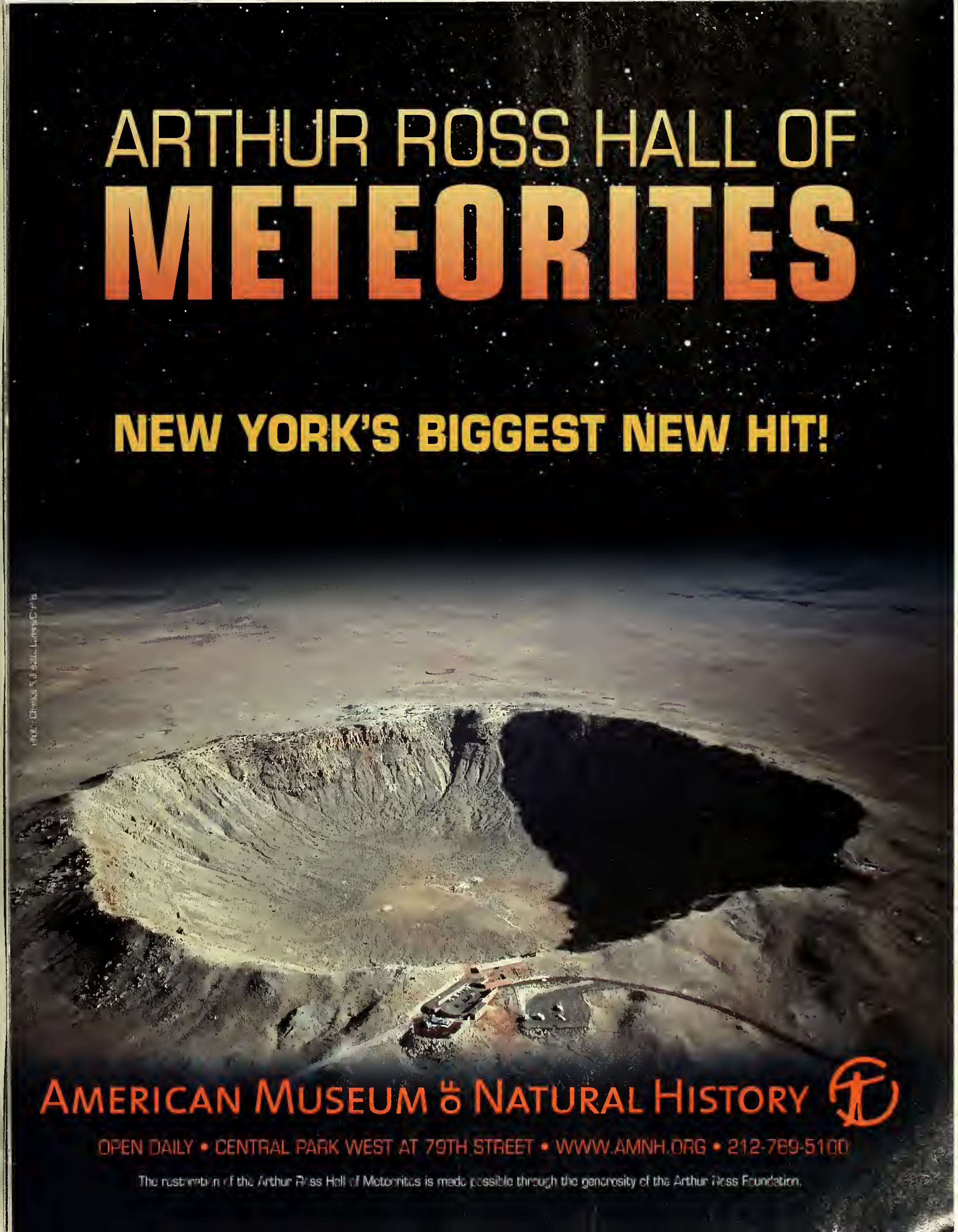

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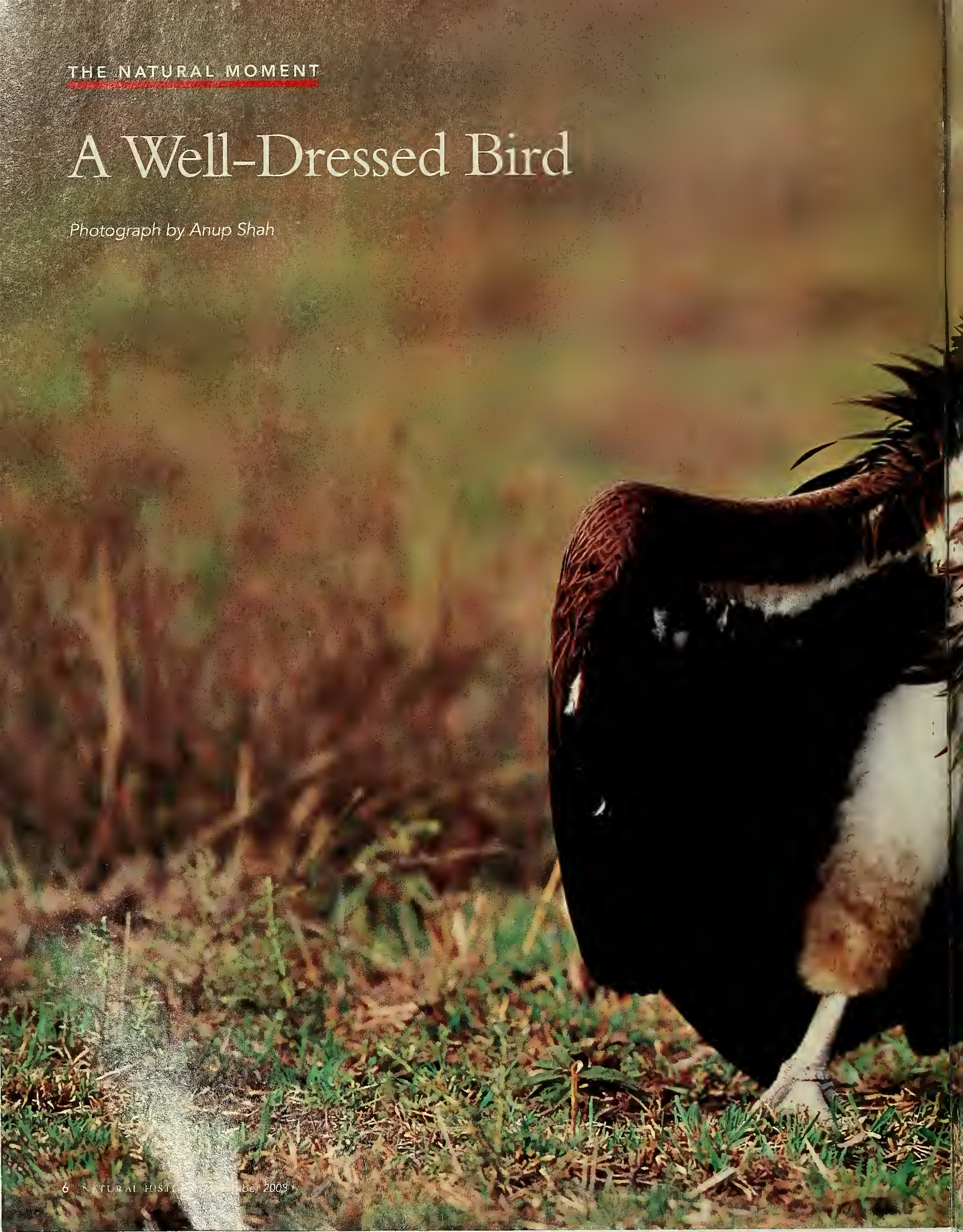
A Well-Dressed Bird

Photograph by Anup Shah



THE NATURAL MOMENT

◄ *See preceding pages*

Cutting the cake, carving the Thanksgiving turkey, or getting first crack at tearing into wildebeest flesh, as the case may be, is an honor usually bestowed upon the senior or perhaps showiest member of the dining party. On the savannas of eastern Africa, the Nubian or lappet-faced vulture *(Torgos tracheliotus)* is king of carrion. With thick, industrial-strength beaks, Nubians are often the only birds that can puncture tough hides—which makes weaker scavengers depend on them for access to the meat of a carcass. The massive vultures also use their might to fend off hyenas and snap up the occasional live flamingo.

Wildlife photographer Anup Shah was in Kenya's Maasai Mara National Park early one overcast morning, keeping his eye on a kill site, when the lappet-faced vulture pictured here arrived—unfashionably late. Minutes earlier, two lions had brought down a wildebeest, and already a spotted hyena, two black-backed jackals, and about twenty-five white-headed and Ruppell's griffon vultures were busily feasting.

The Nubian, after landing close by, did not attract much attention, so it opened its wings—a full nine feet across—to expose a puffed-up chest and downy underfeathers. "After swaggering around in an exaggerated manner," Shah said, the bird found a place among the others and commenced its meal. In less than an hour the assembled scavengers had picked the wildebeest's bones clean.

—*Erin Espelie*

UP FRONT

Flushed

Just when you thought you'd become so jaded about assaults on the natural environment that you'd heard it all, along comes a story that manages to stir shock, depression, and outrage anew. Thousands of miles out to sea, in a remote region of the North Pacific Ocean where even sailors seldom venture, is a vast floating mass of plastic junk, stretching across an area the size of Texas. Plastic bleach bottles, tops of spray cans, discarded TV picture tubes, polypropylene lines from fishing nets, plastic cigarette lighters, even toy "rubber duckies" have collected in a huge mass of slowly rotating seawater known as the North Pacific subtropical gyre, which—if you'll forgive the metaphor—has come to resemble a giant toilet bowl of swirling waste.

Is this the secret dumping ground of some evil junkyard Mafia? In fact, according to Charles Moore (see "Trashed," page 46), the effect is a natural one. Rivers of plastic objects are carried by great ocean currents from North America, Japan, and other lands along the North Pacific rim into the gyre. There, much of the detritus, most prominently the plastic, becomes trapped until it can decay—a process that, by some estimates, could take 500 years.

Worse, this environmental disaster is not merely an eyesore and a health hazard for seabirds. Japanese investigators have discovered that plastics can concentrate hydrophobic chemicals a millionfold. Those chemicals include such toxic substances as DDT, PCBs, and other oily poisons that have already been dispersed in the oceans. No one knows how such concentrations might affect plankton, fish, or other parts of the food web, but it seems unlikely that any good will come of it.

• • •

Not everyone will find the face of the komodo monitor pictured on this month's cover as endearing as I do, but the creature is certainly a poster child for a group of predatory lizards so wily and intelligent that the epithet "mammal-like" has become a cliché among herpetologists. Ecosystems don't even harbor small monitors and small placental carnivores at the same time. According to Samuel S. Sweet and Eric R. Pianka ("The Lizard Kings," page 40), the reason may be that the two groups play such similar roles.

What I find particularly fascinating about small monitors is their success as cold-blooded (more aptly called ectothermic) animals. They can move about all day, and they can strike like lightning when the circumstances call for it—yet they generally spend far less energy simply living than do their mammalian counterparts. The monitor story spotlights a basic lesson of biology: there are many ways to thrive in a threatening world.

—PETER BROWN

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CONTRIBUTORS

A self-taught wildlife photographer, ANUP SHAH ("The Natural Moment," page 6) was born in Kenya of Indian parentage. He credits childhood visits to Nairobi National Park with helping him develop a powerful attachment to African fauna. Shah and his brother Manoj have since teamed up and have been awarded top prizes for their photographic work. Their latest collaborative book, *The Circle of Life: Wildlife on the African Savannah*, will be published next month by Harry N. Abrams.

SAMUEL S. SWEET ("The Lizard Kings," page 40), an associate professor at the University of California, Santa Barbara, has worked on the ecology of salamanders, snakes, and toads, as well as on the ecology and management of such endangered species as arroyo toads and California tiger salamanders. His studies of monitor lizards have led to two and half years of fieldwork in Australia since 1988. ERIC R. PIANKA is Denton A. Cooley Centennial Professor of Zoology at the University of Texas at Austin. Pianka first studied the lizards of Australia during fieldwork in 1966. Together with the late Dennis R. King, he is co-editor of the forthcoming *Varanoid Lizards of the World* (Indiana University Press). A memoir, *The Lizard Man Speaks*, was published by the University of Texas Press in 1994.

A third-generation resident of Long Beach, California, CHARLES MOORE ("Trashed," page 46) is the captain of *Algalita*, an independent oceanographic research vessel. In 1994 he founded the Algalita Marine Research Foundation (www.algalita.org/), dedicated to research, education, and restoration of the marine environment. Since launching his ship in 1995, Moore, who received his captain's license from the U.S. Coast Guard, has conducted ocean and coastal sampling for plastic fragments and debris across a wide swath of the northern Pacific Ocean.

Swiss-born PAUL SCHMID-HEMPEL ("Fight of the Bumblebee," page 52) earned his doctorate in zoology and ecology at the University of Zurich, and pursued postdoctoral research at the University of Oxford, studying with the behavioral ecologist J.R. Krebs. In 1988 Schmid-Hempel was awarded the National Latsis Prize for his work in evolutionary ecology. Since 1991 he has been a professor at ETH Zürich, the Swiss Federal Institute of Technology. He enjoys opera and hiking in the northern tundra.

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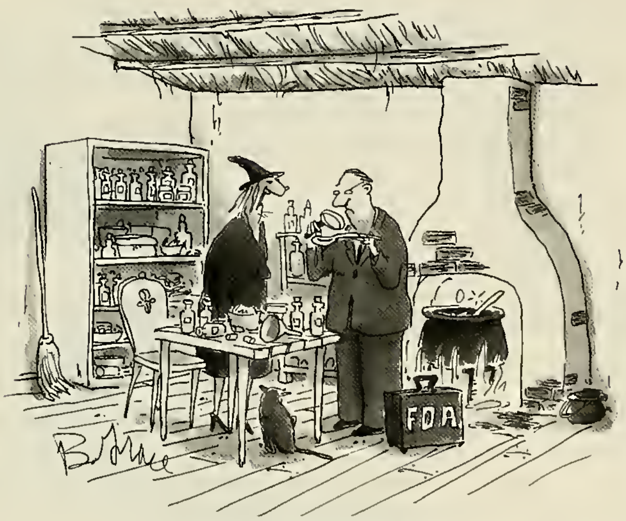
The Light Fantastic

I thought your 9/03 issue was sensational, but one thing puzzled me in Neil deGrasse Tyson's column "In the Beginning," about the early universe. He writes, "By now, one second has passed since the beginning of time. The universe has grown to a few light-years across."

Huh!!?? How could the universe have grown to several light-years across in one second? That would mean it expanded several hundred thousand times faster than the speed of light. Did Einstein's laws not apply at this time?

Hans J. Berliner
Carnegie Mellon University
Pittsburgh, Pennsylvania

NEIL DEGRASSE TYSON REPLIES: During the very early moments of the universe, space-time expanded much, much faster than the speed of light. That staggeringly rapid rate does not violate the principles of Einstein's special theory of relativity, which specifies that an object (or more generally, information) cannot accelerate past the speed of light when traveling within a preexisting space. Einstein's later, more complete general theory of relativity accounts for what can happen to the fabric of space-time itself, and places no restriction on the speed with which that space-time can expand.



"Of course it's full of rodent hairs."

Carl Sagan's Legacy

It was a great comfort to me in 1997, the year following the death of my husband and professional collaborator, Carl Sagan, to read the dedication in Stephen Jay Gould's book *Questioning the Millennium*:

In loving memory of my friend Carl Sagan
The most passionate rationalist of our times
The best advocate for science in our millennium

Steve was learned and highly principled, not one to toss out hyperbolic statements. So I was hurt to discover in Michael Ruse's review of Steve's final book, *The Hedgehog, the Fox, and the Magister's Pox* ["The Mismeasure of Science," 7/03–8/03], the claim that Carl wouldn't "take time out to go to the South and fight the creationists" during the 1981 trial of the Arkansas bill mandating that biology teachers in publicly funded schools evenhandedly discuss both evolution and creationism.

Carl began fighting for science in the dangerous Deep South of 1962, and never stopped as long as he lived. Mr. Ruse's gratuitous swipe at Carl brought to mind another time he was asked to testify against "creationism." It was when he was undergoing one of three bone marrow transplants endured in his heroic struggle for his life. His immune system destroyed by radiation and chemotherapy, emaciated and exhausted, he failed to satisfy the high standards of Mr. Ruse. Instead, he stayed in his hospital room as ordered and wrote *The Demon-Haunted World*.

Ann Druyan
Ithaca, New York

Michael Ruse does Carl Sagan a serious injustice. Sagan had in fact planned to testify at the Little Rock trial, but medical treatment kept him from appearing. He offered to act as a rebuttal witness at the end of the proceedings, but the American Civil Liberties Union's lawyers felt they had already made their case and thus concluded his presence was no longer required.

Frederic Golden
Santa Barbara, California

MICHAEL RUSE REPLIES: As in Akira Kurosawa's film *Rashomon*, the real story is unlikely to emerge at this time. But rather than get into justifications of claims, let me cover my somewhat ungracious reference to Carl Sagan by acknowledging that, in the last half century, he and Steve Gould were two of the most important science popularizers and educators. We owe thanks to both of them.

Whence the Moon

I would like to take issue with three elements in G. Jeffrey Taylor's excellent summary of the legacy of forty years of lunar exploration ["Moonstruck," 9/03].

First, the "giant impact" hypothesis for the origin of the Moon is seriously flawed. There is strong evidence that the lower mantle of the Moon is chemically primitive (chondritic) and could not have been part of either the early Earth or the impactor, nor could it have undergone the heating caused by a giant impact. Serious attention should be given to the hypothesis that the Moon was an independent, co-orbiting planet captured by the Earth.

Second, the Moon was resurfaced by a dozen or so large impacts around 4 billion years ago, not just by the impact that created the huge Imbrium Basin. A cataclysmic period half a billion years long is thus more likely than one lasting 100 million years.

Third, Mr. Taylor does not note the potential connection between the very early huge lunar impacts that created basins with diameters larger than a thousand kilometers (the oldest being the South Pole–Aitken Basin) and the early evolution of Earth's crust.

Harrison H. ("Jack") Schmitt
Albuquerque, New Mexico

Editor's note: The letter writer is the only geologist to have visited the Moon; in December 1972 he was an astronaut member of the crew of Apollo 17, the last manned lunar mission.

G. JEFFREY TAYLOR REPLIES: I welcome Jack Schmitt's comments. Planetary geologists, however, know little about the lower mantle of the Moon, so no one knows whether it is chondritic. New computer models suggest the giant impact might have taken place when the Earth was half built. Then, as planetary construction was being completed, the Moon could have accreted additional material. Such an explanation combines aspects of both ideas.

The article mentioned that the idea of a relatively brief cataclysm isn't universally accepted. The dissenters' view will be debated until samples have been taken from the South Pole–Aitken Basin and from some of the younger impact basins superimposed on it; that will require a return mission to the far side of the Moon.

Mr. Schmitt's third point is right on: huge early impacts on Earth might indeed have affected how the crust formed and evolved, and even how life originated.

Ask Pooh

Robert M. Sapolsky's article "The Pleasure (and Pain) of 'Maybe'" [9/03] gives fresh meaning to Winnie-the-Pooh's response to Christopher Robin's question "What do you like doing best in the world, Pooh?" We read that Pooh "had to stop and think. Because although Eating Honey *was* a very good thing to do, there was a moment just before you began to eat it which was better than when you were, but he didn't know what it was called."

William J. Rihn
Laguna Beach, California

Night Lights

Until my first week as a Marine grunt in Vietnam, I had never seen fireflies. Reading Sara Lewis and James E. Lloyd's "Summer Flings" [7/03–8/03] brought back strong memories.

It's hard to describe the tension and fear you experience on an all-night ambush. Maximum discipline is called for; at times we would even control our breathing to avoid detection. One night as I lay in wait above a trail, I noticed little green flares flying in all directions—as if there were a noiseless firefight of tracer rounds. All of a sudden, one "tracer" flew directly at my face, almost in perfect line with my two wide-open eyeballs. I ducked. To my relief, the green light flew in slow motion over my helmet.

Later the guys asked me why I had been ducking and thrashing around the night before. They nearly died of laughter when I told them. Now I find out the fireflies were making love in front of our killing zone. If those fireflies had only known.

Vicente Rivera
Tucson, Arizona

Natural History*'s e-mail address is* nhmag@naturalhistorymag.com

Naked: It's So 68,000 B.C.

One of the great questions for the fashion industry must be, When was clothing invented? Climate being what it is, body coverings could not have been long in coming after the loss of hominid fur, but the familiar paleontological clues aren't much use in pinning down either of those developments. Fossilized bones say nothing about external layers, and skin and clothes don't fossilize well. But Ralf Kittler, a geneticist now at the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden, Germany, and his colleagues haven't let such details stand in their way.

Body louse: a downside of clothing

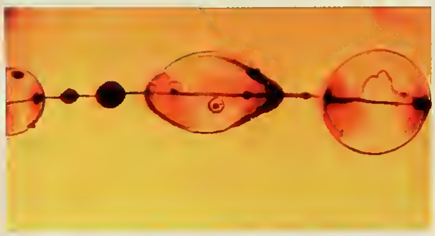
The body louse *(Pediculus humanus corporis)*—an evolutionary offshoot of the head louse—munches on the skin but inhabits clothing. So Kittler and his team reasoned that by estimating when the body louse emerged as a separate subspecies they could estimate when wearing clothes became the normal thing to do. The team examined differences between parts of the genes of body lice and head lice. In addition, because human beings and chimpanzees went their separate ways 5.5 million years ago, the team compared the human louse sequences with the sequences of chimpanzee lice. The latter comparison made it possible to calibrate the rate of change in the genomes of the lice. On the basis of their estimates of those rates of genetic change, they calculated that the human body louse emerged as a species some 70,000 years ago—a time frame that coincides nicely with the spread of modern humans out of Africa and into colder climes.

Earlier estimates for the widespread use of clothing were based on artifacts. Bone needles have been dated to 40,000 years ago; statuettes and clay impressions attest to the variety of weaving techniques in Europe by 30,000 years ago. Fashion mavens, rejoice: the demise of nakedness is no longer completely cloaked in mystery. ("Molecular evolution of *Pediculus humanus* and the origin of clothing," *Current Biology* 13:1414–17, August 19, 2003)

Spinmeisters

You wouldn't think spider webs could be part of the fossil record—and if it weren't for the preservative power of amber, they wouldn't be. Scrutinizing a fragment of Lebanese amber 130 million years old, Samuel Zschokke, a biologist at the University of Basel in Switzerland, discovered a thread of spider silk a sixth of an inch long, studded with thirty-eight minuscule droplets of glue. Both the diameter of the thread and the size, shape, and arrangement of the droplets are nearly identical to those of modern web-weaving spiders.

The specimen, whose true identity had remained unrecognized since 1969, came from the world's oldest deposits of amber containing insect remains. Fossilized spinnerets (the organs that spit out the spider silk) that occur in Middle Devonian rocks in Schoharie County, New York, show that spiders have been making silk for at least 380 million years. But there's no evidence that the threads made by those ancient spinnerets were gluey. Zschokke's discovery thus establishes the earliest time that spider webs became sticky. ("Spider-web silk from the Early Cretaceous," *Nature* 424:636–37; August 7, 2003)



Sticky spider silk in amber, magnified 150 diameters

Poisoning the Waters

Algae are a diverse crew. They range from single cells less than one ten-thousandth of an inch across to gigantic organisms hundreds of feet long. They're also the mainstay of the marine food chain, but that doesn't mean they passively accept their status as food. Certain microalgae actively emit toxins, and recent investigations show the toxins may have an offensive as well as a defensive role. Marine biologists Alf Skovgaard of the Institute of Marine Sciences in Barcelona, Spain, and Per Juel Hansen of the University of Copenhagen now have hard evidence that toxins from the microalga *Prymnesium parvum* may ward off competitors or even help the algae procure lunch.

Marine biologists have long believed that algal toxins repel would-be predators, such as fish and crustaceans. And it is well known that when algae proliferate, their toxic blooms can wipe out a region's aquaculture or close down its seafood restaurants. *P. parvum*—a notorious source of toxic blooms worldwide—photosynthesizes like a plant, but it also has animal ambitions: the creature ingests prey, sidling up to other microorganisms and engulfing them. But that process works well only with prey that aren't mobile: single-celled algae, after all, have no limbs or mouthparts to catch and hold their next meal. *P. parvum's* way around that limitation is to secrete chemical stun guns.

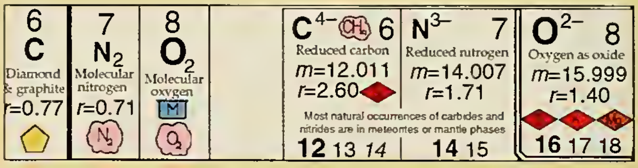
Skovgaard and Hansen have shown that the higher the concentration of *P. parvum* secretions, the more the motile microorganisms become immobilized and the more *P. parvum* move in to feed on them. And besides helping to provide meals, toxins could be disabling competitors and predators. In fact, the multifaceted function of toxins could contribute to the alga's periodic, and destructive, population explosions. ("Food uptake in the harmful alga *Prymnesium parvum* mediated by excreted toxins," *Limnology and Oceanography* 48:1161–66, May 2003)

Elemental Question

When attention wanders in science class, students' eyes often scan a familiar wall adornment: the periodic table of the elements. But if L. Bruce Railsback has his way, that enormous but relatively simple chart will be replaced—at least in earth-sciences classrooms—by a far more complex table.

Railsback, a geologist at the University of Georgia, in Athens, notes that the now-standard version of the periodic table, formulated in Europe in the 1860s, is of little use to earth scientists. It lines up only the pure elements. In nature, though, elements usually occur as ions—that is, in a charged form, often as part of compounds such as salt.

So Railsback has rearranged the elements as ions, not hesitating to revise the "sacred" text of chemistry by repeating elements that commonly occur as different ions, with different electric charges, under different conditions. The rearrangement has the advantage of grouping the ions on the basis of the kinds of combinations in which they often occur. Railsback also depicts interrelations via such devices as color (green for nutrients essential to life, red-brown for ions that make oxide minerals, and so on); size and boldness of the labels, which correspond to the abundance of the ion; and a host of symbols to indicate which minerals an ion forms.



Ions get a place at the geologist's new periodic table.

The result is a visually striking, information-packed chart that goes a long way toward explaining geochemical processes and patterns of abundance in the Earth's crust, mantle, and oceans. A patient student can now make better sense of why certain elements are more soluble than others (and thus more likely to occur in the sea), or why gold doesn't rust. But such a student will need more time to read the elaborate chart than most boring classes will ever afford. ("An earth scientist's periodic table of the elements and their ions," *Geology* 31:737–40, September 2003; www.gly.uga.edu/railsback/PT.html)

Really Sinister

What did Julius Caesar, Marilyn Monroe, Ronald Reagan, and Babe Ruth have in common? If you said all of them were lefties, smile and take a bow. Favoring the use of one side of the body isn't unique to people, though: some cats tend to reach with their left paws, for instance. Nor is the trait restricted to the use of limbs: some fishes tend to use the left eye to check out members of their own species.

But a left-handed snake? Well, yes: when snakes are at rest, they coil their bodies, and that puts one side or the other on the inside of the coil. According to Eric D. Roth, a herpetologist at the University of Oklahoma in Norman, if an individual snake or a species coils one way or the other in a reasonably consistent way, it makes sense to call the behavior "handedness."

Cottonmouth coiling (most of the way) with its left side on the inside

Roth recently spent six months repeatedly noting the coiling configuration of twenty adult cottonmouths, a venomous species native to the southeastern United States. Sixteen of the cottonmouths coiled more often with the left side of the body on the inside of the coil. Roth considered the effect strong enough to regard the population as "left-handed." Among the sixteen lefties, three were southpaws at the individual level: they coiled to the left twice as often as they coiled to the right—too marked a tendency to be caused by chance alone.

Does the frequency of handedness—or, more generally, "behavioral lateralization"—in lower vertebrates suggest that the animal brain became lateralized early in vertebrate evolution? It's too soon to tell. But it is safe to say that the idea of a left-handed snake isn't just a put-on. ("'Handedness' in snakes? Lateralization of coiling behaviour in a cottonmouth, *Agkistrodon piscivorus leucostoma*, population," *Animal Behaviour* 66:337–41, August 2003)

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

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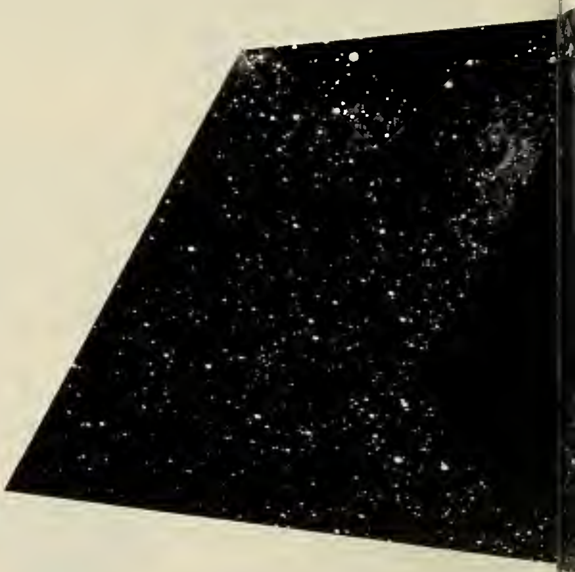
Dark and Darker



There's a lot more gravity in the cosmos than meets the eye.

By Neil deGrasse Tyson

Gravity, that most familiar of nature's forces, is both the best- and least-understood phenomenon in the cosmos. Not until Sir Isaac Newton turned his attention to the problem in the late seventeenth century did anybody figure out that gravity's mysterious "action at a distance" is caused by matter. Newton was the first to realize that a simple algebraic equation could describe the gravitational attraction between any two bodies, and that from that equation you could "weigh" the Earth and predict the future orbits of the planets. And not until Albert Einstein pondered gravity in the early twentieth century did anyone figure out that action at a distance is better understood as a warp of space-time, caused by the presence of matter or energy or both.

Neither Newton nor Einstein thought he was describing anything other than ordinary matter, the kind you can see, touch, feel, and taste. Yet for nearly three-quarters of a century astrophysicists have been waiting for someone to explain why 85 percent of all the gravity in the universe originates in a substance that no one has ever seen, touched, felt, or tasted. There's no guarantee that it even *is* a substance: maybe "excess" gravity emanates from something other than matter. In any event, the experts are clueless—and no closer to an answer today than they were in the 1930s. That's when the colorfully contentious Swiss-American astrophysicist Fritz Zwicky discovered the first sign that there is far more gravity in the cosmos than the stars, galaxies, and other visible objects could ever account for. Where was the "missing mass"?

The dark matter in the universe is six times more common, on average, than ordinary matter.

Zwicky had been studying the Coma cluster, a titanic ensemble of galaxies far beyond the local stars that trace the constellation Coma Berenices (a Latin phrase meaning "hair of Berenice," in honor of an ancient Egyptian queen who willingly cut off her tresses). Isolated and richly populated, the Coma cluster lies more than 300 million light-years from Earth. Thousands of galaxies revolve about its center, moving in every possible orbit like bees circling a beehive.

By measuring the motion of a few dozen galaxies, Zwicky discovered that their average speed is astonishingly high—much too high for the gravity field exerted by all of the Coma cluster's visible matter to be holding the cluster together. By all rights, the galaxies he observed ought to have been flung off into deep space—yet they clearly seemed bound by gravity to the rest of the Coma cluster. Some matter—at least some source of gravity—seemed to be misbehaving.

Zwicky based his conclusion on an intimate relation between the total amount of matter in a galaxy cluster and the observed speeds of its orbiting member galaxies. Assuming the cluster is not in some odd state of expansion or collapse, if you know the size of the cluster, and if you can estimate its mass, you can invoke Newton's equation to calculate what the orbital speed of its galaxies should be.

You can do a similar calculation for the orbital speed of each planet in the solar system. All you need to know is the planet's mass, the Sun's mass, and the distance between the two—well-known quantities by now. Calculate what the orbital speed of the Earth should be, and then measure the actual speed. The two figures will agree. But suppose you measured Earth's speed and it came out ten

Rupert Deese, *Swimmer*, 1988

times greater than Newton's laws said it should be. Knowing that Earth's velocity of escape from the solar system is only one-sixth that figure, you'd have to wonder why Earth (and all the other planets) hadn't flown the coop long ago.

In the Coma cluster, Zwicky found, galaxies were traveling faster than the escape velocity he calculated for them. Hence the cluster should have flung itself apart within several hundred million years of its birth, leaving barely a trace of its existence. Yet Coma's symmetrical beehive shape bespeaks an age perhaps as venerable as that of the universe itself.

In the decades that followed Zwicky's discovery, other galaxy clusters were found to have the same pattern. That meant no one could dismiss the Coma cluster as a renegade, and the significance of the problem became correspondingly magnified. Who—or what—was to blame? Newton? Not likely. His theory had survived two and a half centuries of testing. Einstein? Nope. Even the formidable gravity operating within galaxy clusters is too weak to require the corrective treatment of Einstein's general relativity. Perhaps the absent mass was just ordinary matter that happened to be dark—burned-out stars, for instance, that were no longer emitting visible light. For a short time, in fact, investigators named the problem "missing light" rather than "missing mass." But even when astrophysicists realized that the true problem was surplus gravity, they hurried to invent its presumed source, bestowing upon it the spooky name "dark matter."

Just as astrophysicists were growing accustomed to their ignorance, the problem of dark matter reared its invisible head somewhere else. During the 1970s and 1980s Vera Rubin, an astronomer at the Carnegie Institution of Washington in Washington, D.C., and her colleagues discovered that individual spiral galaxies present a similar anomaly. Beyond the luminous disk of such galaxies, scattered across the largely empty, "rural" areas of the cosmos, are a few gas clouds and isolated regions where bright stars are being born. By observing such star-forming regions, Rubin could trace the gravity field beyond the galaxy's visible edge. If those regions and gas clouds were subject only to the gravity of the visible matter in the galactic disk, their orbital speeds out there in Nowheresville should have dropped. But Rubin discovered that their speeds stayed high, without a trace of dropping off, even in the most remote locations.

Things that make you go hmmm.

If there isn't enough visible matter in the outer zone to account for the sustained orbital speeds of the tracer stars, she reasoned, there must also be some form of dark matter out there. Something was creating enough gravity to prevent the expected drop-off in speed. It turns out that the "extra" gravity, which astrophysicists came to call a dark-matter halo, extends outward to at least ten times the radius of every spiral galaxy ever observed.

Ordinary matter and dark matter loosely track each other in space, but not in a one-to-one ratio. Averaged across the entire universe, cosmic dark matter "outweighs" visible matter by a factor of six. But the ratio varies substantially from one kind of astrophysical environment to another. Dark matter is most dominant in large entities such as galaxy clusters, and unmeasurable in small entities such as planets. The surface gravity of Earth, for instance, can be accounted for entirely by the ordinary matter that's under your feet. So don't try to blame dark matter if you're overweight.

That variation in ratios is a sure sign that dark matter distributes itself more diffusely than ordinary matter. Otherwise, six pieces of dark matter would be clinging to every chunk of ordinary matter. As far as anyone can tell, though, that's not the way things are. Given the six-to-one ratio, all the ordinary, recognizable matter in the universe—the stuff you and I are made of—amounts to no more than a minor ingredient in the birth, evolution, and fate of the cosmos. Get over it.

Best as astrophysicists can figure, dark matter isn't just matter that happens to be dark: it's something else altogether. Yes, it wields gravity, but it doesn't do much else that's familiar. It neither absorbs nor emits light, rendering telescopes practically useless. And so a big, basic question remains unanswered: If all matter has mass, and all mass has gravity, does all gravity have matter?

How can we be sure dark matter isn't simply matter that happens to be dark? Investigators examined all the plausible candidates—as if they were looking over the suspects in a police lineup. Is it made of black holes that come from stars? No, theories of stellar evolution rule out that possibility, and besides, such a huge quantity of black holes would have shown up in other ways. Is it dark clouds of gas? No, they would absorb or otherwise interact with light from the stars behind them, which genuine dark matter doesn't do. Is it interstellar or intergalactic planets, asteroids, or comets, all of which emit no light of their own? Seems unlikely: it's hard to believe the universe would lock up six times as much mass in planets as it does in stars. If it had, there would be 6,000 Jupiters for every Sun, or even less likely, 2 million Earths per Sun. But in our own solar system—if that's a typical example—the mass of everything other than the Sun adds up to less than two-tenths of 1 percent of the solar mass.

When nothing else works, scientists sometimes question the foundations of their assumptions. In the early 1980s the physicist Mordehai Milgrom of the Weizmann Institute of Science in Rehovot, Israel, proposed a new twist to Newton's law of gravity: modified Newtonian dynamics, affectionately called MOND. Admitting that standard Newtonian dynamics works just fine on the scale of stars and planets, Milgrom suggested that Newton needed help at the scale of galaxies and galaxy clusters. His solution was to add a term to Newton's equation—a term mathematically rigged to come to life only when applied to great distances. Although the term was intended primarily as a computational tool, Milgrom didn't rule out the possibility that it referred to an unheralded phenomenon of nature.

MOND enjoyed some success describing isolated spiral galaxies, but it was not conceived as a complete theory of gravity, and so it lacks a mechanism for calculating the motions of more complex systems, such as multiple galaxies. More important, MOND jumps through hoops to say anything about the early universe, where galaxies had not yet formed. In early 2003 NASA published a portrait of the cosmic microwave background made by the Wilkinson Microwave Anisotropy Probe (WMAP); that image, combined with data from other telescopes, isolated and measured the effects of dark matter in the early universe—leaving MOND with nothing to contribute, awaiting a likely burial in the graveyard of creative but wrong ideas.

"Dark matter" wields gravity, all right, but no one knows whether it's really matter at all.

Dark matter, though mysterious, has quite real effects, and helps demystify many phenomena that would otherwise go unexplained. By the time the universe was half a million years old, matter had begun to coalesce into the blobs that later became galaxy clusters and superclusters; during its next half million years the universe grew by 50 percent. All the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while, two competing efforts were at work: gravity was trying to collect and concentrate matter; cosmic expansion was trying to dilute it. When you do the math, you rapidly conclude that the gravity of ordinary matter could not have won the battle on its own. It needed help, and that help came from the gravity of dark matter. Without dark matter the universe would have no structures: no galaxies, no stars, no planets, no astrophysicists. How much extra gravity did ordinary matter need? Six times as much as it could provide on its own.

Dark matter played another crucial role a couple of minutes after the big bang, when the universe was dense and fiery, and protons began to form hydrogen nuclei. Within that cosmic crucible, other atomic nuclei were soon forged by nuclear fusion: significant quantities of helium, as well as minute quantities of deuterium (which is hydrogen with a neutron added to the nucleus) and lithium.

Of the four forces of nature, the strong nuclear force—the one that packs protons and neutrons together to form nuclei—was the prime mover back then. By the time the temperature dropped below the threshold for fusion, one in ten nuclei in the universe had become helium, one in a hundred thousand deuterium, and one in 5 billion lithium. The rest—about 90 percent of all nuclei—remained hydrogen.

What if all the dark matter during the first few minutes after the big bang had been dark ordinary matter? Six times as many interactive particles would have been squeezed into the infant universe. That huge extra quantity of ordinary matter, gung-ho as it was for fusion, would have dramatically pumped up the fusion rate of hydrogen but would have consumed much of the deuterium in the process.

As it happens, all the deuterium in the cosmos was manufactured immediately after the big bang. And because deuterium is readily consumed in the cores of stars, the most unevolved regions of the cosmos should hold no more of the stuff than existed at the end of the fusion era, after the first few minutes of the universe. And sure enough, the spectra of galaxies whose gas clouds have been only minimally processed show one deuterium atom in every hundred thousand. Just what one would expect from a big-bang birthday suit wrapped in a dark-matter blanket.

Without dark matter the universe would have no galaxies, no stars, no planets, no astrophysicists.

Astrophysicists are generally reluctant to base calculations on things they don't understand. Unrelenting skeptics will surely compare the dark matter of today with the hypothetical, now-defunct "luminiferous aether" that generations of physicists had proposed as the carrier of light waves. But dark-matter ignorance is fundamentally different from aether ignorance. Whereas the aether was a cover for scientific cluelessness, dark matter is not merely presumed to exist. Its gravity has been shown to exist. No one is pulling it out of thin space. In fact, dark matter is no less real than the hundred-plus planets now known to orbit stars other than the Sun—planets discovered solely by the effects of their gravity on their central star.

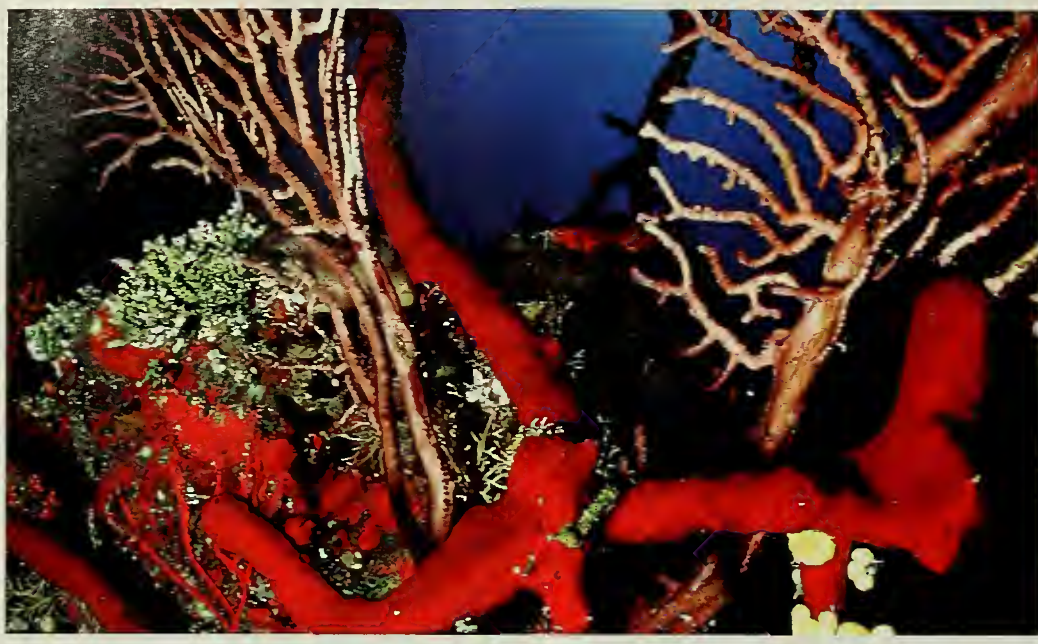
Other unrelenting skeptics might declare, "Seeing is believing." That premise may make you a good carpenter or cook or resident of Missouri, but it won't make you a good physicist. Physics is not about seeing: it's about measuring—preferably with something that's not your own eyes, which are inextricably conjoined with the baggage of your brain.

Having resisted all attempts to understand it, dark matter has become a kind of Rorschach test for investigators. Gravity skeptics say we don't really understand gravity. Particle physicists say dark matter could be some ghostly class of undiscovered particle. Maybe the particles interact through gravity plus some unknown additional force, or maybe (and more likely) they do respond to normal forces, but so weakly that the particles are virtually undetectable. Or how about the cosmic exotica that sometimes appear in "theories of everything"? Perhaps a parallel, phantom universe exists right next to ours, revealed only through its gravity. We'll never actually run into its matter, but we might feel its tug.

Whatever dark matter is, though, its effects in the contemporary universe are straightforward enough to calculate. It doesn't appear to interact through the strong force, so it can't make nuclei. It doesn't interact through the weak force, so its particles don't decay into lighter ones. It doesn't interact through the electromagnetic force, so it doesn't make molecules, nor does it absorb, emit, reflect, or otherwise scatter light. It exerts gravity that ordinary matter responds to. End of story. Beginning of ignorance.

But so far as anyone knows, the march of astrophysics hasn't yet been derailed or stymied by that bit of uncertainty. We astrophysicists don't happen to know what the stuff is. Nevertheless, we carry it along as a strange friend, and invoke it wherever and whenever the universe demands. And by doing so, we get all the right answers—except to the question that matters most.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of the Hayden Planetarium in New York City. Videotapes of a dozen of his lectures, under the title "My Favorite Universe," were recently released by the Teaching Company (www.teachco.com). *All twelve are based on essays that have appeared in* Natural History.

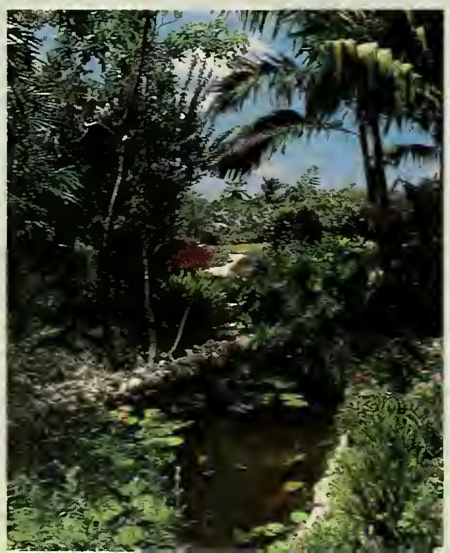


Photos: Cayman Islands Department of Tourism

The Cayman Islands

South of Cuba, the Caymans consist of a trio of islands: Grand Cayman, Cayman Brac, and Little Cayman. All are renowned for their spectacular coral reefs, sun-kissed beaches, waters teeming with fish flecked with gold, and a grand 500 years of culture, history, and beauty.

The best known island is Grand Cayman, a great place to start your adventure. George Town, the capital city, boasts some of the finest cuisine and shopping in the Caribbean, and you can also explore the islands' rich history here. In addition to world-class scuba diving, snorkeling, and sailing, plan a trip under the sea to feed the stingrays, an excursion to the Turtle Farm, or a journey into the past to revisit the first landing by Christopher Columbus. If you're interested in natural history, make sure to visit the sixty-five-acre Queen Elizabeth II Botanic Park and the National Trust's Mastic Trail. This two-mile footpath through unspoiled woodlands guides you through Grand Cayman's largest area of untouched, old growth dry forest—among the last remaining examples of the Caribbean's dry, subtropical forest.



The "Sister Islands," Cayman Brac and Little Cayman, will relax you with their unique Caribbean lifestyle. Walk, hike, bike, take a leisurely drive, or just enjoy the blissful solitude. Just twelve miles long and two miles wide, Cayman Brac is famous for its superb diving and snorkeling. Its sloping, vertical walls as well as shallow sites burst with coral growth. The Brac also is home to over 200 bird species and is a stopping-off place for many birds on their way to warmer weather.

And just eight miles east of Cayman Brac lies Little Cayman. Still mostly undeveloped, Little Cayman has a population of less than 100 and is a nature lover's paradise. Explore its sandy beaches and coastline, lagoons, mangrove forests, salt ponds, and wetlands speckled with orchids. The birding here is outstanding. Among the must-visit stops is the Booby Pond Nature Reserve, with the largest red-footed booby colony in the Caribbean—more than 20,000 birds. There are nature sites with viewing platforms overlooking wild iguanas, egrets, West Indian whistling ducks, and many other birds.

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Distinctive Destinations

Maryland

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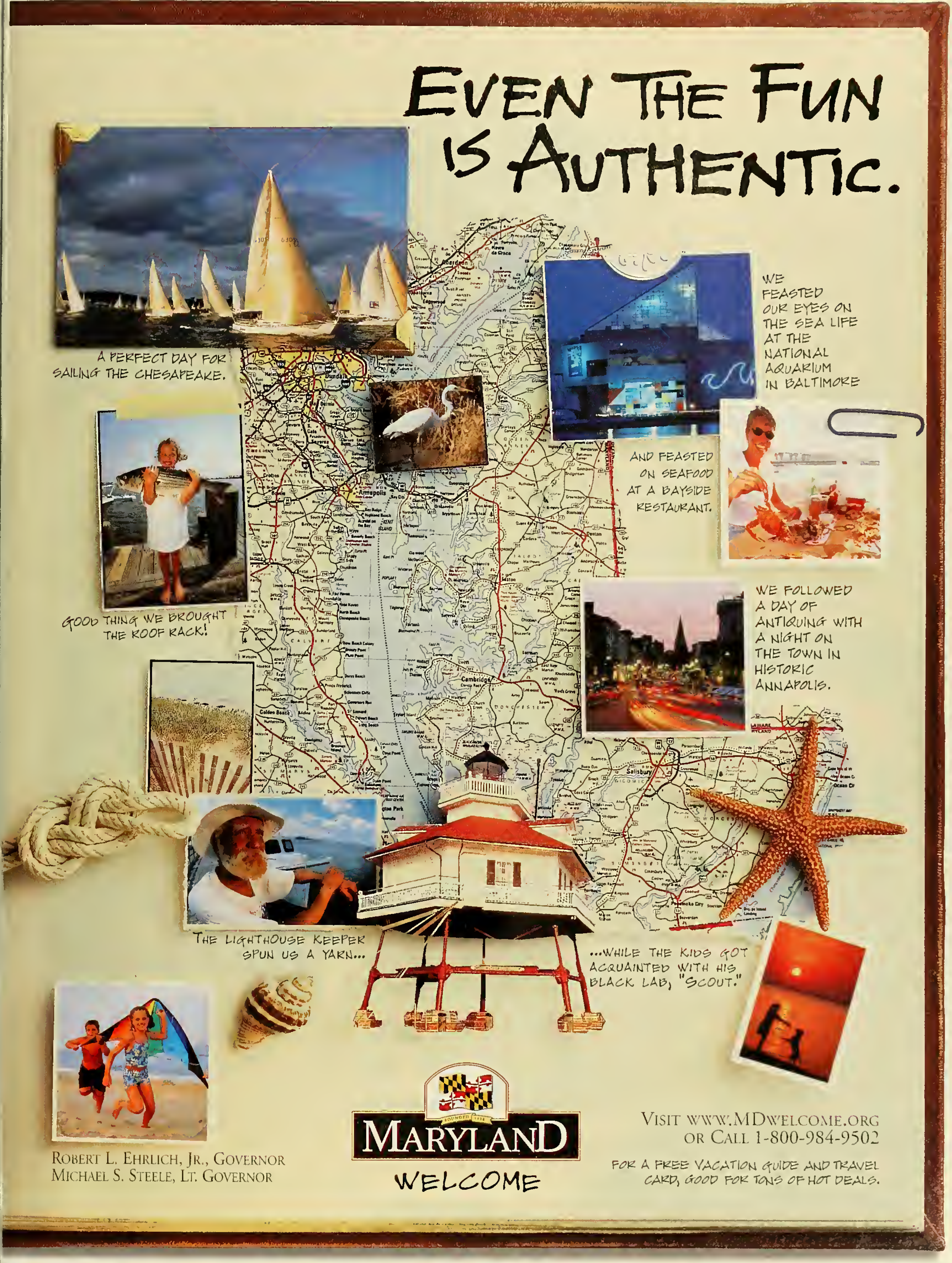
If you're looking for a perfect getaway that has a bit of everything—history, culture, and the great outdoors—then Maryland is the answer.

Nature lovers might start their visit in the state's Western Region, home of Deep Creek Lake, rushing waterfalls, and a portion of the Appalachian Trail. Here you'll find the rugged Allegheny Mountains, and Maryland's tallest mountain, Backbone. Civil War buffs won't want to miss the Antietam National Battlefield, site of the bloodiest single-day battle of the war. In the Southern Region, plan some time for birding: Charles County alone has 321 species of birds, including bald eagles, and miles of marshes teeming with wildlife. Charles also is a center of early Maryland history. Visit the Maryland Indian Cultural Center, in Waldorf, to learn about Native American life before European contact, and the Afro-American Heritage Society, in LaPlata, which depicts the history of African Americans in Charles County. In the Capital Region, near Washington, D.C., learn about space travel at NASA Goddard Space Flight Center. In the Central Region, visit Baltimore, the state's largest city, known for its cultural attractions as well as its famed Inner Harbor. Don't miss the Harbor's renowned National Aquarium, which houses sharks, dolphins, sea turtles, and thousands of other aquatic animals. Maryland's lovely capital city, Annapolis, is also America's sailing capital. With more eighteenth-century edifices than any other city in the U.S., this historic town is still an important maritime center.

And finally, take a drive through the fragile and beautiful Eastern Shore, between the Chesapeake Bay and the Atlantic Ocean. Enjoy the sandy beaches and boardwalk of Ocean City, a year-round resort. Just south of Ocean City, wild ponies roam the beaches and dunes of Assateague Island National Seashore. According to one legend, the ponies on this 37-mile-long barrier island are descendants of horses that survived the shipwreck of a Spanish galleon. Anywhere you go in Maryland, you can have a delectable meal of a just-caught fish, or perhaps some freshly shucked oysters, or the state's famous blue crabs, prepared in a multitude of delicious ways.

With so many things to do, so close together, Maryland will appeal to every taste.



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West Virginia

West Virginia is Wild and Wonderful, says the state's slogan. This is no idle boast: 80 percent of the state is forested. No wonder, then, that there are great opportunities for camping, hiking, and more: Paddling through frothing rapids. Mountain biking down steep tracks. Scaling sheer cliffs. Horseback riding in forests teeming with wildlife. Or making the perfect cast to tempt an elusive trout or bass. Take it outdoors—in West Virginia.

A salt desert in the Bolsón de Pipanaco, an enclosed basin in northern Argentina, is home to a rare species of rodent. The animals dig their tunnels in some of the natural mounds that pepper the landscape. Fresh tracks provide good clues to the whereabouts of the tunnels' occupants.

Desert Dreams

Seeking the secret mammals of the salt pans

By Michael A. Mares

On several forays into the Salinas Grandes—one of Argentina's great salt deserts—we had dug up mysterious burrows, but we had never discovered what kind of animal made them. Our team of biologists was looking for a rare mammal, a salt-pan specialist with a store of unique genetic information. Our failure was like a weight I carried with me every day. The bad news, I told my three co-workers, was that we would go back one more time. There were groans; it was a long, hard field trip. The good news, I said, was that we wouldn't dig anymore. Moving tons of earth had already proved to be no way to find our quarry, presumed to be a rodent.

The year before, I had brought some Conibear traps to Argentina, spring-loaded traps (named for their inventor, Frank Conibear) that can seize and kill animals without the need for bait. The problem had been figuring out where to place the traps so that animals would step into them. I had never been able to catch anything in Conibear traps before, but now I pinned my hopes on them. "There must be some reason I carted them down here," I told myself.

Back we went, to the Gran Chaco area of Central Argentina, the road by now familiar, and made camp. That first day I spread out my two dozen Conibear traps, while the others set our standard array of baited traps. There was nothing to do now but wait. In the frigid winter night, I dreamed that a new, rare, salt-desert rodent got caught in one of my traps. In my dream, though, the animal was dragged away by a predator before I could get to it. The thought jolted me wide-awake. It was 3:00 A.M., and the Sun wouldn't be up for hours. The cold stillness hardly beckoned me out of my sleeping bag. I rationalized: How could I find the trap in the dark, anyway? I decided to wait for dawn.

Salt deserts or salt pans—"salinas" in Latin America—are among the most extreme habitats on Earth. In some cases they formed where ancient seas once intruded on the land, then retreated and evaporated, leaving crystalline salts—mainly sodium chloride—behind. In other areas, where arid mountains surrounded enclosed basins, salts weathered from the uplands by seasonal precipitation were carried with the runoff into the valley below; again, when the water evaporated, the salts remained. But in whatever way the salts accumulated, eventually they covered the soil with a blindingly white patina. Few species, plant or animal, can survive in the forbidding habitat.

Among the exceptions are certain halophytic, or salt-tolerant, plant species in the goosefoot family (the Chenopodiaceae, or chenopods), which thrive in hot salt deserts throughout the world. The salt concentrations in the stems and leaves of these plants are many times what they are in seawater; the salts keep precious fluids in the plants' cells from being drawn by osmotic pressure into the salty soil. At the same time, as the water in their cells evaporates, the plants must prevent their internal salt concentrations from getting too high. Many halophytes compensate for evaporation by depositing salt crystals on the surfaces of their leaves, giving the leaves a grayish silver cast.

Halophytic chenopods, such as saltbushes, are green throughout the year, and their lush color might mislead one into thinking they are an ideal food source for plant-eating mammals. In fact, almost no mammals can process their high concentrations of salts. In three widely separated deserts, however, a few remarkable exceptions have been discovered, some only quite recently. All the species are rodents that have evolved highly specialized features to overcome the challenge of surviving on the salt-filled vegetation of the salt pans.

The first such species to be discovered was the chisel-toothed kangaroo rat *(Dipodomys microps)*. Kangaroo rats belong to a North American family of rodents well known for living in arid habitats, where they forage almost exclusively for seeds. They seldom have access to drinking water, but instead get most of their moisture from digesting the seeds.

Even among kangaroo rats, though, the chisel-toothed species is unusual. Unlike other species in the family, which have pointed upper and lower incisors, the upper incisors of *D. microps* have a broad cutting edge, and the lower incisors have the bladelike profile of a wood chisel. Investigators who studied the animal in the Great Basin Desert of the western United States in the 1970s discovered that it scrapes saltbush leaves against the lower incisors, thereby peeling away the crystalline layer of salt. The succulent green leaf tissues that remain still contain high levels of salt, but the rat's specialized kidneys produce a highly concentrated urine that removes those salts. Those adaptations enable the rodent to rely on the evergreen saltbush plants for sustenance throughout the year. But for many years ecologists thought it was the only mammal to have solved the riddle of living on the poisonous saltbush.

Then, in the 1980s, biologists began to study another desert denizen, the fat sand rat *(Psammomys obesus)* of the northern Sahara. The species belongs to the same family as the house mouse and the Norway and black rats, but it is only distantly related to the kangaroo rat. Even the basic body forms of the two desert rodents underscore the remoteness of their evolutionary kinship. The kangaroo rat has long hind legs on which it hops—a bit like its Australian namesake in miniature. The fat sand rat looks more like a gerbil. Yet, just like the chisel-toothed kangaroo rat, the fat sand rat inhabits saltbush areas in a desert; it feeds on the saltbush; it scrapes salt crystals from leaves with its lower incisors; and its kidneys excrete a highly concentrated urine. Having embarked long ago on distinct evolutionary journeys in widely separated arid areas of the planet, the two species have converged in certain remarkable details of their anatomy, physiology, behavior, and ecology.

Chisel-toothed kangaroo rat (Dipodomys microps) survives on a diet of salt-loving desert plants in the Great Basin Desert of the western United States. It was the first mammal discovered that could cope with such salty food in the absence of a source of freshwater.

The two saltbush-eating species remained the only ones known to science until the 1990s. But in 1995 I was able to determine that there is a third species, native to a third desert habitat: the Argentine Monte. I had first worked in this biogeographical region, a 1,200-mile-long strip of western Argentina, in the 1970s, when I studied the evolution of the mammals of the Monte. On one of my field trips, I had hoped to find a little-known rodent called the plains, or red, viscacha rat *(Tympanoctomys barrerae)*. The species was known to be a ratlike creature with a somewhat bushy-tipped tail, which presumably lived in saltbush areas near salt flats. It had been classified among the Octodontidae, a family of rodents that has inhabited South America for tens of millions of years. But the plains viscacha rat had not been found again in four decades, and only a few museum specimens were available for study.

My own search in the 1970s came up short, but in the late 1980s my former student, Ricardo Ojeda, an Argentine desert biologist working for the Institute of Arid Zone Studies (IADIZA) in Mendoza city, and several Chilean colleagues, finally collected some live specimens of the elusive animal. In the decades that had passed since the species had first been captured, scientific techniques had entered the era of genomics. The investigators discovered that the plains viscacha rat has 102 pairs of chromosomes, the highest number then known for a mammal. At the time, the nearest known relative of the plains viscacha rat was another viscacha rat, *Octomys mimax*, with fifty-six chromosomes.

In the mid-1990s, working in the Monte desert with Janet Braun, a colleague at the Sam Noble Oklahoma Museum of Natural History in Norman, and Robert B. Channell, then a graduate student at the University of Oklahoma and now of Fort Hays State University in Kansas, I was finally able to capture several plains viscacha rats alive. We learned that they make their homes in mounds largely formed through soil erosion and deposition. The mounds afford protection from the floodwaters that arise each summer, when monsoonlike rains and runoff water from the surrounding mountains inundate the parched salt flats. A typical mound is thirty feet long, ten feet wide, and three feet high, with as many as thirty openings and burrows at three different levels, perhaps dug over more than one generation. Sometimes several mounds lie close together. Surprisingly, however, each mound or set of mounds houses only one plains viscacha rat.

We examined a captive animal in a terrarium, where I fed it samples of the plants that grow on the mounds. It refused to feed on most of them, but when saltbush was offered, the creature quickly gobbled up the gray-green leaves. I noticed that as it held the plant in its forepaws, it rapidly moved its face and mouth, so that at times they appeared to vibrate. Bits of plant tissue flew aside, some sticking to the glass walls of the terrarium.

As I gathered up the bits, I was astonished to find that they were the salt covering of the leaves. How did the rodent manage to strip the salt from the leaves so quickly? I examined its mouth. Not too surprisingly, it had broad upper incisors and chisel-shaped lower incisors. But remarkably, in the soft tissue of the mouth, the animal appeared to have an extra pair of upper incisors, something no one had noticed while preparing the few museum specimens.

Examining these structures with a hand lens (and later with a light microscope and an electron microscope), I found that the extra "teeth" are actually stiffened bristles of hair [*see photomicrograph on page 32*]. The bristles are gathered into bundles that not only look like teeth, but are also sharpened against the tips of the lower incisors, much the way the true upper incisors are. (Both upper and lower incisors continue growing throughout the animal's life.) Hence for all practical purposes, the rodent has three sets of incisors with which to deal with the salt-encrusted leaves. And like the North American kangaroo rat and the North African fat sand rat, the South American plains viscacha rat also proved to have kidneys that produce highly concentrated urine.

After our work with the plains viscacha rat, I became convinced that the vast salt flats scattered throughout the deserts and arid thorn forests of northern Argentina could harbor other salt-pan specialists. In 1999, along with Rubén Barquez of the National University of Tucumán in Argentina, Mónica Díaz of Texas Tech University in Lubbock, and Braun, I traveled to a salt desert within the Bolsón de Pipanaco, in Catamarca Province, Argentina. An enclosed basin that runs 120 miles from north to south, and as wide as 80 miles, the Bolsón de Pipanaco appeared to be just the kind of place where another octodontid might have become isolated sometime in the past 15 million years, as the Andean mountain chains were uplifted.

Saltbushes—such as this Atriplex canescens, which ranges from northern Mexico to southern Canada—excrete excess salt onto their leaves. The salt crystals that form not only discourage consumption by herbivores, but may also help protect the plants from the intense sunlight.

After crossing through dense desert woodland with large, thorny mesquite trees, we entered the salt flat and began to search for telltale mounds that might belong to our hypothetical rodent. Within half an hour we had found mounds riddled with tunnels that looked unlike the mounds of any species we were familiar with. Tellingly, the only vegetation growing on or near them was a halophytic chenopod, *Heterostachys ritteriana*. The plant lacked the broad, grayish leaves of saltbush; instead, the leaves were compressed into small bluish green balls, only slightly larger than BBs. But when I tasted them, they were extremely salty, and the leaves had obviously been cropped by a rodent.

The mounds occurred in clusters of as many as six, and the larger mounds were connected to several smaller ones. Each was about twelve feet by six feet—somewhat smaller than the mounds of the plains viscacha rat—and had many openings. A few were covered with fresh rodent tracks. We grabbed our shovels and began to dig.

Our customary tactic was to plug the burrow openings with live traps (boxlike traps with a door that swings shut when an animal enters, thus capturing the animal alive), expecting to catch the animal as it raced away from the mound in panic. We found burrows at several levels, with many intersecting passages and large chambers at the intersections.

We would follow a tunnel from the central part of the mound to the trap we had placed at the exit. As each tunnel was opened and cleared, we would move on to the next. But after opening an entire cluster—and moving half a ton of soil—we had found nothing. We began to excavate a second cluster. We uncovered food stores and latrines, but no traps slammed shut. There were about thirty tunnels in the mound complex, some as deep as three feet underground and snaking among the tough roots of the salt plants. Finally only a single tunnel remained. If an animal occupied the cluster at all, it had to be here.

All of us were on high alert, waiting for it to run into the last trap. We cleared away the final bit of tunnel. Then: Nothing. Our hopes were dashed. We stared at the sand as if willing an animal to appear. Suddenly Janet screamed, "There it is!" We watched transfixed as a large golden rodent with a bright red bushy tail sprang from the sand and tried to escape. Mónica dove on the animal and grabbed it. It was beautiful. We all leaped with joy and hugged one another. We had found it! As we examined our prize it seemed obvious that it belonged to no genus and species that had ever before been described. But it was, indeed, an octodontid.

*Bundle of bristles (left), here shown fifteen times natural size, is one of a pair of such bundles on the mouth of the plains viscacha rat (*Tympanoctomys barrerae*) of western Argentina (right). The bundles act as an extra pair of upper incisors, enabling the animal to quickly strip salt off the surface of saltbush leaves. The animal belongs to the rodent family Octodontidae, a group whose fossil record in South America extends back tens of millions of years. Such rare desert mammals embody ancient genetic lineages that are not preserved in the continent's biologically rich rainforests.*

We named our find the golden viscacha rat, *Pipanacoctomys aureus*, its genus reflecting the isolated valley where it lives and its species name highlighting its golden color. Like the plains viscacha rat, it has a pair of little toothlike brushes behind its upper incisors, but they are less pronounced and less stiff than they are in the plains species. The golden viscacha rat has ninety-two chromosomes. Because genetic analysis shows that this animal is the closest relative of the plains viscacha rat, the high number of chromosomes in the latter species no longer seems so anomalous.

The golden viscacha rat is an extremely rare species, occurring over less than ten square miles of salt desert. That gives it one of the most restricted ranges of any mammal.

Why bother at all with these few little rodents? To most people, their desert realms appear to be wastelands. In some ways, however, deserts have a more distinctive biodiversity than the much-touted tropical forests: In South America, for instance, more genera and families of mammals occur in the grasslands, scrublands, and deserts of the continent than live in the vast Amazonian rainforest. Numerous families of the continent's mammals are restricted to deserts, whereas only one or two mammalian families are restricted to the tropical forest proper.

It is hard for any organism to survive in extremely arid regions. When today's deserts began to form, often millions of years ago, some mammals colonized them and gradually evolved unique adaptations. With time those early colonists differentiated through natural selection into species, genera, and even families. Their tough descendants, which have few relatives outside the desert, are a store of unique genetic information.

Unfortunately, that heritage is imperiled throughout the world by such man-made factors as global climate change, agricultural biotechnology, overgrazing, habitat destruction, uncontrolled hunting, petroleum production, and urbanization. Even the isolated Bolsón de Pipanaco is not immune. Large parts of the region have been cleared to make way for olive groves and vineyards, crops that are being irrigated with so-called fossil water—underground aquifers that accumulated in ancient times. Eventually the water table of the valley will drop, the drainage pattern of the salt flat will change, and the plants that the golden viscacha rat depends on will disappear.

My story might have ended here, if I had not been so persistent in convincing my colleagues to try our luck again. That was how, during our year 2000 field season, we had come to the Salinas Grandes, to begin a survey of that 3,200-square-mile area within the thorn forest of central Argentina known as the Gran Chaco. And so, after my anxiety dream about losing a trapped rodent, I was up at first light to check my Conibear traps. As I approached the end of the trapline, I still had caught nothing. Only two traps remained. Then I saw it. The next-to-the-last trap held an animal—a viscacha rat, unlike any I had ever seen. My nightmare notwithstanding, no predator had robbed me of it while I slept!

In the past, we had saved something special to celebrate the discovery of a new species. Usually it was a bottle of champagne or fine wine, but even a can of hearts of palm would

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suffice. For this trip I had splurged on a bottle of exceptionally good Argentine wine, which I packed with care and kept from freezing or overheating. In the several weeks we had been on the road, the rest of our wine supply had been depleted, but I had not allowed anyone to open this special bottle. "If you want to drink the wine, you have to catch the mammal," I would say.

As I returned to camp in the cold light of dawn, I hid the rodent behind my back, hanging it from my belt. Janet was already up, making coffee. I put on a dejected look. "Catch anything?" she asked. "Nothing," I said. Rubén and Mónica emerged from their respective tents. "Nothing?" they asked. "Nothing," I said. The sun was peeking above the horizon, and the aroma of coffee and salt mingled in the damp air. I began to rummage through the food boxes.

"What are you looking for?" Janet and Mónica asked, knowing I can never find anything around camp. "I'm looking for that bottle of wine," I said. Everyone stopped and looked at me. They knew I had caught an animal, and that it had to be new to science: it would become a type specimen, the specimen that is needed for the first scientific description of any new species or genus.

"Get the wine!" I said.

We named the new genus *Salinoctomys,* "the octodontid rodent of the salt flat." The species name, *loschalchalerosorum,* honors the great Argentine folklore group, Los Chalchaleros, whose songs my crews had sung during thirty years of field research across Argentina. The musicians had announced they would retire in 2001, after singing together for fifty-two years. We felt that they had accompanied us on every trip; we even joked that some of their songs could be called "type locality" songs, because their lyrics mentioned so many places our field crews had collected type specimens. It seemed the most appropriate and permanent way for us to thank the musicians for all the enjoyment their music had given us.

We celebrated our good fortune by drinking that wonderful bottle of wine, but the joy of discovery was tinged with a hint of melancholy. Such a moment would likely never be repeated. We planned to explore other isolated valleys and equally isolated mountaintops—habitat islands at high and low elevations, each as ecologically distant from the others as the islands in a Pacific archipelago—but we doubted we would ever encounter such a pair of distinctively new animals again, much less deduce their existence beforehand using only inferences about the habitat.

Still, we take satisfaction in encountering other new or rare animals. The world still harbors many undiscovered mammals. Each time a new species is found we peel back another layer of mystery about the complex history of life on earth. Crisscrossing the complex terrain of northwest Argentina, our routes bisect the ancient paths of Incas, as well as the unexcavated ruins of desert peoples who lived a millennium before the Incas. We gasp for air as we climb above 15,000 feet, pop Tylenol like candy for headaches, suffer in the freezing Andean winds, and broil in the heat of lowland desert. It is hard work, to be sure, but we couldn't be happier.

Michael A. Mares, former director of the Sam Noble Oklahoma Museum of Natural History, is a research curator and professor at the University of Oklahoma in Norman. He is the author of A Desert Calling: Life in a Forbidding Landscape *(Harvard University Press, 2002).*

Golden viscacha rat (Pipanacoctomys aureus) *was discovered by the author and his colleagues in the Bolsón de Pipanaco. Here the animal nibbles on* Heterostachys ritteriana*, a salt-tolerant plant.*

Catch and Release

Sea cucumbers might put a torn Achilles tendon back together again.

By Adam Summers ~ Illustration by Mick Ellison

North Atlantic sea cucumber, *Cucumaria frondosa*

When football season rolls around, a biomechanist's thoughts inevitably turn to connective tissue—and then, of course, to sea cucumbers. Most fans focus on cutbacks, open-field tackles and chop blocks, but I can't help but ponder the common casualties of these maneuvers: anterior cruciate ligaments (of the infamous ACL injury), hamstrings, and Achilles tendons. Anyone who has had to endure an injury in one of those body parts understands why they come to mind. Although tendons and ligaments—generally referred to as connective tissue—do stretch, they aren't nearly as elastic as rubber bands. In fact, they have a distressing tendency to tear or break, and when they do, they are devils to repair.

Sea cucumbers, invertebrate animals of the phylum Echinodermata, might hold out some hope for the afflicted. Although they have no internal skeleton, sea cucumbers and other echinoderms do have a kind of connective tissue, but one whose qualities are quite unlike those of mammalian ligaments and tendons. Biochemists and biomechanists are studying the stuff, known as catch connective tissue, because it might lead to new and dramatically superior repairs for injuries such as a running back's torn ACL.

Tendon is made up mostly of collagen, a protein that spontaneously aggregates into long, thin structures known as fibrils. The fibrils interact with each other and with their surroundings to form a stiff and cohesive tissue. But the process is apparently irreversible and non-renewable, and so if physical strain sunders the fibril bonds, tearing the tendon, it is impossible to reform them, at least in living tissue. The standard treatment is to tie the ruptured ends together and let scar tissue bridge the gap. But the bridge between fibrils is not terribly effective, and the scar tissue forms unwanted adhesions to other surrounding tissue. As a result, the tendon never regains more than about 60 percent of its original strength.

Imagine, then, the implications of an ointment that could cleanly break bonds between collagen fibrils and form new ones. A surgeon could chemically undo the rest of the bonds between two partially disjoined fibrils in the torn ends of a tendon, add fibrils to the gap at the frayed ends, and finally stabilize the repair by reestablishing the bonds between new and old fibrils and the rest of the tissue in the matrix: no gap, no scar, no loss of strength.

The armchair anatomist would be hard-pressed to find similarities between a sea cucumber and any part of a quarterback . Lacking arms, legs, and head, the brown cuke looks more like a football than a football player. Without an internal skeleton, it has to propel itself across the seafloor with bands of minute, hydraulically powered tube feet.

Catch connective tissue, also called mutable connective tissue, is a dense, white, fibrous material that makes up the dermis, or body wall, of the sea cucumber. What grabs the biomechanist's interest is that it can change from stiff to flexible and back again with ease. For example, when you hold the sea cucumber's skin between your thumb and forefinger, at first it feels soft. Within moments, though, it hardens, retaining the indentations of your hand for some time. Catch connective tissue enables the foraging sea cucumber to be soft enough to flow into nooks and crannies in pursuit of food. But it could also enable the creature to "don" leathery armor rapidly when a predator threatens (though that possiblity has not been tested).

A mammal's tendon can do no such trick. But both mammalian and catch connective tissue do share common structures. Both are made up of collagen fibrils, and the fibrils of both are suspended in a gooey material that makes the tissues "viscoelastic." (The goo, called the extracellular matrix, is made of water, proteins, and compounds known as proteoglycans, with filaments known as microfibrils suspended in it to serve as scaffolding.) A viscoelastic material acts partly like a solid and partly like a fluid. Under a rapidly applied load, the material reacts like a solid, deforming slightly but holding its shape, and pushing back as hard as it is pushed on. Under a force applied for a sustained period of time, the material reacts like a liquid, slowly taking whatever shape its surroundings impose. Silly Putty is a good example. A ball of the stuff bounces like a Super Ball when thrown, but it flows so well under steady, slow pressure that it takes a nice fingerprint.

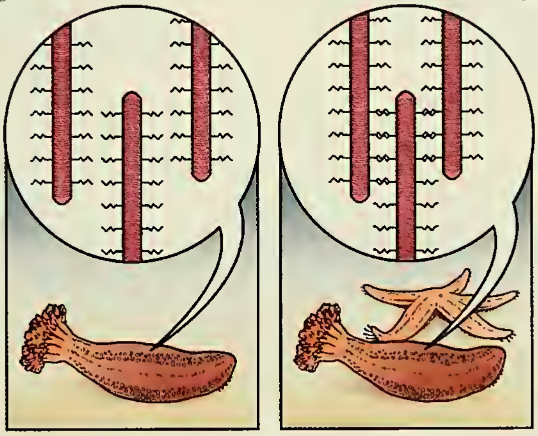
The great trick of catch connective tissue, however, isn't just that it has both viscous (fluid) and elastic (solid) properties; it's that the tissue's viscoelasticity can change. Some cells in the dermis secrete a plasticizing protein that loosens the grip on the collagen fibrils, enabling them to slide past one another and making the overall tissue soft and pliable. Other cells release a stiffening factor that causes the fibrils to "catch" and make the dermis far stiffer.

Biomechanists Greg K. Szulgit of Hiram College in Ohio and Robert E. Shadwick of the Scripps Institution of Oceanography in La Jolla, California, were able to extract chemical derivatives of both the "stiffeners" and the "plasticizers" from the dermis cells. Those derivatives gave the investigators a tool for altering the material properties of pieces of dermis at will, and thus to address a key question about the mechanism for the mutable viscoelasticity: Does the mutability originate from changes in the solid collagen fibrils, or from changes in the viscous, gooey matrix in which they are suspended (or both)?

Szulgit and Shadwick posited three different mechanisms for the mutable viscoelasticity: First, the linkages between the collagen fibrils might unfasten in the presence of the plasticizer, allowing the fibrils to move independently of each other and thus making the dermis flexible. Second, the fibrils might become more tightly bound to the gooey fluid. Or, third, the goo might become more viscous.

To distinguish among the three possibilities Szulgit and Shadwick set slabs of sea cucumber dermis on a fixed bottom and rapidly oscillated the top surface of each slab. They measured the force it took to move the top relative to the bottom when the tissue was stiff, and again when it was relaxed. The two investigators confirmed early work indicating that cellular extracts can change the stiffness of dermis between tenfold and seventyfold. Furthermore, the way the movements of the top and bottom of the dermis responded to the applied force shed light on the nature of the stiffened tissue. As the stiffness of the dermis samples increased, the contribution of the viscous matrix to the stiffness decreased.

The most likely explanation for those results is that the stiffener causes bonds to form between pairs of collagen fibrils or between collagen and other solid elements in the matrix. The plasticizer probably works by breaking those same bonds. That mechanism, though better understood, is still a ways from becoming the basis of a practical alternative to the crude splicing of tendons performed by surgeons today. For one thing, the plasticizers and stiffeners have not been well characterized; their exact composition is still a mystery. Nevertheless, I have high hopes that someday soon a surgeon somewhere will repair a career-ending ligament injury with the help of a sea cuke.



Echinoderms, the phylum that includes sea stars, sea urchins, and sea cucumbers, possess a kind of connective tissue that, unlike human ligaments and tendons, has variable viscoelastic properties. The material, known as catch (or mutable) connective tissue, has two states—pliable and stiff—that are mediated by two proteins. Recent research suggests that in the pliable state, collagen fibrils that make up the catch connective tissue are unattached to each other (left panel of schematic diagram). Something, perhaps a threat from a predator, causes bonds to form between the fibrils (right panel), stiffening the tissue and making it resist physical deformation.

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The Lizard Kings

Small monitors roam to the east of an unseen frontier; mammals roam to the west

By Samuel S. Sweet and Eric R. Pianka

A small lizard, caught in the open, flushes ahead of a pursuing monitor. The prey, desperately seeking escape, begins to run a winding course. The tactic could throw a predator off, but the monitor doesn't bite. Rather than engage in a tail chase, the monitor heads straight for a pile of rocks—the only nearby feature to which the hunted animal could possibly escape. The smaller lizard, outsmarted, arrives at the refuge too late.

Such a display of intelligence in monitor lizards, the animals of the family Varanidae, is not unusual. As a rule, monitors do not have to chase their prey very far, and in many cases they seem to anticipate some gambit by their prey. When arboreal lizards are being hunted and run for a tree, they usually spiral around to the back side to ascend; one of us (Sweet) has watched pursuing monitors of two species *(Varanus tristis* and *V. glauerti)*, on at least three occasions, spiral around the tree in the opposite direction to catch the prey unawares. (Experienced human lizard-catchers do the same thing.)

The black-palmed rock monitor *(V. glebopalma)*, a three-foot-long lizard from northern Australia, hunts by taking up perches on three- to six-foot-high boulders along the margins of ledges, where it has a good view of some area of more-or-less open ground. If it spots prey—such as, in Sweet's observations, a skink or a frog—it literally projects itself off the boulder, dashes after the prey, and then returns with its quarry at top speed to some rock crevice before doing anything like chomping or whacking the prey and gulping it down. "Lizards" don't do this: if they have something in their mouth, they eat it then and there—no matter that something else may be zooming in at top speed in hopes of a double lunch. But monitors do.

Predators and their prey are locked into a co-evolutionary arms race, in which any advantage gained by one calls for a countermeasure by the other. Less sophisticated, or perhaps just unlucky, prey individuals perish. On average, those with better means of escape survive. More effective escape, in turn, favors predators better able to capture evasive prey, and the bar for both species rises in a reciprocating fashion. Similarly, competing lineages of predators—cats and foxes, for example—are also subject to the Red Queen's dictum that "it takes all the running you can do, to keep in the same place."

A common result of such pressures—less adept animals either don't catch a meal or can't avoid being eaten—is the evolution of larger brains and more sophisticated nervous systems, as well as a potential for increased intelligence. A successful carnivore might have better neuromuscular coordination than its peers or its prey; more refined senses (and brain to process the information); or enhanced problem-solving capabilities. Those aspects of neurophysiology co-evolve in turn with ecological and behavioral differences among various kinds of carnivores. The range of possibilities for a predator's behavior—whether it hunts alone or in a pack; whether it lies in wait to ambush or actively chases down its prey; and the degree to which it relies on visual, auditory, or olfactory input to find its meal—all affect the nature and sophistication of the animal's brain.

None of the logic of this arms race leads to the conclusion that effective brains and neural sophistication are restricted to mammals; monitor lizards make that much clear. Superb predators, these animals surpass all other lizards in intelligence. They are alert and agile. Their styles of hunting rely on acute vision and extremely sensitive chemoreception to cover what are typically huge areas relative

Mertens' water monitor (Varanus mertensi) *hunts aquatic life in waterways across north central Australia.*

to their size. In these and other ways, convergent evolution has led to many similarities between monitors and mammals. Herpetologists have relied on terms such as "mammal-like" and "near-mammalian" so often to describe the monitors that such phrases have nearly become clichés.

The descriptions, however, divert attention from a question that is far more intriguing than mere similarities in habits between the two groups of vertebrates: Are the two groups so similar that they are ecologically incompatible as top carnivores? In other words, does the presence of one group in an ecosystem restrict the presence of the other? An analysis of the capabilities of monitor lizards and small mammalian carnivores, combined with the study of their biogeography, may throw some light on whether, in some ecosystems, the monitor lizards became a fair match for the mammals.

The similar adaptations of monitor lizards and mammalian carnivores are certainly not the products of a shared family history. The most recent common ancestor of the two groups lived more than 300 million years ago. It was a far less sophisticated animal, lacking the metabolic scope, visual and chemoreceptive abilities, and complex information processing that characterize both groups today. Most contemporary features of monitors and mammals that function in similar ways are clearly not the results of similar anatomical endowments.

One substantial difference is that monitors are ectotherms—loosely referred to as being cold-blooded. The more familiar term is something of a misnomer, because the "cold-blooded" monitors, at least, typically operate at tightly regulated body temperatures equal to or higher than those of mammals. Monitors, however, do without the costly molecular and physiological control mechanisms required by endotherms, the so-called warm-blooded animals. Both monitors and mammals can sustain their activities for long periods.

Monitors do not sense chemicals with the nasal olfactory chamber that is so well developed in mammals. Instead, they transfer compounds from their tongues into two elaborate sensory receptors known as the vomeronasal organs. Vestigial in mammals, these organs occupy paired cavities that open onto the roof of the monitor's mouth.

Many accounts of monitors in captivity cite behaviors unusual among reptiles that attest to sophisticated information-processing capabilities. White-throated monitors *(V. albigularis)* can count up to six. Komodo dragons *(V. komodoensis)* recognize their keepers. When chasing rats, crocodile monitors *(V. salvadorii)* anticipate evasive tactics. Few field studies, however, have explored the monitor intellect, and the wariness of monitors in the wild is legendary. But the work that has been done demonstrates that the animals can locate terrain features, mates, and food both by memory and with their remarkably sensitive chemical detectors.

Monitors are renowned trackers. Alexey Y. Tsellarius of the Severtsov Institute of Ecology and Evolution in Moscow and his colleagues found that Caspian monitors *(V. griseus caspius)* can distinguish male from female and resident from nonresident monitors merely by sampling their tracks with the vomeronasal organ. If the monitor then gives chase, it unhesitatingly follows the track of the other animal in the correct direction. Our observations in Australia corroborate Tsellarius's finding for both desert and woodland species. One of us (Pianka) once came upon the track of a large monitor known as a perentie *(V. giganteus)* that had intercepted his own. The track showed that the lizard "ricocheted" off the human footprints and fled in the direction it came from, illustrating its chemosensory talents.

Monitors that feed on the eggs of other reptiles can locate a clutch buried in sloping, backfilled tunnels. They do not gain access via the tunnel entrance, which is often three feet or more away from the eggs; instead, they dig straight down from above. Walter Auffenberg, a herpetologist formerly at the Florida Museum of Natural History in Gainesville, demonstrated that Komodo monitors can detect carrion from nearly seven miles away. Auffenberg also concluded that some monitors climb to ridgelines expressly to sniff the wind for carrion odors over a large area, a foraging strategy that requires substantial planning.

Monitors can apparently recall the positions of refuges within their home ranges. Pianka has observed that such Australian desert species as the perentie and the rusty desert monitor *(V. eremius)* remember exactly where good burrows are located: the lizards head directly toward them cross-country, which for perenties may be a mile or more. Lace monitors *(V. varius)* display a similar talent, though put to different use: They lay their eggs in active termite mounds, then return about nine months later to reopen the nests for the hatchlings to exit. Such a feat calls for map knowledge as well as an accurate sense of timing.

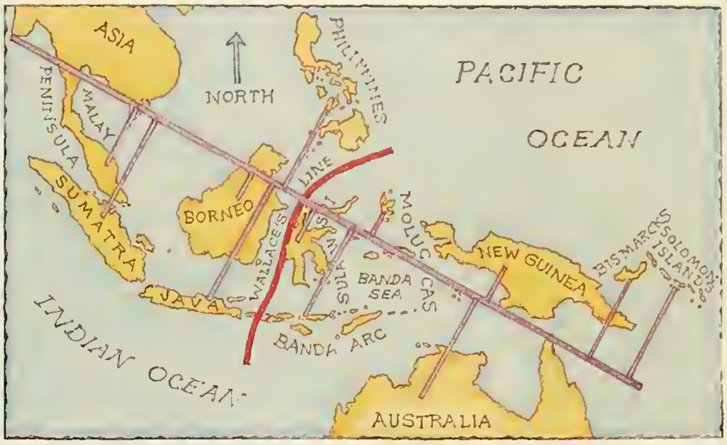
With the tongue monitor lizards sample the air for chemical compounds, then transfer the compounds into two cavities that open into the roof of the mouth. The cavities house elaborate chemical sensors called the vomeronasal organs. Pictured here is the common water monitor (V. salvator).

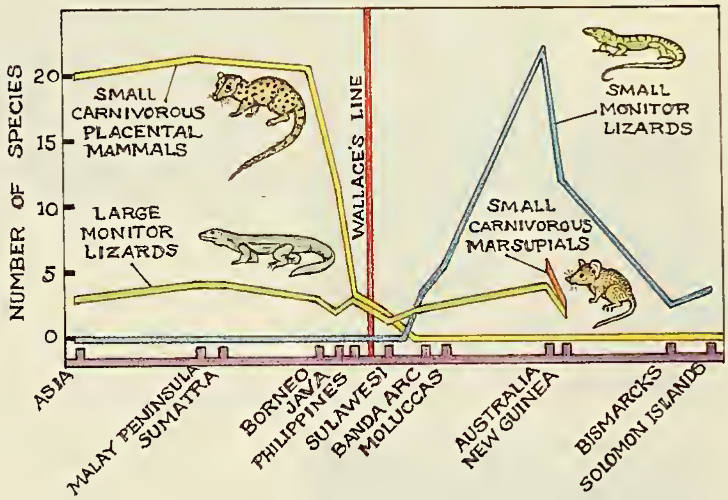
Radiotransmitters attached to individual monitors make it possible to follow them closely. We have learned, for instance, that male monitors seek out multiple partners by visiting the home ranges of several females. Sweet observed a male of the small arboreal species *V. glauerti* descend the home tree of one female and travel more than 300 yards in a straight line, through dense forest and rock outcrops, to the base of another tree. Six days earlier, he had mated with a second female in that tree, but in the interim she had relocated twice. So, finding no one home, the male trailed her to a third tree fifty yards away, then traveled another seventy-six yards to a fourth tree, where the second female then resided. The entire episode took only forty-five minutes and covered nearly 440 yards in rugged terrain.

This feat called on both mental maps and expert chemical detection. The male was familiar enough with his eighteen-acre home range to make a straight-line return to the second female's old location. Then he tracked her by her odor trail. Each of five male *V. glauerti* studied displayed similar abilities. And Pianka in Australia observed a male of the small arboreal black-tailed monitor *V. tristis* travel 790 yards in a straight line into the wind in one day; it was found in a hollow tree with a female, suggesting that it may have followed an airborne scent trail to find her.

Monitors sometimes adopt unusual foraging tactics. Some semiaquatic species, such as Mertens' water monitor *(V. mertensi)*, use their body and tail to herd fishes into shallow water. The black-tailed monitor has a unique tactic to rustle up skinks, the small lizards on which it feeds. Sweet watched several black-tailed monitors hunting skinks in leaf-filled depressions. The monitors would surge forward under the dry litter and then pop up, holding the head high and ready to pounce on any movement. After a few moments of watching, some individuals abruptly began to twitch and wiggle their tails under the leaves. The twitching sometimes caused a concealed skink to reveal its location.

Many people are familiar with the differences between cats and dogs, as well as between individuals of either group. Similar patterns show up in monitors, both in species and in individuals. During field studies that brought Sweet into daily contact with individuals of several species, he found that some male members of some species became habituated to his presence. Those lizards could be followed closely, and some even climbed onto him a few times. Others, however, became less approachable as his studies continued. Four out of six *V. glauerti*, two out of forty-two *V. scalaris*, and three out of twelve *V. tristis* habituated, whereas each of twelve *V. glebopalma* and five each of *V. scalaris* and *V. tristis* became increasingly wary with time. Either way, the animals clearly recognized and remembered him. Curiously, however, no females of any of these species ever habituated.





Transect line (purple line on map and on horizontal axis of graph) reveals a complementary distribution of species of carnivorous mammals and small monitor lizards. The transect, defined by the authors, makes a roughly perpendicular intersection with a biogeographic barrier first described by Alfred Russel Wallace. Wallace's Line marks the eastern limit of many animals having Southeast Asian affinities, and the western limit of a fauna derived from Australia and New Guinea. On the graph below the map, the number of species belonging to four groups of animals is plotted for various ecosystems that occur along the transect. The graph shows that the diversity of small carnivorous mammals (yellow) and that of small monitors (blue) are virtually mirror images of each other, as if they were reflected across Wallace's Line. The diversity of large monitor species (green) fluctuates randomly across the transect line. The pattern suggests that carnivorous mammals and small monitors may be too similar as predators to coexist, or that the small monitors become prey for the mammals when both are introduced into the same ecosystem. Interestingly, carnivorous marsupials (orange) do not prey on monitors, suggesting that the monitors can outsmart the marsupials but are outdone by the mammals.

None of the complex behaviors we are describing commonly occurs in other reptiles. And certainly no reptiles except monitors have such a broad repertoire of "mammal-like" attributes.

Throughout Africa and southern Asia monitors coexist successfully with a wide range of carnivorous mammals. The diversity of monitor species on those continents, however, is fairly low, and most of them are large (meaning the adults are more than four feet long) and relatively bulky. Six species occur in Africa and the Arabian peninsula, and one of those extends well into central Asia. Six more species range across mainland southern Asia.

As one moves east, into offshore Southeast Asia, the diversity of monitors increases sharply. Fourteen species are native to the East Indies and the Philippines (four of them also live on the mainland), and sixteen species are native to New Guinea, the Solomon Islands, and the islands of the Bismarck Archipelago.

That high diversity of small monitors in eastern Indonesia and Melanesia has only recently been recognized. Before 1990 only three small species were known in the region: the widespread mangrove monitor *(V. indicus)*, which varied greatly from island to island; the green tree monitor *(V. prasinus)* of New Guinea; and *V. timorensis*, of Timor. Through the efforts of Wolfgang Boehme, a zoologist at the Alexander Koenig Research Institute in Bonn, Germany, and his colleagues, sixteen additional species are now recognized. That work alone has increased the species count of the family Varanidae by about 25 percent. Some of the newly recognized species are local derivatives of the widely ranging *V. indicus* and *V. prasinus;* others are more distinct.

*Northern quoll (*Dasyurus hallucatus*; top), a carnivorous marsupial native to Australia, and the masked palm civet (*Paguma larvata*; above), a carnivorous mammal native to Southeast Asia, both coexist with large monitor lizards. Species of small monitors, however, thrive only where the civet and its kin are absent.*

The diversity of monitors reaches its peak in Australia, which hosts twenty-seven named species (five are shared with New Guinea) and more than a dozen as yet undescribed species as well. In parts of northern Australia as many as eight or nine species may occur in the same areas, partitioning resources according to differences in body size and habit. One unique and important feature of the Australasian radiation of monitor species is that more than half of them are small (adults less than four feet long) and of slender build.

To understand why small monitor species have radiated so dramatically through Australia, New Guinea, and their adjacent islands, but not elsewhere, we examined the possible role of Wallace's Line [*see map on preceding page*]. Alfred Russel Wallace, the nineteenth-century naturalist, did extensive fieldwork in what is now Indonesia, where he noted a sharp dichotomy in fauna between certain islands. One side of the line he traced to mark the dichotomy represents the eastern limit of many animals with Southeast Asian affinities; the other side is the western limit of a fauna derived from Australia and New Guinea.

Wallace's Line is now understood to overlie a region incorporating three major tectonic plates and several smaller ones. Thousands of islands made up of transient volcanic peaks and scattered microcontinental fragments are sandwiched between the eastern edge of the Asian continental shelf and the shelf that encloses Australia and New Guinea. Most important to the biota, no land connections have ever spanned Wallace's Line, and so it represents an absolute limit to the dispersal of organisms that cannot cross the sea. For other species, the line is just a filter, and it is almost irrelevant for many plants or insects that can fly long distances.

The lands in the vicinity of Wallace's Line provide a natural laboratory for testing ideas about the ecological equivalence of mammals and monitors. Virtually none of the small carnivorous mammals of Southeast Asia (cats, civets, mongooses, weasels) have crossed it from west to east on their own. Just one species of civet is native to Sulawesi, to the east of Wallace's Line; other civet and mongoose species in the archipelago were introduced by people.

In contrast to its influence on the mammals, Wallace's Line is not a barrier to monitors—or is it? That depends on the adult size of the species [*see lower illustration on preceding page*]. Large monitor species (in which adults are greater than four feet long) are just as diverse on lands east of Wallace's Line as they are to the west, or for that matter in mainland Asia and Africa. Small monitor species, however, occur only to the east of the line. Their diversity in that region forms a near-mirror image of the species distribution of small carnivorous mammals to the west. And Sulawesi, the only island east of Wallace's Line that harbors a native placental mammalian carnivore, lacks small monitors.

Did the small monitors, like the small carnivorous mammals, simply halt their radiation at Wal-

Member of the mangrove monitor group (V. indicus *and other species) is pictured in New Guinea. The group's domain extends from the islands around the Banda Sea to the Solomon Islands. The* indicus *group radiated into a variety of habitats; the absence of small placental carnivores has probably facilitated that spread.*

lace's Line? Probably not: most monitors are accomplished rafters, and so their distributions probably did not arise from any geographical barrier. Instead, the distributions may have an ecological explanation: the two groups are simply too similar as predators to coexist, and on the landmasses west of Wallace's Line, the small mammals prevailed.

One informative twist on this idea arises in Australia and New Guinea. Many small carnivorous marsupials live there, and some of them—six species of quolls and one phascogale—grow to about the size of civets and mongooses [*see photographs on opposite page*]. These marsupial carnivores are fierce and agile predators, yet they have evolved and coexist with many species of small monitors.

The behavior of these groups and the ways their ecologies overlap suggest that small monitors are, roughly speaking, "dumber than civets but smarter than quolls." Unfortunately, that simple generalization is being tested by human interventions. Mongooses and civets have been introduced to islands east of Wallace's Line, and foxes and feral cats have been brought to Australia. In a recent field study in northern Australia, Sweet lost thirteen out of fifty-four individual monitors to predation: four were killed by native predators, but nine were taken by a single feral cat. The northern quoll *(Dasyurus hallucatus)*, however, failed to catch any of the monitors.

To complete our story, we must point out that small monitors actually do coexist with small placental mammalian carnivores such as civets and mongooses—in the form of juveniles of the large monitor species! The young of these large monitors are typically highly secretive and often arboreal, but so are many of the small monitor species. Thus, secrecy is not a sufficient explanation for coexistence. We suggest that this coexistence succeeds because large adults can lay many eggs and the young grow quickly; even if many become prey to carnivores, a few will probably reach adult size. Species of small monitors lay fewer eggs, and must spend their entire lives in the arms race with small mammals. Whether they lose out primarily because they become prey, or because they must compete for prey with mammals, remains to be studied.

Wherever monitors live, the arms race has honed their original predatory tool kit. Particularly to the east of Wallace's Line, monitors appear to have achieved striking ecological and behavioral parity with mammals. A century ago the German herpetologist Franz Werner proclaimed monitors "the proudest, best-proportioned, mightiest, and most intelligent of all lizards." We certainly concur, and could add many superlatives to Werner's list. Human beings are fortunate to share this planet with such extraordinary animals, and we should try to learn from them whatever we can. □

Trashed

Across the Pacific Ocean, plastics, plastics, everywhere

By Charles Moore

It was on our way home, after finishing the Los Angeles-to-Hawaii sail race known as the Transpac, that my crew and I first caught sight of the trash, floating in one of the most remote regions of all the oceans. I had entered my cutter-rigged research vessel, *Alguita,* an aluminum-hulled catamaran, in the race to test a new mast. Although *Alguita* was built for research trawling, she was also a smart sailor, and she fit into the "cruising class" of boats that regularly enter the race. We did well, hitting a top speed of twenty knots under sail and winning a trophy for finishing in third place.

Throughout the race our strategy, like that of every other boat in the race, had been mainly to avoid the North Pacific subtropical gyre—the great high-pressure system in the central Pacific Ocean that, most of the time, is centered just north of the racecourse and halfway between Hawaii and the mainland. But after our success with the race we were feeling mellow and unhurried, and our vessel was equipped with auxiliary twin diesels and carried an extra supply of fuel. So on the way back to our home port in Long Beach, California, we decided to take a shortcut through the gyre, which few seafarers ever cross. Fishermen shun it because its waters lack the nutrients to support an abundant catch. Sailors dodge it because it lacks the wind to propel their sailboats.

Laysan albatross is a species that forages throughout the North Pacific. The regurgitated stomach contents, or boluses, of many such birds contain plastic debris.

I often struggle to find words that will communicate the vastness of the Pacific Ocean to people who have never been to sea. Day after day, *Alguita* was the only vehicle on a highway without landmarks, stretching from horizon to horizon. Yet as I gazed from the deck at the surface of what ought to have been a pristine ocean, I was confronted, as far as the eye could see, with the sight of plastic.

It seemed unbelievable, but I never found a clear spot. In the week it took to cross the subtropical high, no matter what time of day I looked, plastic debris was floating everywhere: bottles, bottle caps, wrappers, fragments. Months later, after I discussed what I had seen with the oceanographer Curtis Ebbesmeyer, perhaps the world's leading expert on flotsam, he began referring to the area as the "eastern garbage patch." But "patch" doesn't begin to convey the reality. Ebbesmeyer has estimated that the area, nearly covered with floating plastic debris, is roughly the size of Texas.

My interest in marine debris did not begin with my crossing of the North Pacific subtropical gyre. Voyaging in the Pacific has been part of my life since earliest childhood. In fifty-odd years as a deckhand, stock tender, able seaman, and now captain, I became increasingly alarmed by the growth in plastic debris I was seeing. But the floating plastics in the gyre galvanized my interest.

I did a quick calculation, estimating the debris at half a pound for every hundred square meters of sea surface. Multiplied by the circular area defined by

Bottle caps and other plastic objects are visible inside the decomposed carcass of this Laysan albatross on Kure Atoll, which lies in a remote and virtually uninhabited region of the North Pacific. The bird probably mistook the plastics for food and ingested them while foraging for prey.

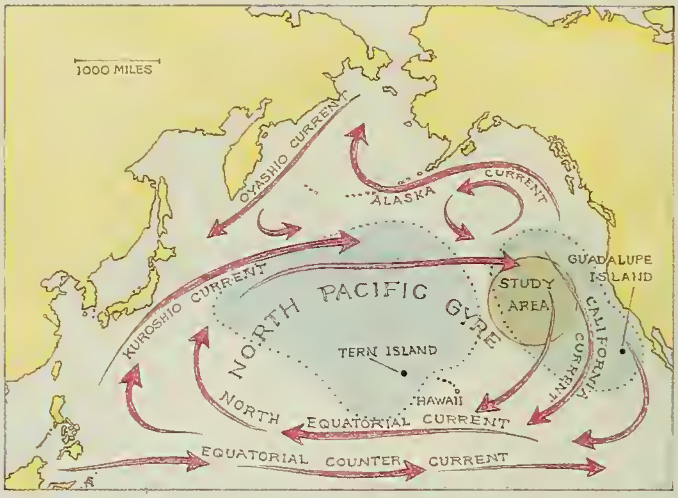
our roughly thousand-mile course through the gyre, the weight of the debris was about 3 million tons, comparable to a year's deposition at Puente Hills, Los Angeles's largest landfill. I resolved to return someday to test my alarming estimate.

Historically, the kind of drastic accumulation I encountered is a brand-new kind of despoilment. Trash has always been tossed into the seas, but it has been broken down in a fairly short time into carbon dioxide and water by marine microorganisms. Now, however, in the quest for lightweight but durable means of storing goods, we have created a class of products—plastics—that defeat even the most creative and voracious bacteria.

Unlike many discarded materials, most plastics in common use do not biodegrade. Instead they "photodegrade," a process whereby sunlight breaks them into progressively smaller pieces, all of which are still plastic polymers. In fact, the degradation eventually yields individual molecules of plastic, but these are still too tough for most anything—even such indiscriminate consumers as bacteria—to digest. And for the past fifty years or so, plastics that have made their way into the Pacific Ocean have been fragmenting and accumulating as a kind of swirling sewer in the North Pacific subtropical gyre.

It surprised me that the debris problem in the gyre had not already been looked at more closely by the scientific community. In fact, only recently—starting in the early 1990s—has the scientific community begun to focus attention on the trash in the gyre. One of the first investigators to study the problem was W. James Ingraham Jr., an oceanographer at the National Oceanic and Atmospheric Administration (NOAA) in Seattle. Ingraham's Ocean Surface Current Simulator (OSCURS) predicts that objects reaching this area might revolve around in it for sixteen years or more [*see illustrations on opposite page*].

A year after my sobering voyage, I asked Steven B. Weisberg, director of the Southern California Coastal Water Research Project and an expert in marine environmental monitoring, to help me make a more rigorous estimate of the extent of the debris in the subtropical gyre. Weisberg's group had already published an article on the debris they had collected in fish trawls of the Southern California Bight, a region along the Pacific coast extending a hundred miles both north and south of Los Angeles. As I discussed the design plan for our survey with Weisberg's statisticians, Molly K. Leecaster and Shelly L. Moore, it became apparent that we were facing a new problem. In the coastal ocean, bodies of water are naturally defined, in part, by the coasts they lie against. In the open ocean, however, bodies of water are bounded by atmospheric pressure systems and the currents those systems create. In other words, air, not land, defines the body of water. Because air pressure systems move, the body of water we wanted to survey would be moving as well. A random sample of a moving area such as the gyre would have to be done quite differently from the way Weisberg's group had conducted their survey along the Pacific coast.



Currents in the North Pacific move in a clockwise spiral, or gyre, which tends to trap debris originating from sources along the North Pacific rim. Plastics and other waste have accumulated in the region, which includes the foraging areas of Pacific bird colonies, such as that of the Tern Island albatross, shown in blue, and that of the Guadalupe Island albatross, shown in green.

The gyre we planned to survey is one of the largest ocean realms on Earth, and one of five major subtropical gyres on the planet. Each subtropical gyre is created by mountainous flows of air moving from the tropics toward the polar regions. The air in the North Pacific subtropical gyre is heated at the equator and rises high into the atmosphere because of its buoyancy in cooler, surrounding air masses. The rotation of the Earth on its axis moves the heated air mass westward as it rises, then eastward once it cools and descends at around 30 degrees north latitude, creating a huge, clockwise-rotating mass of air [*see map on this page*].

The rotating air mass creates a high-pressure system throughout the region. Those high pressures depress the ocean surface, and the rotating air mass also drives a slow but oceanic-scale surface current that moves with the air in a clockwise spiral. Winds near the center of the high are light or even calm, and so they do not mix the floating debris into the water column. This huge region, what I call a "gentle maelstrom," has become an accumulator of debris from innumerable sources along the North Pacific rim, as well as from ships at sea.

The subtropical gyres are also oceanic deserts—in fact, many of the world's land-based deserts lie at nearly the same latitudes as the oceanic gyres. Like their terrestrial counterparts, the oceanic deserts are low in biomass. On land the low biomass is caused by the lack of moisture; in oceanic deserts the low biomass is a consequence of great ocean depths.

Filter-feeding chordate jellyfishes known as "salps" dominate the North Pacific subtropical gyre. Investigators aboard the research vessel Alguita observed salps in the gyre, such as the one shown here, with brightly colored plastic fragments in their bellies.

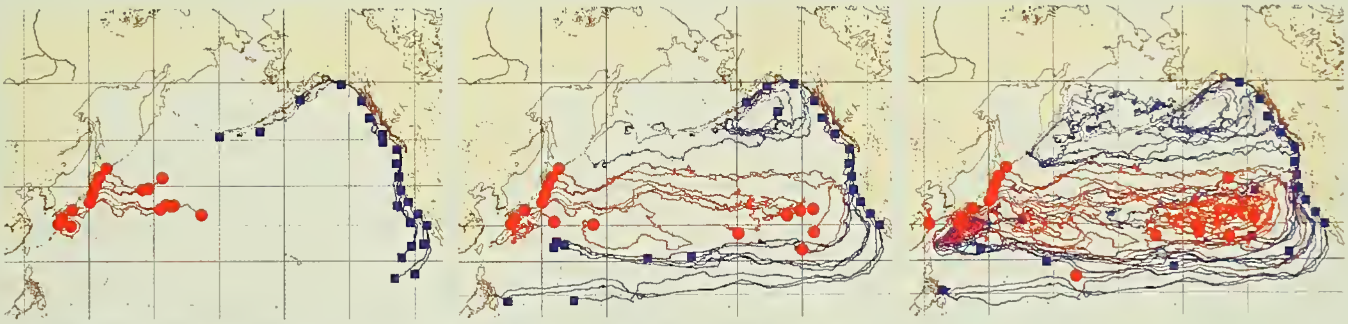
In coastal areas and shallow seas, winds and waves constantly stir up and recycle nutrients, increasing the biomass of the food web. In the deep oceans, though, such forces have no effect: the bottom sequesters the nutrient-rich residue of millions of years of near-surface photosynthetic production, as well as the decomposed fragments of life in the sea, trapping them miles below the surface. Hence the major source of food for the web of life in deep ocean areas is photosynthesis.

But even in the clear waters that prevail in the subtropical gyres, photosynthesis is confined to the top of the water column. Sunlight attenuates rapidly with depth, and by the time it has gone only about 5 percent of the way to the bottom, the light is too weak to fuel marine plants. The net effect is a vast area poor in resources, an effect that makes itself felt throughout the food web. Top predators such as tuna and other commercially viable fish don't hang out in the gyres because the density of prey is so low. The human predator stays away too: the resources that have drawn entrepreneurs and scientists alike to various regions of the ocean are not present in the subtropical gyres.

What does exist in the gyres is a great variety of filter-feeding organisms that prey on the ever-renewed crop of tiny plants, or phytoplankton. Each day the phytoplankton grow in the sunlit part of the water, and each night they are consumed by the filter feeders, a fantastic array of alien-looking animals called zooplankton. The zooplankton include chordate jellyfishes known as "salps," which are among the fastest-growing multicellular organisms on the planet. By fashioning their bodies into pulsating tubes, the salps are able, each day, to filter half the water column they inhabit, drawing out the phytoplankton and smaller zooplankton for food. But salps are gelatinous creatures with a low biomass, and so there is no market for them, either. Hence the realm they dominate, one of the largest uniform habitats on the planet, remains unexploited and largely unexplored.

Leecaster, Moore, and I came up with a plan to make a series of trawls with a surface plankton net, along paths within a circle with a 564-mile radius. The area of the circle would then be almost exactly 1 million square miles. Trawling would start when we estimated we were under the central pressure cell of the high-pressure system that creates the gyre. We would regard the starting point as the easternmost point along the circumference of the circle. Then we would proceed due west to the center of the circle, turn south, and sail back to the southernmost point on the circumference, alternating between trawling and cruising. We intended to obtain transect samples with random lengths and random spacing between trawls. To be conservative about our sampling technique, we decided that any debris we collected would count only as a sample of the debris within the area of the transected circle.

In August 1998 I set out with a four-member volunteer crew from Point Conception, California heading northwest toward the subtropical gyre. Onboard *Alguita* was a manta trawl, an apparatus resembling a manta ray with wings and a broad mouth, which skimmed the ocean surface trailing a net with a fine mesh. Eight days out of port, the wind dropped below ten knots and we decided to practice our manta trawling technique, taking a sample at the edge of the subtropical gyre, about 800 miles offshore. We pulled in the manta after trawling three and a half miles.



Ocean Surface Current Simulator (OSCURS) model developed by W. James Ingraham Jr., an oceanographer at the National Oceanic and Atmospheric Administration (NOAA), predicts the trajectory of drift originating along the coasts of the North Pacific rim. Drift from Japan is shown in red; drift from the United States, in blue. The diagrams show the position of drift after 183 days (left), three years (center), and ten years (right).

What we saw amazed us. We were looking at a rich broth of minute sea creatures mixed with hundreds of colored plastic fragments—a plastic-plankton soup. The easy pickings energized all of us, and soon we began sampling in earnest. Because plankton move up and down in the water column each day, we needed to trawl nonstop, day and night, to get representative samples. When we encountered the light winds typical of the subtropical gyre, we deployed the manta outside the port wake, along with two other kinds of nets. Each net caught plenty of debris, but far and away the most productive trawl was the manta.

There was plenty of larger debris in our path as well, which the crew members retrieved with an inflatable dingy. In the end, we took about a ton of this debris on board. The items included

- a drum of hazardous chemicals;
- an inflated volleyball, half covered in gooseneck barnacles;
- a plastic coat hanger with a swivel hook;
- a cathode-ray tube for a nineteen-inch TV;
- an inflated truck tire mounted on a steel rim;
- numerous plastic, and some glass, fishing floats;
- a gallon bleach bottle that was so brittle it crumbled in our hands; and
- a menacing medusa of tangled net lines and hawsers that we hung from the A-frame of our catamaran and named Polly P, for the polypropylene lines that made up its bulk.

In 2001, in the *Marine Pollution Bulletin,* we published the results of our survey and the analysis we had made of the debris, reporting, among other things, that there are six pounds of plastic floating in the North Pacific subtropical gyre for every pound of naturally occurring zooplankton. Our readers were as shocked as we were when we saw the yield of our first trawl. Since then we have returned to the area twice to continue documenting the phenomenon. During the latest trip, in the summer of 2002, our photographers captured underwater images of jellyfish hopelessly entangled in frayed lines, and transparent filter feeding organisms with colored plastic fragments in their bellies.

Entanglement and indigestion, however, are not the worst problems caused by the ubiquitous plastic pollution. Hideshige Takada, an environmental geochemist at Tokyo University, and his colleagues have discovered that floating plastic fragments accumulate hydrophobic—that is, non-water-soluble—toxic chemicals. Plastic polymers, it turns out, are sponges for DDT, PCBs, and other oily pollutants. The Japanese investigators found that plastic resin pellets concentrate such poisons to levels as high as a million times their concentrations in the water as free-floating substances.

Bolus coughed up by an albatross on Guadalupe Island, Mexico, includes many plastic fragments. Differences in the condition of debris the birds consume—whether it is whole or fragmented—can be traced to the way trash flows into their respective foraging areas. Debris leaving the West Coast of the United States drifts for six years or more—enough time to photodegrade into fragments—before it reaches the Guadalupe Island birds.

The potential scope of the problem is staggering. Every year some 5.5 quadrillion (5.5×10^{15}) plastic pellets—about 250 billion pounds of them—are produced worldwide for use in the manufacture of plastic products. When those pellets or products degrade, break into fragments, and disperse, the pieces may also become concentrators and transporters of toxic chemicals in the marine environment. Thus an astronomical number of vectors for some of the most toxic pollutants known are being released into an ecosystem dominated by the most efficient natural vacuum cleaners nature ever invented: the jellies and salps living in the ocean. After those organisms ingest the toxins, they are eaten in turn by fish, and so the poisons pass into the food web that leads, in some cases, to human beings. Farmers can grow pesticide-free organic produce, but can nature still produce a pollutant-free organic fish? After what I have seen firsthand in the Pacific, I have my doubts.

Many people have seen photographs of seals trapped in nets or choked by plastic six-pack rings, or sea turtles feeding on plastic shopping bags, but the poster child for the consumption of pelagic plastic debris has to be the Laysan albatross. The plastic gadgets one typically finds in the stomach of the bird—whose range encompasses the remote, virtually uninhabited region around the northwest Hawaiian Islands—could stock the checkout counter at a convenience store. My analysis of the stomach contents of birds from two colonies of Laysan albatrosses that nest and feed in divergent areas of the North Pacific [*see map on page 48*] show differences in the types of plastic they eat. I believe those differences reveal something about the way plastic is transported and breaks down in the ocean.

On Midway Island in the Hawaiian chain, a bolus, or mass of chewed food, coughed up by one bird included many identifiable objects. By contrast, a bird on Guadalupe Island, which lies 150 miles off the coast of Baja California, produced a bolus containing only plastic fragments. The principal natural prey of both bird colonies is squid, but as the ecologist Carl Safina notes in his book

Eye of the Albatross, the birds' foraging style can be described as "better full than fussy." Robert W. Henry III, a biologist at the University of California, Santa Cruz, and his colleagues have tracked both the Hawaiian and the Guadalupe populations of birds and found that the foraging areas of each colony in the Pacific are generally nonoverlapping and wide apart.

One difference between the two areas is apparently the way debris flows into them. In Ingraham's OSCURS model, debris from the coast of Japan reaches the foraging area of the Hawaiian birds within a year. Debris from the West Coast of the United States, however, sticks close to the coast until it bypasses the foraging area of the Guadalupe birds, then heads westward to Asia, not to return for six years or more. The lengthy passage seems to give the plastic debris time to break into fragments.

Ironically, the debris is re-entering the oceans whence it came; the ancient plankton that once floated on Earth's primordial sea gave rise to the petroleum now being transformed into plastic polymers. That exhumed life, our "civilized plankton," is, in effect, competing with its natural counterparts, as well as with those life-forms that directly or indirectly feed on them.

And the scale of the phenomenon is astounding. I now believe plastic debris to be the most common surface feature of the world's oceans. Because 40 percent of the oceans are classified as subtropical gyres, a fourth of the planet's surface area has become an accumulator of floating plastic debris. What can be done with this new class of products made specifically to defeat natural recycling? How can the dictum "In ecosystems, everything is used" be made to work with plastic? □

The subtropical gyres of the world are part of the deep ocean realm, whose ability to absorb, hide, and recycle refuse has long been seen as limitless. That ecologically sound image, however, was born in an era devoid of petroleum-based plastic polymers. Yet the many benefits of modern society's productivity have made nearly all of us hopelessly, and to a large degree rationally, addicted to plastic. Many, if not most, of the products we use daily contain or are contained by plastic. Plastic wraps, packaging, and even clothing defeat air and moisture and so defeat bacterial and oxidative decay. Plastic is ubiquitous precisely because it is so good at preventing nature from robbing us of our hard-earned goods through incessant decay.

But the plastic polymers commonly used in consumer products, even as single molecules of plastic, are indigestible by any known organism. Even those single molecules must be further degraded by sunlight or slow oxidative breakdown before their constituents can be recycled into the building blocks of life. There is no data on how long such recycling takes in the ocean—some ecologists have made estimates of 500 years or more. Even more ominously, no one knows the ultimate consequences of the worldwide dispersion of plastic fragments that can concentrate the toxic chemicals already present in the world's oceans.

Contents of a bolus coughed up by an albatross on Midway Island shows that the Hawaiian bird has consumed many identifiable objects. Debris from Japan reaches the foraging area of the Hawaiian birds within a year and is mostly intact.

Fight of the Bumblebee

Insects, like people, are constantly threatened by disease. Bumblebees' simple but effective immune systems shed light on the evolution of immune defenses and the costs of maintaining them.

By Paul Schmid-Hempel

Humming from flower to flower, a bumblebee worker busily collecting nectar and pollen for its colony is, for many, the epitome of nature's peace and tranquillity. Yet nothing could be further from the truth. Not only is the foraging bumblebee always on the verge of an energy crisis; it is also entangled in a lifelong battle with microscopic enemies that try to capitalize on its efforts.

All complex organisms, people included, face essentially the same predicament. Coping with actual disease, of course, makes prodigious demands on one's energy: taking to bed is often the only possible solution. Yet even as we go about the business of ordinary living—working, crowding together in close quarters, caring for children, shopping at a local market—keeping disease at bay takes a constant toll on the body's resources. Ironically, the insects that carry some of the disease organisms against which people must be most on guard, including malaria, dengue, West Nile virus, and leishmaniasis, are themselves locked in equally desperate battles with similar, if not identical, parasites.

Insects battle some of the same parasites that they transmit to people.

Because of their importance as pollinators of fruit crops and flowers, bees have been a focus in the study of disease and disease resistance in "lower" organisms. The most prevalent disease in bumblebees is caused by the trypanosome *Crithidia bombi*—a mobile protozoan closely related to the microorganism that causes human sleeping sickness. *C. bombi* cells are left behind when an infected bee visits a flower, and those cells can survive for a day or two at the bottom of flower tubes. When the next bee visits the flower, the infectious cells are picked up and carried back to the nest, where a few dozen other workers and a queen are put at risk. The disease often spreads rapidly through the colony and then, via more flower visits, to other colonies in the population. By June almost all bumblebee colonies in a population have become infected by *C. bombi,* though a large fraction of workers within each colony do survive the infection.

Another health hazard of collecting nectar and pollen in flowering meadows is that workers are forced to fly slowly when they maneuver around flower stalks. Slower flying speeds invite attacks by female parasitic flies of the family Conopidae. The conopids inject their eggs into the abdomens of foraging worker bees. There the eggs hatch, and the parasite larvae develop inside each bee, rapidly consuming their host from the inside out. Between ten and twelve days later the worker dies as the parasitic larvae pupate inside its body. The pupas survive the winter—while the bee colony hibernates—and in the spring, as new queens and drone bees are born, they develop into adult flies, ready to attack the next batch of vulnerable workers.

The biology of social insects—ants, bees, termites, and wasps—is fascinating in its own right. But I became intrigued with how such organisms deal with the additional threats posed by disease and parasites. Social insect colonies offer a standing invitation for parasites to thrive. Besides being crowded together in one nest, colony members typically are close relatives of one another and therefore susceptible to similar diseases. An abundance of parasites, such as viruses, bacteria, fungi, nematodes, tapeworms, and the larvae of flies, wasps, and moths, are known to infect bumblebees. Collecting common European bumblebees

Bumblebee worker runs a double risk when collecting nectar from a flower. First, viruses, bacteria, and other disease organisms left behind by infected bees can contaminate the flower parts and thereby spread from bee to bee. Second, hovering in place before landing on the flower exposes the bee to attacks by parasitic flies, which inject their eggs into the abdomen of the bee.

(Bombus terrestris) from summer meadows shows that in some years and locations the larvae of conopid flies parasitize two-thirds or more of the worker bees, leaving them with just a week or so to live. A scene of busy bees may look untroubled, but what is actually charming our senses is an army of the living dead. How do bumblebees survive such an onslaught?

Fortunately, bees and other social insects have their countermeasures. The most potent weapon against parasites in the arsenal of every complex organism is the immune system. The insect immune system has ties to that of the common ancestor of insects and vertebrates, dating back more than 450 million years, and has even older affinities with the defense systems of plants. In a dangerous world, it seems, no organism—not even the smallest or most "primitive"—has been able to go entirely without immune defenses. Yet even immunity has its downside. In our work on bumblebees, my colleagues and I have been able to make quantitative estimates of the costs of sustaining a simple

Social insect populations such as (top to bottom) honeybees, weaver ants, and soldier termites live in ideal conditions for the spread of disease. They share close quarters, making rapid infection possible, and they are often close relatives of one another, making them all susceptible to similar disease strains.

immune system. That work has implications beyond the insect world, however, because the insect immune system is, in many ways, a simplified model of our own. Our observations of bees have made it clear that the benefits of immune protection, like nearly everything else in life, must ultimately be balanced against its costs.

Roughly speaking, insects have two kinds of immune responses, which differ primarily in response time and specificity. The more general branch of the immune system is known as the innate, or constitutive, response. Innate defensive machinery can be directed against an infection immediately, though in a nonspecific way. A main element of that response is the so-called proPO cascade (PO stands for the enzyme phenoloxidase), a rapid sequence of biochemical steps that make a large molecule called melanin. Together with its intermediate products, melanin is toxic to most microorganisms. The cascade of reactions begins when PO is converted to an active form that helps catalyze the further chemical steps that lead to melanin. The proPO cascade—stepped up when an infection is recognized—is characteristic of defense systems that occur in such diverse invertebrate organisms as butterflies, starfish, and water fleas.

The proPO cascade and melanin also play a key role in the second major defensive action of the insect's innate immune response. That response, known as encapsulation, is directed mainly against relatively large parasites that invade an insect's body. At least in most insects, the principal players in the process are the blood cells, more properly called hemolymph cells. (Insect "blood," or hemolymph, unlike our own blood, is not delivered to body cells through vessels by a pump. Instead, it freely laps around all the internal organs, propelled by muscle action.)

During encapsulation, specialized hemolymph cells called hemocytes become attracted to an invader, such as the larva of a conopid fly. As the hemocytes attach to its surface and aggregate, the proPO cascade is activated. The resulting melanin acts as a kind of mortar that cements hemocyte "bricks" in place around the larva. Within a few hours, the invader becomes enclosed in a hardened capsule of melanized cells, which seals it off from the rest of the interior of the host.

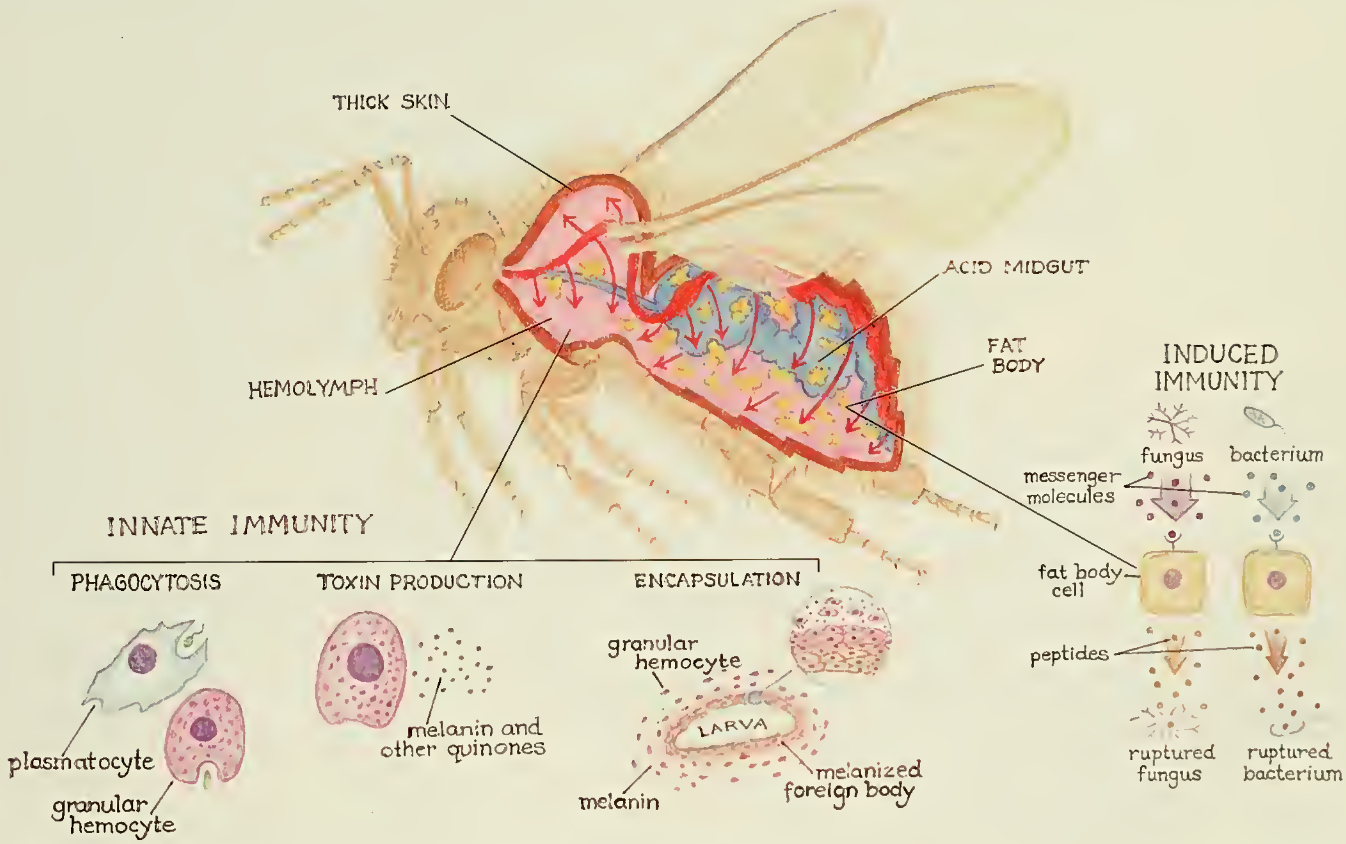
In addition to their innate immune system, insects can also mount a so-called induced immune response. In that case, the immune system responds more specifically to certain invaders. For example, within thirty minutes after a fungus has penetrated the larva or adult of a fruit fly (Drosophila melanogaster), the fly's immune system starts producing a peptide, or short protein, called drosomycin. The peptide is inactive against bacteria, but it is highly potent against filamentous fungi. Drosophila also produces peptides such as defensin, in response to infection by gram-positive bacteria, and diptericin, in response to gram-negative ones.

The foreign intruders that trigger distinct induced immune responses in insects belong to fairly broad categories—bacteria, fungi, and protozoa. At its core, though, the system is a simpler but functional equivalent to the system of induced immunity in mammals. Human immune cells, for example, are exquisitely tuned to produce custom-made antibodies in response to millions of foreign substances, or antigens. The highly specific antibodies and the battalion of destroyer cells of the mammalian induced immune system may seem like the evolutionary pinnacle of precision. Yet, in fact, the simpler insect system requires a smaller overhead to function, and its general effectiveness against the insect's enemies may well render it no less sophisticated than our own.

Whether the immune response is innate or induced, the host must first manage to recognize that a foreign molecule has breached the skin and gotten into its body. In people, a great deal of work has led to a reasonably clear scientific understanding of how the cells of the immune system patrol for foreign substances. Basically, each cell that belongs to the body displays a kind of molecular identity card. Cells acting as sentries patrol for intruders and constantly check the ID cards. Foreign bodies without proper identification are marked for destruction.

Understandably, perhaps, the workings of the insect immune identification system are far less well known. A few of the proteins that act as sentries and recognize intruders have been identified, but most are still obscure. The specificity of the insect system has been deduced simply by observing how it reacts to various experimental infections.

What is clear, nonetheless, is that in both insect and human systems, once an intruder is recognized, a cascade of events is set in motion. Any sentry cell that identifies an intruder spews messenger molecules into the hemolymph (or the blood). Those molecules must then reach various classes of receptors on the surfaces of the cells responsible for the immune reaction. In people, immune cells are concentrated in the bone marrow and the lymph glands. In insects, immune cells occur mostly in the so-



Simplified and stylized diagram of the bee immune system. After getting past the bee's exoskeleton, or "skin," and its acidic midgut, an intruder faces two branches of immune defense: the innate and induced responses. The innate response is a general yet speedy reaction, whereas the slower induced response can tell the difference between, say, fungi or bacteria. (Early steps in the activation of the induced immune response are not well understood.)

called fat body, a decentralized organ that is spread out over almost the entire interior of the insect.

Two main insect immune receptors have been identified to date: the Toll-receptor, which plays a role in the defense against fungi, and a receptor associated with the so-called IMD pathway, which is mostly a mechanism for defense against bacteria. Once activated by the messenger molecules, the insect immune cells produce peptides, which are then secreted into the hemolymph.

Insect peptides have potent antimicrobial properties, and act more or less specifically against the various categories of pathogens: gram-negative bacteria, gram-positive bacteria, and fungi. Not much is known about how the peptides act against bacteria, but one important effect is that they alter the permeability of the bacterial cell membrane. That change eventually kills the invader.

Insects may turn out to be a rich source of powerful antibiotics for people.

Two such peptides in the bee, hymenoptaecin and apidaecin, attack many kinds of bacteria. In fact, their targets include several well-known human pathogens, such as *Enterobacter, Escherichia coli, Salmonella, Shigella, Streptococcus, Staphylococcus,* and *Yersinia.* That raises an exciting possibility for medicine. Insects are by far the most species-rich group of animals on the planet, and the diversity of their antimicrobial peptides must also be enormous. Some of those peptides may well turn out to be powerful antibiotics for our own medical purposes.

The insect immune system mobilizes defenses for coping with the various threats bumblebees may encounter. But effective protection comes at a cost. Everyday life offers plenty of good analogies. A burglar alarm in your house, for instance, is costly to purchase and operate, even if you never use it. Moreover, once it is activated, you have to call in the police for an effective defense.

Insects face similar trade-offs—though the currency in which costs are counted is Darwinian fitness, not dollars. Consider what happens when closely related honeybees, or lines, are selected for resistance to foulbrood, a bacterial disease of honeybee larvae. It turns out that the foulbrood-resistant larvae grow more slowly than the lines susceptible to the disease. Similarly, fruit flies selected to resist the attacks of parasites are less competitive foragers than their nonresistant counterparts. And Indian meal moths selected to resist granulosis virus have fewer offspring than the moths that carry no such immunity. In all those cases the price of having the immunity is paid in the reduced fitness of some other component of the organism.

Immune readiness is not the only aspect of immunity that has a cost; the actual deployment of an immune response is costly, too. Along with my collaborators, I have experimentally investigated that cost in bumblebees. We first tested their innate response by fooling their immune systems into reacting to an artificial parasite. Early in the morning, we implanted a thread of nylon into the body cavities of workers of *B. terrestris.* The nylon was chosen to mimic the larva of a conopid fly.

One group of bees was then allowed to fly out for food, while the other group was kept from leaving the hive. Flying consumes a great deal of energy, and so, we reasoned, the energy demands of flying would compete with the energy needed to fuel the immune response. We retrieved the nylon implant after the bees had worked for a day. Sure enough, the bees that were allowed to fly encapsulated the nylon thread 20 percent less often than the bees that were kept from flying. Such a difference could be just enough for a parasite to survive a bee's immune response, with fatal consequences for the bee.

We also tested the bees for the costs of mounting an induced immune response. In that experiment we again activated the bumblebees' immune systems, but without introducing any stand-in for an actual parasitic infection. Instead, we extracted lipopolysaccharide (LPS) molecules from the surface of gram-negative bacteria and injected a dose of LPS into the worker bees' hemolymph with a fine needle. As we expected, the bees' immune systems recognized the molecules and subsequently released specific antibacterial peptides into the hemolymph—even though no bacterial infection was ever really present. To our surprise, however, we detected no negative consequences. The test bees behaved normally, unimpressed by the energy challenge of having to activate their immune systems. They seemed to carry on with their daily routines.

Only later were we able to tease out the costs of the immune response. Our first group of bees had free access to energy, in the form of sugar water. But in a later test group, we denied the bees sugar water, then carried out the rest of our procedure with LPS. That time, the immune response took its toll. Almost regardless of how their immune systems were challenged, those bees were more than 50 percent more likely to die than their unchallenged counterparts.

Our findings suggest that sometimes the actual damage inflicted by a parasite on its host—whether bumblebee, human, or otherwise—may not even be caused directly by the parasite. Rather, the costs to the host of mounting a defense, even a "successful" one, could lead to damage unless the host can offset those costs, say, by consuming more food. The costs of defense are probably borne by all organisms all the time, just to keep parasites in check. Usually organisms are oblivious to the stress, except when conditions become so unfavorable as to reveal it.

We also discovered that individual bumblebees were not the only entities to pay a price. When we challenged the workers of a colony with small injections of LPS over the life cycle of the entire colony, a major loss in reproductive capacity ensued. Even though no worker ever got sick (since no actual parasite is involved), the colony still lost at least half its normal numbers of daughter queens and drones. The bumblebees paid a high price for their immune response.

The study of insect immunity has become a hot topic in immunology. Major new discoveries about the underlying molecular and biochemical processes are made each year. Investigators have become particularly excited about tracing several elements of insect immune defenses to the system of innate immunity that goes back more than 450 million years. That innate system, exhaustively tested by evolutionary change, has played a crucial role in the more recent evolution of the induced immune defenses of mammals. To understand the evolutionary process, it will be essential to understand how the benefits and costs of various kinds of immune response were balanced against the prevailing parasitic threats. Bumblebees are a good living model in which to study those issues. Examining their struggles with disease promises to shed light on how and why immune systems evolved the way we observe. □

Bees loaded down with parasites may not appear sick, until their routine is disrupted. If forced to fly a bit farther for nectar, for instance, disease-ridden bees—initially unfazed by an infection—can die suddenly and in large numbers.

Oasis in the Everglades

A Florida wildlife refuge combines nature and nurture.

By Robert H. Mohlenbrock

Spider lily

Wetlands once covered much of the southern third of the Florida peninsula. Cypress swamps dominated the western part of the region and mangrove swamps the south coast. In the east lay a vast tract of water and sawgrass known as the Everglades. Prior to the nineteenth century, most of the settlement in southern Florida was confined to the strip of elevated land along the Atlantic coast. But by the 1800s people bent on farming began draining the Everglades by constructing canals and levees.

White water lilies bloom along a canoe trail in the Arthur R. Marshall Loxahatchee National Wildlife Refuge.

In 1934 Congress established the Everglades National Park to preserve the southern part of the original Everglades. North of the park and south of Lake Okeechobee, however, development continued. There, in the late 1940s, the U.S. Army Corps of Engineers began the establishment of three so-called water conservation areas, which further reduced the natural flow of water through the Everglades. The good news for the plants and animals that depended on the vanishing wetlands is that in 1951, the U.S. Fish and Wildlife Service and the State of Florida, under the Migratory Bird Conservation Act, turned one of the water conservation areas into a national wildlife refuge.

Still managed by the Fish and Wildlife Service, the Arthur R. Marshall Loxahatchee National Wildlife Refuge (named for the nearby town of Loxahatchee and in honor of a former employee of the Fish and Wildlife Service) covers more than 220 square miles. Most of the refuge is Everglades marsh bordered by levees. The water flow is managed to create marsh areas for waterfowl and other plant and animal species. Within the marsh are slightly elevated portions of terrain known as tree islands, which, true to their name, support the growth of trees. In addition, a 400-acre cypress swamp conserves the remains of a habitat that once extended all the way from Lake Okeechobee southeast to Fort Lauderdale.

Perhaps the most striking plants in the cypress swamp are the epiphytic bromeliads, which are members of the pineapple family. These gray or gray-green plants live on the branches and trunks of the trees, but they are not parasitic. Instead, their leaves absorb moisture and nutrient particles directly from the air, such as the remains of decaying leaves and the droppings of insects and birds. Spanish moss is the most familiar example, though a misnomer: it is not a moss but a flowering plant. Its small, yellow-green flowers are particularly fragrant after sundown.

The main entrance and the visitor's center of the refuge are located west of Boynton Beach, on Lee Road, off U.S. Highway 441. The only other public entry point (from Loxahatchee Road, also off route 441) is farther south, west of Boca Raton. The northern two-thirds of the refuge is closed to public use, but the rest provides ample opportunities for biking, canoeing, fishing, and hiking.

The refuge needs extensive management to maintain its present condition. Periodic prescribed burning enhances the growth of certain native species and, perhaps more important, slows the growth of an aggressive invasive species, melaleuca. Furthermore, the refuge is a part of the Comprehensive Everglades Restoration Project, which is trying to return as much of the Everglades as possible to more natural conditions.

A major part of the project, under the direction of the Corps of Engineers, is to restore the natural flow of water. The South Florida Water Management District, which is manipulating water depths and flows under its jurisdiction and examining the responses of plants and animals, is conducting experimental studies at the refuge. The hope is to learn how to re-create, on a small scale, natural communities similar to the ones that still occur in the Everglades. Results from these studies will be applied to the larger Everglades complex.

HABITATS

Cypress swamp Visitors can see a good cross section of the cypress swamp by following a 0.4-mile boardwalk near the main entrance. The standing water along the way can be as much as two feet deep in rainy seasons, or it can vanish entirely in dry periods. Pond cypress is the dominant tree, but other species such as coco plum, red bay, and red maple also grow here. Native shrubs scattered beneath the canopy include buttonbush, dahoon holly, Virginia willow and wax myrtle. Among the invasive species found here and there are Brazilian peppertree, guava, laurel fig, melaleuca, Old World climbing fern, and strangler fig. Climbing hempweed, laurel greenbrier (bamboo vine), muscadine grape, pepper vine, saltmarsh morning glory, Virginia creeper, wild balsam pear, and other vines form dense entanglements.

Ferns range in size from the giant leather fern, with fronds as much as ten feet long, to the tiny water spangles and mosquito fern that float on the water. In between are cinnamon fern, giant sword fern, long strap fern, royal fern, and swamp fern. Apart from Spanish moss, epiphytic bromeliads include ball moss, Schultes northern needleleaf (with curved leaves) and southern needleleaf, and the rare spreading air plant. The showiest bromeliad is the wild pineapple, which produces small purple flowers emerging from red, usually yellow-tipped bracts.

Wild pineapple grows on trees but is not a parasitic plant; it gets its nutrients from moisture and particles in the air.

Marsh About a mile from the visitors center, a 0.8-mile hiking trail circles one of the marshes. Various plants are visible floating in the water or protruding above it. Among them are arrow arum, bull-tongue arrowhead, pickerelweed, water lettuce, white water lily, yellow water lily, and the invasive alligator weed. Growing in soggy soil but usually not in standing water are such species as alligator lily, bog hemp, camphor pluchea, seaside goldenrod, southern swamp crinum lily, sweetscent, Virginia saltmarsh mallow, and winged loosestrife.

Sawgrass The species is actually a sedge, not a grass, though at least it is aptly named for its notched leaf edges and their effects on unprotected legs. It often grows in dense colonies interspersed with dahoon holly and wax myrtle. This habitat typically borders tree islands.

Tree island Areas of the marsh slightly elevated above the water level usually have a dense growth of trees. Among them are buttonbush, coco plum, dahoon holly, and red bay.

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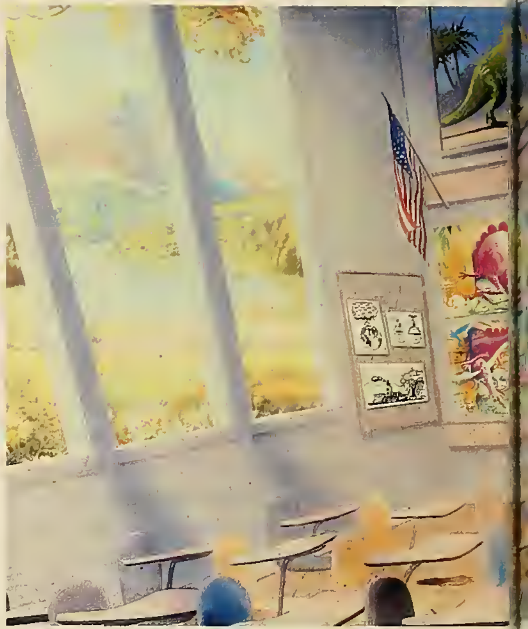
For visitor information, contact:
Arthur R. Marshall Loxahatchee National Wildlife Refuge
10216 Lee Road
Boynton Beach, FL 33437
(561) 734-8303
http://loxahatchee.fws.gov

REVIEW

Stand and Deliver

Why did early hominids begin to walk on two feet?

By Ian Tattersall



Ask any paleoanthropologist what got humankind started on its unique evolutionary trajectory, and the reflex answer will almost certainly be "the adoption of upright bipedalism." And whatever the exact characteristics of the most ancient hominid may have been, there is no question that the adoption of upright locomotion on the ground was an epoch-making event for our hominid family.

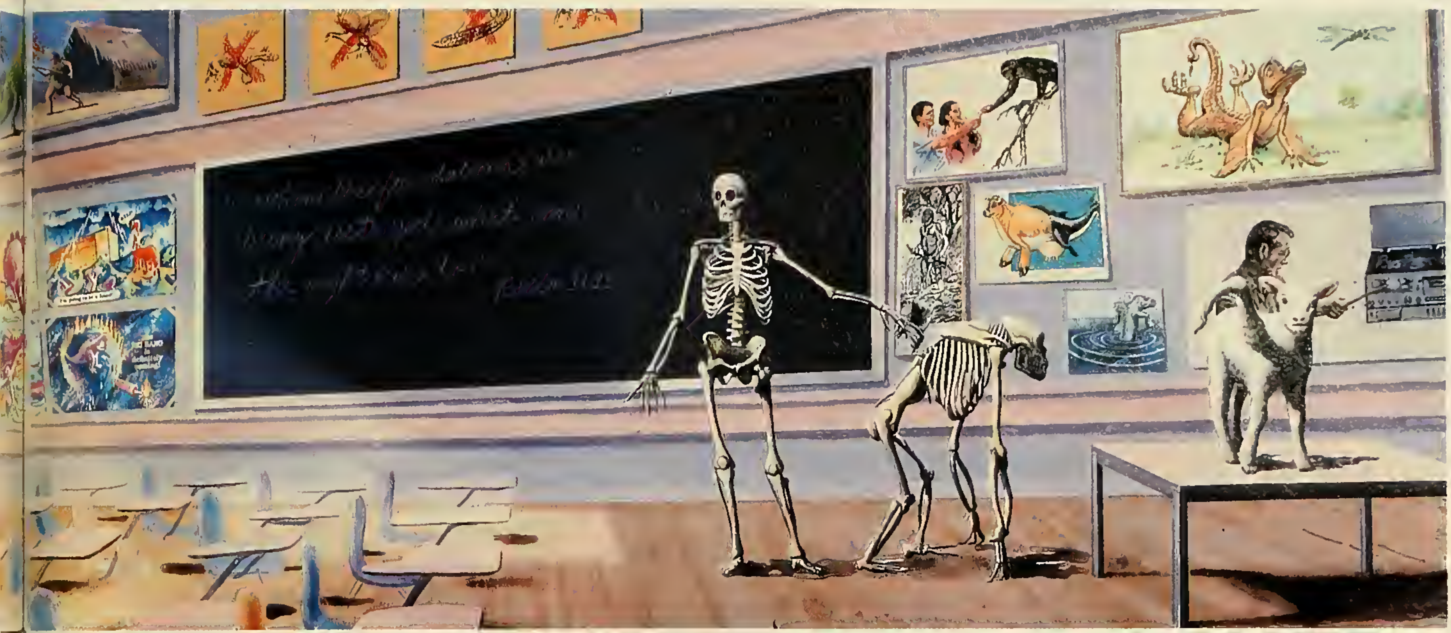
The idea that *Homo sapiens* might be descended from some ancient apelike animal that walked around on its two hind legs goes back at least as far as Jean-Baptiste Lamarck's great *Philosophie Zoologique,* which appeared in the opening decade of the nineteenth century. And Darwin famously expressed a similar viewpoint in *The Descent of Man,* published in 1871. Darwin speculated that the importance of bipedalism was that it freed the hands from the demands of locomotion, thereby opening the way for toolmaking and other manual activities that make us uniquely human. If so, it took some time for our precursors to realize the potential of their upright posture: it is now clear that the origin of stone toolmaking postdated the acquisition of bipedalism by millions of years. Still, it is hard to resist the idea that bipedalism was a necessary condition for all that followed, even if it might not have been a sufficient one.

Since Darwin's day, paleoanthropologists have energetically sought the key to hominid erectness in many different places. Nearly always, though, these scientists have sought the Holy Grail of a single critical function: what exactly was it about being upright that gave early hominids the edge? For, given that teetering along on a single pair of feet is, to all appearances, hardly an optimal solution for a hominid whose ancestors almost certainly got around using four limbs, isn't it intuitively obvious that the particular advantage of walking upright on two limbs must have been an overwhelming one? And, at the very least, it's clear that upright bipedalism is not an automatic primate response to descending from the trees to live on the ground. Even patas monkeys, apart from ourselves the most committed-to-ground-dwelling of all living primates, have accomplished that shift by becoming even more specialized quadrupeds than their more arboreal ancestors had been before them.

So just what was going on when our ancient forebears, in a period of climate change that transformed their ancestral forested habitats in Africa into one of trees, shrubs, and grasses, started opting for upright, two-legged locomotion on the ground? There has been no dearth of suggestions, all based on adaptation to some aspect or another of ground-dwelling life. I have to confess here that I have long been suspicious of the profligate use of "adaptation" to simultaneously explain any and all evolutionary innovations. After all, any individual is made up of a whole host of features that one could describe as adaptations, whereas natural selection can only vote up and down on the whole thing, warts and all. Still, there is no doubt that paleoanthropologists have come up with a whole host of terrific stories on the subject.

The first to describe a truly ancient biped was the Australian-born physical anthropologist and paleontologist Raymond Dart, in 1925. Dart understood that life on the predator-ridden open savannas would have been pretty dangerous for the relatively small, slow, and defenseless early hominids. He suggested that standing up would have enabled the creatures to peer over tall grass and spot dangerous animals at a distance. Other investigators have pointed out that an animal looks bigger when it stands up, which might help discourage predators from attacking it. Corroborating that idea, contemporary studies do seem to show that the predatory interest of big cats is more readily triggered by horizontal silhouettes than by vertical ones.

Those who prefer to look upon even our remotest ancestors as bush-league versions of ourselves have tended to side with Darwin. They see bipedalism as a mechanism for freeing the hands to carry food and other ob-



Alexis Rockman, *Creationist's Classroom*, 1998

jects back to home base, or as a way of making it easier for mothers to tote babies around. The most recent wrinkle in this hypothesis has been the suggestion (by male paleoanthropologists) that bipedal early hominid males used their free hands to carry food back to hapless females, whose baby-toting activities had dramatically curtailed their food seeking. This social behavior supposedly led in turn to such far-reaching consequences as pair-bonding, concealed ovulation, and the prominence of female breasts. The story has the undeniable attraction of tying bipedalism to a variety of human physical and social peculiarities, but it is no less controversial for that, and it has recently come under attack on a variety of grounds. Feminist anthropologists, for example, perhaps in retaliation for the perceived sexual slight, have directly blamed erect bipedalism on the appalling exhibitionist tendencies of males.

Lately, the bulk of the debate on the subject has focused on what might be called the thermoregulatory hypothesis. When you're out of the forest, the argument goes, you're out of the shade. With direct exposure to the tropical Sun, you need some way to cool down your body—particularly your heat-sensitive brain. Lacking specialized means for such cooling, hominids might have discovered that by standing up, they absorbed less of the Sun's heat (by minimizing the surface area exposed directly to the Sun's vertical rays). Furthermore, standing exposed the heat-radiating portions of their bodies to the cooling breezes that blow above ground-level vegetation. The idea is persuasive. The cooling effects dovetail nicely with such special human characteristics as sweating and the drastic reduction—compared with our ape ancestors—of body hair.

Lowly Origin: Where, When, and Why Our Ancestors First Stood Up
by Jonathan Kingdon
Princeton University Press, 2003; $35.00

Upright: The Evolutionary Key to Becoming Human
by Craig Stanford
Houghton Mifflin, 2003; $23.00

But the thermoregulatory hypothesis has by no means met with universal acclaim. An opposing camp argues that bipedalism is simply the most energy-efficient way for a hominid to get around on a flat surface. Careful calculations show that, under certain plausible conditions, ground-living hominids expend less energy moving around on two legs than they do on four. And the less energy you expend, the less food you need to find—another clear advantage.

Will the real reason for bipedalism please stand up?

In light of all the competing theories, some cautious weighing of their relative merits is clearly welcome. With excellent timing, here now are two books that, from rather different perspectives, devote themselves to the question of why hominids became upright, and to exploring exactly how that event may have shaped subsequent human evolutionary history. Intriguingly, both authors at least partly avoid the Holy Grail trap by developing quite complex scenarios. Each book, moreover, is a work of advocacy, with a clear and well-defined story to tell. That approach has the advantage of making both books highly readable. At the same time, though, it leaves readers with little choice but to embrace or to spurn the arguments in their entirety, instead of offering readers a chance to shop around among the various components of each story.

Jonathan Kingdon commands a unique position at the interface of science and art. Not only has he made a substantial contribution to the scientific understanding of African mammal evolution and diversity; he has also enhanced our aesthetic appreciation of these animals through his graceful drawings and paintings. Predictably, his book *Lowly Origin* (a title drawn from Darwin's concluding statement in *The Descent of Man*) is enlivened by a generous selection of engaging illustrations. After listing at least thirteen distinct explanations that have been advanced at one time or another for hominid bipedalism (including all the ones mentioned above, and many more besides), Kingdon plumps for a multicausal argument, drawing on his extensive knowledge of African ecology and biogeography.

A. Demarle, *Evolution of Man from Mammals*, 1883

His scenario is a gradualist one. At first an ancestral quadrupedal "ground ape" slowly but smoothly progresses to a long-lasting squat-feeding phase. Whenever the creature forages on the forest or woodland floor, the trunk is held upright. Over millions of years the hind legs gradually assume the support of the upper body's weight. The resulting reduction of upper-body bulk improves the balance of the vertical trunk, until "four-legged movement cease[s] to be as efficient as simple straightening of the legs." At the same time, the pressure from predators on the ground becomes greater than it ever was in the trees, and so survival dictates greater social cooperation and more complex behaviors than ever before. Those developments enable the hominids to explore an increasingly broad range of environments, until they occupy the open savanna.

Governing this proposed sequence of events is the African environment in which the early hominids lived. Somewhat controversially, Kingdon contends that apelike human ancestors from Eurasia, originally of African ancestry, crossed back into Africa from Arabia about 10.5 million years ago. At that time the ancient Tethys Sea, which preceded the Mediterranean, was closing, permitting intercontinental contact between Africa and Eurasia. These apelike ancestors ultimately evolved to become chimpanzees and gorillas in the dense rainforests of central Africa, while, isolated on the other side of a relatively arid, treeless barrier, another group of descendants occupied the drier littoral forests of the African continent's eastern edge. Those latter primates eventually gave rise to the early hominids: creatures who were forced to change their ancestral feeding habits as a result of a changing environment. More specifically, they had to supplement the food resources available in the forest canopy with nutrients found on the forest floor.

Such a bald statement of Kingdon's complex and nuanced argument—which actually reaches back to explore our remotest primate origins, and beyond—does little justice to his elegant and thoughtful, if somewhat idiosyncratic, book. Whether or not Kingdon manages to convince you of his larger thesis, you will be provoked along the way by the many connections he makes. And just as important, *Lowly Origin* is a landmark for its thoroughness in integrating the story of human evolution (which he brings up to the present day) with that of the evolving landscapes and habitats of the African continent. What's more, Kingdon doesn't shy away from extrapolating the past to the future, painting an unattractive portrait of our species as a "niche thief" whose past success has depended on invading the ecological niches of others, but whose rapacious activities now threaten even its own future survival.

Craig Stanford, the author of *Upright*, is an accomplished primatologist who has specialized in studying the behaviors of African apes. His knowledge of chimpanzees, and, in particular, his field experience with them, inform much of his new book. Stanford points out that bipedal locomotion is a pretty bizarre way of getting around, with the clear implication that it calls for a pretty special explanation. He looks for that explanation in all the usual places, notably in the energetics of walking and the cooling of the brain, but he finds problems with them all.

One of the pleasures of Stanford's book is its splendidly gossipy account of recent research into the early history of hominid bipedalism. It dwells lovingly, for instance, on the prolonged sniping that went on between two

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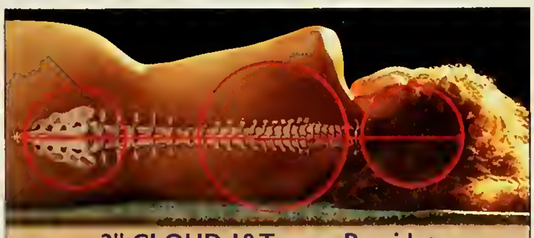

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For fastest service, call toll-free 24 hours a day **800-859-2923** groups of scientists, one based in the Midwest and the other on the East Coast, over the interpretation of the famous 3.2-million-year-old skeleton from Ethiopia known as Lucy. Stanford places himself somewhere in the middle. Reasonably, he rejects the East Coast scientists' assertion that Lucy's locomotor adaptation was "transitional." Just as reasonably, he accepts their (totally correct) conclusion that Lucy's bipedalism differed significantly from that of her successors of the genus *Homo*.

Oddly, in view of what Stanford has to say later on in his book, he also takes time to trash the idea that bipedalism was driven by environmental change. More significant, he argues, was that from the beginning hominids appear to have been ecological generalists. The key to their success was, and is, their ability to thrive in diverse environments. Yet despite his emphasis on environmental adaptability, he is still convinced that the hominids' unusual and implication-ridden form of locomotion was a response to *something*, and he is clearly concerned to discover a single underlying explanation for it. He finds it in meat eating.

Between 7 million and 8 million years ago, at the beginning of the scenario he reconstructs, some very early hominids "shuffled across the ground a bit between fruit trees." But as the climate became increasingly seasonal, and the grasslands expanded at the expense of the forest, natural selection would have favored those individuals who shuffled most efficiently across the enlarging open areas. That would have laid the groundwork for the success of the archaic bipedal hominids. They were the animals that could most effectively scavenge meat from carcasses they encountered in increasingly open areas, even as they hunted smaller game in forests and woodlands—much as some chimpanzees do today. Thus, despite Stanford's earlier insistence that hominids succeeded because they were generalists, he eventually falls back on environmental change as at least the initial external impetus for the multistage sequence of events that led to bipedalism.

Once a taste for meat had been acquired, everything else followed. "By three million years ago," he writes, "the whole equation of foraging energetics and diet had begun a fundamental shift." A "virtuous circle" had been established. More efficient upright walking fed back into increasing intelligence and social complexity, and those attributes led to ever more effective hunting. The last part of Stanford's short book is devoted to a once-over-lightly of the later hominid fossil record, illustrating how that dynamic has played out over the past couple of million years.

Did early hominids begin to move upright on the ground because their ancestors favored upright postures in trees?

Two very different books, then, presenting radically different scenarios for the origin of bipedalism in our lineage. But, significantly, what both books have in common is a firm belief in the gradual environmental molding of lineages, generation by generation, through natural selection. Indeed, both authors see natural selection as a driving force in human evolution—though Stanford correctly emphasizes that natural selection promotes the diversity of species, and stoutly denies that evolution is *toward* anything.

Yet natural selection can only work on novelties presented to it spontaneously: it cannot call anatomical innovations into being, however desirable they might appear. In nature, form has to precede function, for without form there can be no function. Yes, in retrospect bipedalism opened up a huge range of radical new possibilities for hominids. But evolutionists can hardly invoke those possibilities and their exploitation as explanations for the appearance of the new behavior.

So what can be said about how this fateful innovation came to pass? Well, it is clear that bipedalism arose quite early in hominid history, even if no one can be certain, in the strictest genealogical sense, that the earliest hominid was an upright biped. It is also pretty safe to conclude that the adoption of bipedalism was a formative event, with the profoundest possible consequences for later hominid evolution.

And there is a simple explanation, potentially testable by future fossil discoveries, for why early hominids began to move upright on the ground as their ancestral forests started to fragment. The explanation is that their own ancestors already favored upright postures in the trees, keeping their trunks erect during foraging, as many other primates do today. In other words, the early hominids were bipedal because they were already creatures that would have been most comfortable (if initially not totally at ease) moving upright on the ground.

If that was indeed the case, paleoanthropologists don't need to make difficult choices from the extensive menu of potential advantages that upright locomotion may or may not have offered the early hominids. Once our precursors had begun to descend from the trees, at the very least encouraged to do so by a changing milieu, they stood and moved upright simply because it was the most natural thing for them to do. Of course, once they had made this move, all the advantages of this new posture were theirs. And all of the liabilities too, for that matter.

Ian Tattersall is a curator in the Division of Anthropology at the American Museum of Natural History, and the author of numerous books, most recently The Monkey in the Mirror *(Harcourt, 2002).*

By Laurence A. Marschall

Ancient Wine: The Search for the Origins of Viniculture
by Patrick E. McGovern
Princeton University Press, 2003; $29.95

So old is the love of wine, and so rich in lore and legend, that its origins remain lost in the tangles of time. In Greco-Roman legend the god Dionysus is identified with bringing the art of wine making westward, from lands east of Persia. Biblical scholars who name Noah as the first cultivator of wine grapes describe him as settling down after the flood to become the first wine maker. He loved his work so much, according to the story, that he became the first town drunk.

In one of the most charming tales about the origins of wine, from ancient Persia, a fictitious King Jamsheed keeps jars of fresh grapes year-round, which he enjoys almost as much as he does his concubines. One of his consorts, suffering from severe headaches, mistakenly drinks from a jar containing spoiled fruit and falls into a deep slumber, from which she awakes refreshed and cured of her illness. She reports her experience to the king, who deliberately ferments his next batch of grapes, and the rest is what passed for history in those times.

In the wry judgment of a Persian poet of a later period, however, "Whoever seeks the origins of wine must be crazy." Clearly, the problem is not the lack of evidence but too much of it. Millions of clay pots that may have held intoxicating beverages are buried at countless archaeological sites. Pictures of drinkers and grape stompers decorate tomb walls and ceremonial vessels from sites throughout the ancient world. In the Fertile Crescent alone, so many clay tablets record the holdings of royal wine cellars and the commerce of wine makers that experts have translated and studied only a fraction of them so far.

And then there is a wealth of linguistic and cultural evidence. Dozens of living rituals, from the kiddush, or Sabbath "blessing over wine," which is central to Jewish life, to the communion wine of Christianity, attest to an ancient connection between wine and civilization.

Patrick E. McGovern, who heads the Molecular Archaeology Laboratory at the University of Pennsylvania Museum, brings a unique set of skills to this daunting study. He's a practitioner of molecular archaeology, an emerging field that applies the precision tools of microchemical analysis to the study of prehistoric artifacts. By measuring the precise mix of isotopes in a potsherd, for instance, he can identify its source in a specific clay deposit, and tie it to other pots whose locations trace out trade routes and cultural migrations that would otherwise remain unknown. Scrapings of residue from pots can identify key ingredients that once were stored inside them, even if only a few micrograms of material remain. The jumble of ancient remains can be sorted out to reveal hidden patterns of wine usage and distinctive variations in wine composition never before suspected.

With those tools McGovern and his coworkers have investigated wine cultures that go back well before written records. The ancient legends, it turns out, may have contained more than a "grape seed" of truth. The first wines, he believes, were made at least 7,000 years ago in the Caucasus, perhaps in the shadow of Mount Ararat, where Noah's ark supposedly came to rest. From there, not surprisingly, the art of wine making spread quickly: down the Tigris and Euphrates Rivers, along the coast of the Levant to Egypt, and west to Turkey and Greece.

Molecular archaeology can identify not only the source of the clay pots but the substances they once contained.

Fresco of putti pouring wine, Casa dei Vettii, Pompeii, first century

Many early wines, judging from the residues they left, were liberally mixed with pungent tree resins that probably served as preservatives in the absence of effective seals for containers. Few today except the Greeks, who continue to produce and consume retsina table wine, seem to regard the practice as anything other than an odd way to spoil a god-given drink.

The methods of McGovern and his colleagues have only begun to reveal the details of how grape cultivation and wine making developed in the ancient Mediterranean and the Near East. But their findings so far, summarized in the book, are already a rich treasury of lore on viticulture and on the drinking habits of the Assyrians, Egyptians, Greeks, and other cultural groups in the region. This field of study is clearly destined to yield bumper crops in years to come, but McGovern's book will likely remain a standard in every serious wine-lover's library for a long time. To that achievement—and to glorious wine itself—let us raise our glasses high.

Mutants: On Genetic Variety and the Human Body
by Armand Marie Leroi
Viking Press, 2003; $25.95

Rosamond Purcell, *Twins Joined at the Rib Cage,* 1987

Don't let the bearded lady on the dust jacket fool you: this book is not a smarmy gallery of freaks and monsters. Armand Marie Leroi, a developmental biologist at Imperial College, London, has written an elegant study, filled with narratives from early medical literature and insights from the latest biomolecular research, on the subject of genetic variability and its manifestations in the developing human organism.

Not that the book isn't bulging with such oddities as flies born without eyes and babies born without irises—not to mention the person born with five nipples on one side and four on the other (a record). Leroi is also a gifted raconteur, and he's assembled a cast of fascinating and exotic characters. Josef Boruwlaski, an eighteenth-century Polish courtier whose memoirs introduce a chapter on human stature, stood just over three feet tall. He was a fixture at the courts of Europe, however, married well, raised a family, and died at the respectable age of 98. Carl Herman Unthan, born without arms in 1848, appears in a chapter on limb development. By age 20 Unthan was an established violin virtuoso, performing in Viennese concert halls with the great classical musicians of his time. In 1928, by then a naturalized citizen of the United States, he produced an autobiographical "pediscript" (so named because he had typed it out with his toes) that was published under the title *The armless fiddler.*

For every uplifting story, of course, there are many tales far more disturbing: conjoined twins sharing a single pair of legs; a man virtually frozen in place when his flesh turned to bone; people with single eyes, or with no eyes at all.

But Leroi's aim is to illuminate, not to titillate. Variability in the human species can be trivial, heroic, or tragic, but in all cases it is evidence of the coded blueprint in our genes, and of the way that blueprint is expressed in the developing organism. Although it is ethically impossible to experiment with the blueprint in the laboratory—turning genes on and off to see what happens—the outcome can be studied if nature does the experiment. Each mutation thus offers a glimpse of how one set of instructions, written in our genes, ends up forming a body.

Sometimes a mutant form arises from one alteration in a single gene. Leroi cites the descendants of an "exceptionally philoprogenitive" Chinese sailor, who in 1896 came ashore at Cape Town, South Africa, and settled in the Cape Malay quarter. All of his numerous progeny carry a mutation, on a gene called *CBFA1,* that affects cells that produce bone. And many of his descendants have inherited the mutation's traits, which include soft skulls, missing clavicles, and missing teeth—a fact that does not seem to affect their vitality: a 1996 survey turned up about a thousand people around Cape Town with the mutation, and they all speak with pride of their cartilaginous ancestor.

Other mutations involve multiple genes and work in ways far subtler

than do single-point mutations. Such characteristics as skin color, stature, longevity, and propensities for particular types of cancers often require several mutations to express themselves. Many variations in the human form, such as dwarfism or gigantism, can arise from such combined mutations. To make matters even more complicated, the DNA blueprint can be modified during the "construction" phase, and changing conditions in the embryonic environment can have far-reaching effects on later development. The thalidomide disaster of the 1960s, for instance, was caused by a drug prescribed to alleviate morning sickness. Inadvertently, though, it affected the growth of limb buds, and thousands of infants worldwide were born without the long bones of their arms or legs.

Although the entire human genome has been officially mapped since 2001, most of the ways it expresses itself are still unexplored. Leroi has written a guidebook to the territory, in which mutations are the landmarks that give an overview of the terrain. But it is clear that geneticists are only beginning to understand the connection between the dull sequences of C's, A's, G's, and T's in the genome map and the "real stuff" of bodies and minds. Leroi's book is a testament to both the ingenuity of organic life and the protean nature of what it means to be human.

Built for Speed: A Year in the Life of Pronghorn
by John A. Byers
Harvard University Press, 2003; $24.95

Travelers passing through the Great Plains called pronghorn antelope "prairie ghosts," as a testament to their speed and agility; an adult pronghorn can accelerate from zero to almost sixty miles an hour like a benzene-fueled dragster, and it cruises along effortlessly at forty-five miles an hour, easily outrunning anything that comes after it. Ever since the last lions and cheetahs died out in North America more than 10,000 years ago, there has been no serious predator on the continent that can match the pronghorn for speed. Today's hungry coyotes—the only mammals, other than you-know-who, that effectively hunt pronghorn—can only hope to snatch an occasional fawn in an unguarded moment.

John A. Byers is a field biologist who has spent almost a quarter of a century chasing pronghorn antelopes on Montana's National Bison Range. Byers observes his subjects with such patience that he can recognize individual faces the way most people recognize friends and family. He's read John

Pronghorn antelope fawn, built for racing and ruminating

James Audubon and John Muir, and, as he proves with stirring accounts of his experiences in big-sky country, he can spin a phrase with a skill worthy of those master wordsmiths. But Byers is a hard scientist as well as a lucid writer, and the image of the pronghorn that emerges from his research is not altogether a model of grace and beauty.

If you spied a pronghorn browsing among the summer grasses on the western plains of North America, you'd think they haven't a care in the world. But pronghorns maintain an exceedingly rigid dominance hierarchy that makes everyday life a constant battle. Females, Byers found, expend huge efforts bullying other prong-

EXPLORER GUIDE

horns, and much of their time is taken up jostling each other for the choicest napping spots. When one female gets pushed out of her spot by a more dominant individual, she'll wander around looking for an even weaker female to rouse—and so on, until everyone except the weakest has gotten in a lick. Young males challenge equals and inferiors with their horns, playfully at first—then, as they mature and begin to compete for mates, with injurious and even deadly intent.

It's even a bit misleading to describe them as "placidly browsing." Unlike bison or sheep, which simply mow down everything edible in their path, pronghorns are extremely fussy diners. Most of the time they aren't actually eating but nervously nuzzling plants, like a matron at a tea party looking for the choicest nibbles.

And yet, despite their choosiness, I wouldn't want to adopt their nutritional habits. Like cows and camels, they are ruminants, and true pronghorn serenity comes from burping up a recent meal, which has been fermenting in an outer stomach, and then chewing it all over and over again for an hour or more. The continuing mastication helps digest the tough material they take in, but it reminds me of one of those stomach-churning ads that run on the seven o'clock news.

What sounds even worse are the special snacks reserved for nursing mothers. After dining on fresh placenta, a pronghorn mom regularly chows down her fawn's feces for several weeks, apparently as a way to manufacture disease-fighting antibodies transmitted to her offspring through the mother's milk. "Natural selection," Byers writes, "can shape the brain to make anything that contributes directly to reproduction feel like fun." Yummy.

The dramatic climax of the pronghorn year, and of the book, is the rut. With winter approaching, pronghorn males each gather small harems of females into gullies and valleys on the prairie, trying to keep them out of sight of their rivals while they woo them. But the females will have none of it. They resist amorous advances time and again. Often, for several weeks, they move from one harem to another, sometimes with a male in pursuit, leaving behind the spilled blood of rejected suitors. Byers's account of one female's experiences is filled with white-knuckle suspense. Which male gets to mate with the lovely pronghorn ingenue? Will she fall in love with Archie's subauricular gland? Will an interloping yearling take her by force before Kareem gets a chance to charm her? It's the pronghorn equivalent of a bodice-ripper, and a natural history lover's delight.

Laurence A. Marschall, author of The Supernova Story, *is the 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.*

Time Will Tell

By Robert Anderson

The movie camera is a marvelous tool in the hands of anyone, scientist or amateur, who is curious about time. The camera, after all, can control time—speed it up or slow it down—and so open a new and often surprising window on reality.

The best collection of time-altered movies on the Internet can be found at a site created by Red Hill Studios in Larkspur, California, in cooperation with the Science Museum of Minnesota in St. Paul. Appropriately, its address is playingwithtime.org. Select "to see and do" from the bar at the top of the page and then go to "gallery." On nine pages of choices, you'll find an eclectic mix of fascinating movies that go beyond Harold Edgerton's familiar stop-action work with drops of milk and apples pierced by bullets. The site also encourages viewers to create their own time-lapse movie projects.

At "Plants in Motion" (sunflower.bio.indiana.edu/rhangart/plantmotion/PlantsInMotion.html), maintained by Roger Hangarter, a biologist at Indiana University at Bloomington, is a collection of movie clips that make the growth of plants come alive. Choose from the category selections in the menu at the right, and watch the slender new stalks of sunflower seeds twisting toward the light, or the "sleep movements" of bean leaves responding to their biological clock.

Stephen Deban, a biologist at the University of Utah in Salt Lake City, has a page with movies showing how fourteen species of salamanders zap insect prey with their tongues (autodax.net/feeding movieindex.html). The Department of Biology at the University of Alberta runs an unusual instructional multimedia site (www.biology.ualberta.ca/facilities/multimedia). Click on the blue-lettered directions at the bottom of the page to see the time-lapse selections. You might want to skip a few if, like me, you're squeamish about bot flies, but don't miss the "Clam Escape Response."

I particularly liked a collection of movies from Erta Ale, an extremely photogenic volcano in Ethiopia (www.educeth.ch/stromboli/perm/erta/movies-en.html). Scroll down this page and you'll find five accelerated clips of the lava lake. Like a miniature version of Earth's plate tectonics, thin slabs of basalt crust jostle about, driven by the heat below. New crust is quickly formed, then subducted and recycled. Another site, at the NASA Goddard Space Flight Center (svs.gsfc.nasa.gov/search/Keywords/Glacier.html), speeds up the movement of glaciers, some of nature's most famous slowpokes, in a series of satellite images.

Astronomy, too, benefits from the miracle of time-lapse photography. On António Cicadão's "Lunar and Planetary Observation" page (www.astrosurf.com/cidadao/animations.htm) are beautifully presented solar and lunar eclipses, dancing satellites, and spinning planetary atmospheres. And at solarviews.com/eng/jupiter.htm#movie, click on "Animations of Jupiter" in the table of contents to view Jupiter's famous red spot. At the same Web site, another page (solar views.com/raw/nep/nepspot.mov), presents Neptune's dark spot.

Finally, the site of the Chandra X-ray Observatory has a remarkable movie, taken over a span of half a year, of the pulsar at the center of the Crab Nebula (Chandra.harvard.edu/photo/2002/0052/movies.html). Watch the spinning neutron star spew wisps and jets of matter and antimatter into the surrounding nebula.

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

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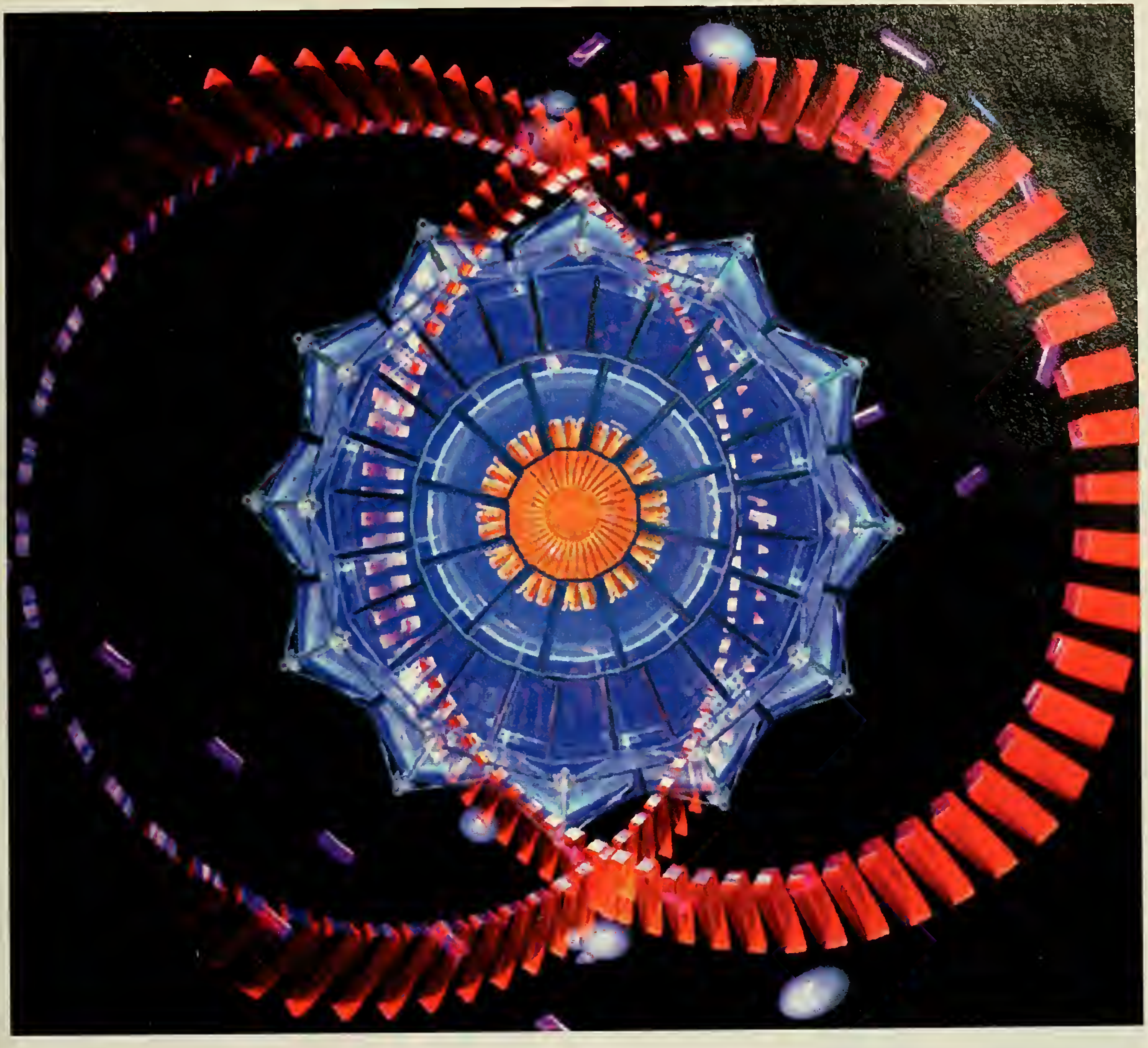
The American Museum of Natural History, in association with internationally renowned performer Moby and MTV2, presents *SonicVision*—a new digitally animated alternative rock music show. Shown in the Hayden Planetarium Space Theater of the Rose Center for Earth and Space, *SonicVision* blends contemporary music, mind-bending immersive animations, and state-of-the-art technology into a theatrical and musical presentation unlike anything else in the world. *SonicVision*, the first music show in the Hayden Planetarium since the Rose Center opened in February 2000, brings the laser light shows of the 1970s and '80s into the 21st century.

Moby has sold more than ten million albums worldwide to critical acclaim. A longtime fan of space and astronomy, Moby began collaborating with the Museum six months ago, using his legendary mixing and musical abilities to develop the soundtrack for *SonicVision*. The mix features music by Radiohead, U2, Coldplay, The Flaming Lips, Stereolab, Queens of the Stone Age, David Bowie, Boards of Canada, and Moby, among others.

The music explodes to life on the Space Theater dome in digital images and animations. The visual landscape of *SonicVision* was directed by former MTV Art Director Chris Harvey, who is the recipient of numerous awards, including an Emmy, a Peabody, and several Broadcast Design Association awards, and who has worked extensively in broadcast design for more than a decade. The show was produced by the same Rose Center team that created the Museum's groundbreaking Space Shows, *Passport to the Universe* and *The Search for Life: Are We Alone?* Other major collaborators include the commercial production company Curious Pictures; artists Alex Gray, Perry Hall, and Darrel Anderson; and over a dozen animators including popular VJs Bionic Dots, Benton C., Madam Chao, Atmospherex, and Vishwanath Bush. VJ art is the rapidly growing underground arts movement where artists manipulate video in the same way DJs mix records. A feature of dance clubs, VJ art is also finding its way into fine arts institutions and galleries.

Each segment of the music show smoothly progresses into the next, blending different visions into a single thrilling journey. The dizzying animation launches audience members into fantasy space, brings them to a far-off planet with cathedral-like structures, and then spins them wildly up to the heavens. Viewers watch aliens rave at a dance party, float off into space while fireworks explode, and witness a fiery kaleidoscope descending from overhead. These images evoke a continuous journey that is at times tranquil and at times raucous—leading the viewer through seemingly impossible spaces and landing finally amid a peaceful, heavenly calm.

SonicVision would not be possible without the Rose Center's breathtaking digital video technology. Its 429-seat Space Theater is the largest virtual reality theater in the world, and the



world's largest nonmilitary flight simulator. Its dome shape, seven light projectors, low-frequency shakers in the seats and floors, 23 speakers, and the audio spatialization system create a panorama of visuals and sound—a truly immersive experience. With Museum computers displaying on the dome 28 times more image information than a television, the dome envelops the viewer in one huge seamless image-space.

To achieve this spectacular illusion, animators use software programs with real-time visualization capabilities including MAYA, XSI, Shake, Virtual Director, and a special multipipe version of Filmbox designed especially for use in the Hayden Sphere. The software used to create the show mixes standard animation tools to create colossal, multilayered images that are uniquely tailored to the dome display, some of which took weeks to render. Audio response analysis technology was also used to make some of the animations coordinate with the music.

With its cutting-edge technology that merges thrilling visuals and pumping music into a mind-blowing sensory experience, *SonicVision* defines a new generation of planetarium music shows.

SonicVision is presented Friday and Saturday nights in the Hayden Planetarium Space Theater of the Rose Center for Earth and Space. Show times are 7:30, 8:30, 9:30, and 10:30 p.m. Tickets are $15 for the general public and $12 for Museum Members. For advance tickets, call 212-769-5200 or visit www.amnh.org. A service charge may apply.

***SonicVision* is made possible by generous sponsorship and technology support from Sun Microsystems.**

D. FINNIN/AMNH

MUSEUM EVENTS

EXHIBITIONS

Petra: Lost City of Stone

Through July 6, 2004

This exhibition tells the story of a thriving metropolis at the crossroads of the ancient world's major trade routes and of the technological virtuosity that allowed the Nabataeans to build and maintain Petra in the harsh desert environment.

In New York, Petra: Lost City of Stone *is made possible by Banc of America Securities and Con Edison. The American Museum of Natural History also gratefully acknowledges the generous support of Lionel I. Pincus and HRH Princess Firyal and of The Andrew W. Mellon Foundation. This exhibition is organized by the American Museum of Natural History, New York, and the Cincinnati Art Museum, under the patronage of Her Majesty Queen Rania Al-Abdullah of the Hashemite Kingdom of Jordan. Air transportation generously provided by Royal Jordanian.*

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Frederic Edwin Church, El Khasné, Petra, 1874. Oil on canvas

The Bedouin of Petra

Through July 6, 2004

Photojournalist Vivian Ronay's evocative color photographs document the Bdoul group of Bedouin tribes living around the archaeological site of Petra in Jordan.

This exhibition is made possible by the generosity of the Arthur Ross Foundation.

The Butterfly Conservatory: Tropical Butterflies Alive in Winter

Through May 31, 2004

The butterflies are back! This popular exhibition includes more than 500 live, free-flying tropical butterflies in an enclosed tropical habitat where visitors can mingle with them.

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

Vietnam: Journeys of Body, Mind & Spirit

Through January 4, 2004

Gallery 77, first floor

This comprehensive exhibition presents Vietnamese culture in the early 21st century. The visitor is invited to "walk in Vietnamese shoes" and explore daily life among Vietnam's more than 50 ethnic groups.

Organized by the American Museum of Natural History, New York, and the Vietnam Museum of Ethnology, Hanoi. This exhibition and related programs are made possible by the philanthropic leadership of the Freeman Foundation. *Additional generous funding provided by the Ford Foundation for the collaboration between the American Museum of Natural History and the Vietnam Museum of Ethnology. Also supported by the Asian Cultural Council. Planning grant provided by the National Endowment for the Humanities.*

LECTURES

Over the Edge of the World

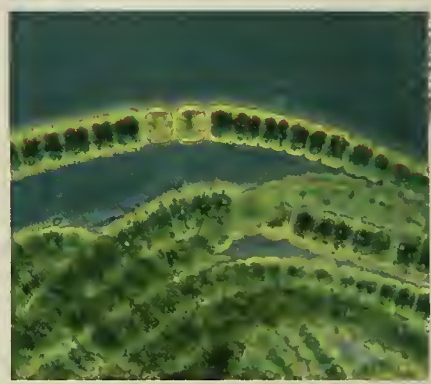
Thursday, 11/6, 7:00 p.m.

Laurence Bergreen discusses Ferdinand Magellan's daring circumnavigation of the globe in the 16th century.

From Sea to Pharmacy

Thursday, 11/13, 7:00–9:00 p.m.

Are marine invertebrates and microorganisms the next source of anticancer and other drugs? Three top researchers in marine biomedicine discuss the latest findings.



CHRISTINE MROZEK

This blue-green alga, *Hormothamnion*, produces peptides toxic to cancer cells.

The Lost Camels of Tartary

Tuesday, 11/18, 7:00 p.m.

John Hare, founder of the Wild Camel Protection Foundation, tells the compelling story of his expeditions in search of the elusive and critically endangered wild Bactrian camel.

Petra and the Middle East: Uncovering History's Earthquakes

Thursday, 11/20, 7:00 p.m.

Paleoseismology, the study of past earthquakes, provides new insights into the archaeological interpretation of Petra's fall. With Tom Rockwell, San Diego State University.

FAMILY AND CHILDREN'S PROGRAMS

Mosaic Tile Workshop

Sunday, 11/2 (Ages 7–9)

11:30 a.m.–12:30 p.m. or 1:30–2:30 p.m.

Sunday, 11/9 (Ages 4–6, each child with one adult)

11:30 a.m.–12:30 p.m. or 1:30–2:30 p.m.

Nature for Kids and Caregivers

Four Wednesdays, 11/12–12/10, 9:30–10:15 a.m. (Ages 2 and 3, each child with one adult)

Ocean Fridays

Four Fridays, 11/14–12/12

2:00–3:30 p.m. (Ages 5–7)

CHILDREN'S ASTRONOMY PROGRAMS

Solar System Adventures
Saturday, 11/1, 1:00–2:30 p.m.
(Ages 7–9)

Journey through the Solar System
Sunday, 11/9, 1:00–2:30 p.m.
(Ages 4–6, each child with one adult)

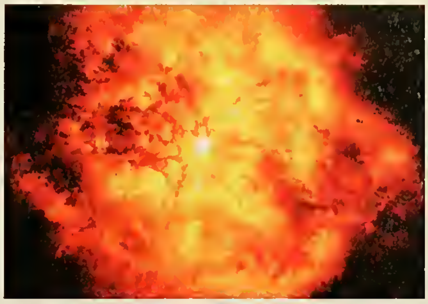
Space Explorers: Galaxies
Tuesday, 11/11, 4:30–5:45 p.m.
(Ages 10 and up)

Einstein for Everyone: Adventures in Light!
Tuesday, 11/18, 4:00–5:30 p.m.
(Ages 4–6, each child with one adult)

HAYDEN PLANETARIUM PROGRAMS

Virtual Universe:
Black Holes and Quasars
Tuesday, 11/4, 6:30–7:30 p.m.
Redefine your sense of "home" on this monthly tour through charted space.

Truth and Beauty in Cosmology: Does the Universe Have an Aesthetic?
Monday, 11/10, 7:30 p.m.
With Chris Impey, University of Arizona.


NASA

The super-hot star WR124

Echo of the Big Bang
Monday, 11/24, 7:30 p.m.
The Wilkinson Microwave Anisotropy Probe, with Michael Lemonick, *Time* magazine senior science writer.

Celestial Highlights:
Winter Preview
Tuesday, 11/25, 6:30–7:30 p.m.
Find out what's up in the December sky.

SPACE SHOWS

The Search for Life: Are We Alone?
Narrated by Harrison Ford

Passport to the Universe
Narrated by Tom Hanks

Look Up!
Saturday and Sunday, 10:15 a.m.
(Recommended for children ages 5 and under)

LARGE-FORMAT FILMS

In the LeFrak IMAX® Theater

Coral Reef Adventure
Closes November 7
A fantastic underwater journey to document some of the world's largest and most beautiful—and most threatened—reefs.

Volcanoes of the Deep Sea
Opens November 8
Explore Earth's most hostile environments and its strangest creatures, and consider the implications for our search for life.

India: Kingdom of the Tiger
A glorious tribute to this magnificent land and its greatest ambassador—the mighty Bengal tiger.

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.

Starry Nights
Live Jazz

Friday, 11/7, 5:30 and 7:00 p.m.

Rose Center for Earth and Space

The Louis Hayes Quartet

Starry Nights is made possible by Lead Sponsor Verizon and Associate Sponsors CenterCare Health Plan and WNBC-TV.

Up the Chimney

Pipes of hot gas stream from superbubbles bursting out of the disk of the Milky Way.

By Charles Liu

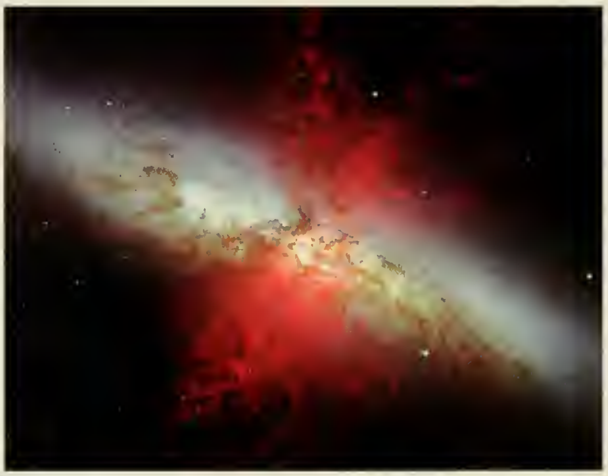
The Milky Way has gas—and lots of it. Throughout the flapjack-shaped spiral galaxy we live in, there's at least half a quadrillion Earth-masses' worth of free-floating gas, most of it cold, neutral hydrogen just a few degrees above absolute zero. That's impressive, but it's still just a drop in the bucket on a galactic scale. Even excluding the ubiquitous dark matter that surrounds our galaxy [*see "Dark and Darker," by Neil deGrasse Tyson, page 18*], gas comprises only about 1 percent of the total mass of the Milky Way.

Still, that 1 percent packs a lot of astrophysical punch. As it flows and ebbs through the galaxy, interstellar gas serves as the raw material of creation—from the tiniest planet-bound life-forms to the grandest stars and nebulae.

Among the most spectacular patterns of gas flow are galactic chimneys—vast rivers of hot gas thousands of light-years long that can transport matter from the galactic disk into intergalactic space. Recently, a research group led by Naomi McClure-Griffiths of the Australia Telescope National Facility in Epping, New South Wales, has produced the most detailed map ever made of a galactic chimney, and it has shed new light on the fascinating movement of life-bearing gas into, out of, and throughout the Milky Way.

Imagine the stream of smoke rising from a just-extinguished candle. At first the smoke rises straight up, but then it starts to bend, spreading outward and upward. What the plume looks like a few seconds later depends on the local atmospheric conditions around the candle. Set the candle outdoors, on a breezy day, and the smoke blows away in a formless, ashy wind. Place it indoors, in a quiet room, and the smoke becomes a cloud of wispy filaments, swirling gently until they all blend into a screen of gray.

Gas moving around in a galaxy acts like candle smoke on a cosmic scale. Nearly all the gas in a typical spiral galaxy is confined to the galactic disk. Left undisturbed, the gas moves languidly around in the disk, settling into clouds made of softly swirling wisps and loops. But if a breeze blows through it—say, a stellar wind from a giant star nearby—the gas is driven outward. Depending on the strength and persistence of the winds, the gas gets piled up into new configurations: shells, bubbles, and walls.



Massive outflow of hot gas (red in this false-color image) emerges from the stellar disk of the starburst galaxy M82. More than 10,000 light-years long, the flow is driven by "winds" of particles and by supernovae from a large collection of massive stars within the galaxy. Similar, smaller-scale chimneylike structures erupt out of many galaxies, including our own Milky Way, into intergalactic space.

In extreme cases, entire clusters of hot, massive stars combine to blow superwinds outward at more than a million miles an hour. The superwinds are then further energized when the most massive stars in the cluster self-destruct in titanic supernova explosions, releasing more energy in seconds than our Sun gives off in a billion years. The result: a "superbubble" forms in the surrounding interstellar space, rapidly expanding to hundreds or even thousands of light-years across. Inside the superbubble is very sparse, hot gas; all around it is a thin, dense shell of the cooler gas that was once drifting near the central star cluster. Eventually, a weak spot on the shell may rupture and the superbubble will burst, allowing the hot gas to stream out and causing the bubble to break up.

But if a superbubble does not burst, it can grow large enough to reach an edge "above" or "below" the galaxy's disk. There, with no more cool gas to pile up against its expansion, the superbubble pops out of the disk and into the much sparser galactic halo. The hot gas pours out of this hole, spewing energy and superheated particles into the halo and sometimes beyond, into intergalactic space. A galactic chimney is born.

Well, that's one idea, anyway. But the model has its problems, and one of them comes from observations of gas in the Milky Way: there aren't enough hot, luminous stars in our own galaxy to generate the supernovae and superwinds needed to make all the shells, bubbles and galactic chimneys that have been observed. Why should other galaxies act any differently? To patch up the galactic-chimney model, energy sources other than stellar winds have been suggested over the years, but none has been altogether satisfactory. Recently supercomputer simulations have suggested that stellar winds aren't even necessary; the random swirling of the gas can give rise to galactic chimneys by chance.

One way to address the problem is to look closely at a chimney's interior walls. If they are smooth, they're more likely to have formed by gentle, fairly random processes. But if the walls have fine structures, ripples, or intrusions, they probably reflect an interaction of hot, sparse gas with dense, cold gas—what you'd expect if a superwind were at work.

McClure-Griffiths and her collaborators made images of the galactic chimney designated GSH 277+00 +36; some images show structures more than 3,000 light-years long, others zoom in on details less than thirty light-years long. Studying the overviews, they noted that the chimney bifurcates, both at the top and the bottom of the superbubble, into vast "pipes" that direct the gas thousands of light-years outside the disk of the Milky Way and into the galactic halo. In the detailed images the investigators found countless loops, whorls, drips, and blips on the chimney's inside walls—like huge villi along a giant interstellar intestine. By themselves, the images don't resolve the question of how galactic chimneys form. But they do bring us one step closer to the answer—and afford us a beautiful glimpse of streaming, swirling star smoke.

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

THE SKY IN NOVEMBER

By Joe Rao

Mercury spends most of November lost in the Sun's glare. But at month's end the planet may be visible through binoculars, low in the southwestern sky after sunset.

Brilliant Venus, at magnitude –3.9, shines low in the southwestern sky as darkness gathers. As the month begins, the planet sets less than an hour after the Sun. By month's end, though, the rapidly shortening days in the onrush to the (northern) winter solstice leave the planet setting more than an hour and a half after the Sun.

Orange-yellow Mars makes a good apparition this month; it's already high overhead at sunset and doesn't set until around 1 A.M. In early November Mars culminates, or reaches its highest point in the sky, at about 7 P.M.; by month's end it culminates an hour earlier. On the 1st Mars is 59 million miles from Earth and shines at magnitude –1.2. Among the stars, only Sirius is brighter. By the 30th the distance to Mars increases to 79 million miles, and the planet has dimmed to magnitude –0.4. The waxing gibbous Moon overtakes Mars on November 2 and 3.

Jupiter, in the constellation Leo, rises at about 1:45 A.M. at the beginning of November and just after midnight by month's end. The best time for viewing the planet this month is at approximately 5 A.M., when it shines brightly, high in the southeast.

Saturn, in the constellation Gemini, the Twins, rises at about 8:45 P.M. on the 1st and two hours earlier by the 30th. At midmonth the planet shines with a yellow-white light at magnitude –0.2. Its great ring system is tilted at 25 degrees to our line of sight, making it breathtakingly beautiful, even through a small telescope.

Less than six months after the lunar eclipse in May, the Moon will again undergo total eclipse, this time on the 8th. And again, eastern North America has the best view: those living east of a line running roughly from Medicine Hat, Alberta, to Corpus Christi, Texas, will be able to see the entire eclipse as the full Moon slowly climbs the eastern sky. Farther west, the eclipse is under way as the Moon rises; for skywatchers along the Pacific coast of California, the beginning of the total phase nearly coincides with moonrise.

Totality is brief, just twenty-five minutes. The Moon's disk should remain relatively bright (for an eclipse). The light-scattering effects of our planet's atmosphere could make for some colorful viewing. At the midpoint of totality the Moon's upper rim should look reddish brown; its middle should glow reddish orange; and its lower rim may be brighter orange—perhaps even tinged with a whitish "cap."

The Moon enters the Earth's shadow at 6:32 P.M. and leaves it at 10:05 P.M. Totality begins at 8:06 P.M. and ends at 8:31 P.M. Our satellite waxes full on the 8th at 8:13 P.M. It wanes to last quarter on the 16th at 11:15 P.M. and to new on the 23rd at 5:59 P.M. Just one minute later the Moon arrives at perigee, its closest point to Earth, 221,722 miles away. The Moon returns to first quarter on the 30th at 12:16 P.M.

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

Captivated

By Meredith F. Small

I'm sitting on a bench in New York City's Central Park, waiting for the zoo to open. I have spent years observing macaque monkeys in the field, but these days I only teach and write about what they do, and I miss them. So whenever I'm in Manhattan, I hang out here with the snow monkeys (*Macaca fuscata*).

I've been visiting this troop for years. I have seen them in sunshine and snow; stood in the rain and watched them lick drops of wetness off their fur; held short business meetings in front of their exhibit; forced friends to meet me here. Unbeknownst to them, these furry gray monkeys from Japan have become my primate touchstone.

On this visit it's clear and sunny, and through the entrance gates I see the macaques jumping around their island exhibit. A path of rocks breaks the surface of the retaining pond that surrounds their enclosure, and a young female hops from one to another, leapfrogging over her troopmates as she goes.

Finally the gates open, and as I approach the group, my professional observing skills click in. By the time I reach them, my training as an observer—and that touch of magic I always feel in the presence of monkeys—has locked out the world: all that matters is the movement of these animals.

Today I count nine adults, one juvenile, and no babies. I know that fall is breeding season, and the females are signaling their fertility with red behinds. To my right a status interaction is unfolding—a female turns her rear to another female, indicating her lower position. I lean across the rail and get into the Zen of figuring out what these monkeys already know about each other: who is related to whom, how do they rank, which pair will be the next to mate?

My primatological reverie is interrupted by a crowd of visitors. I hear one woman call a male "she," and I'm compelled to correct her. "It's the shape of his face," I tell her, "and his size—and those bright red testicles." But I should know better than to be so patronizing, such a know-it-all. Several years ago, on one frozen January day, I asked some of the zoo's wild-animal keepers why the snow monkeys were indoors. After all, I told them, these monkeys are accustomed to crawling through snowdrifts in their native Japan. "If the pond froze over," they patiently responded, "the monkeys would simply walk out of the zoo." Humbled, I went to see the polar bear.

When I have the monkeys to myself again, I walk up the hill behind the exhibit and lean over the granite wall overlooking their enclosure, focusing on a pair of females. One is stretched out on a rock, arms and legs splayed in relaxation. Her eyelids droop. She is at peace. The other methodically moves a hand across her partner's belly, separating each strand of hair, gently touching each exposed patch of skin. Monkeys have done this to me, sitting on my shoulders with their handlike feet pressed against my neck, picking through my hair. I know it feels like heaven.

Concentrating on the grooming females, I stretch my own arms across the wall and feel the reflected warmth of the sun seep up from the granite slab. I, too, let my eyelids droop in contentment. For a few precious minutes I pretend that I have done nothing for the past few months but watch this group, that we know each other intimately, observer and observed. Monkey noises, their barks and calls, fill my ears. The familiar, musty odor of monkey fur at close quarters fills my nostrils.

I am, once again, renewed.

Snow monkey family, ink and water color on paper, Japan

Meredith F. Small is a writer and professor of anthropology at Cornell University.

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