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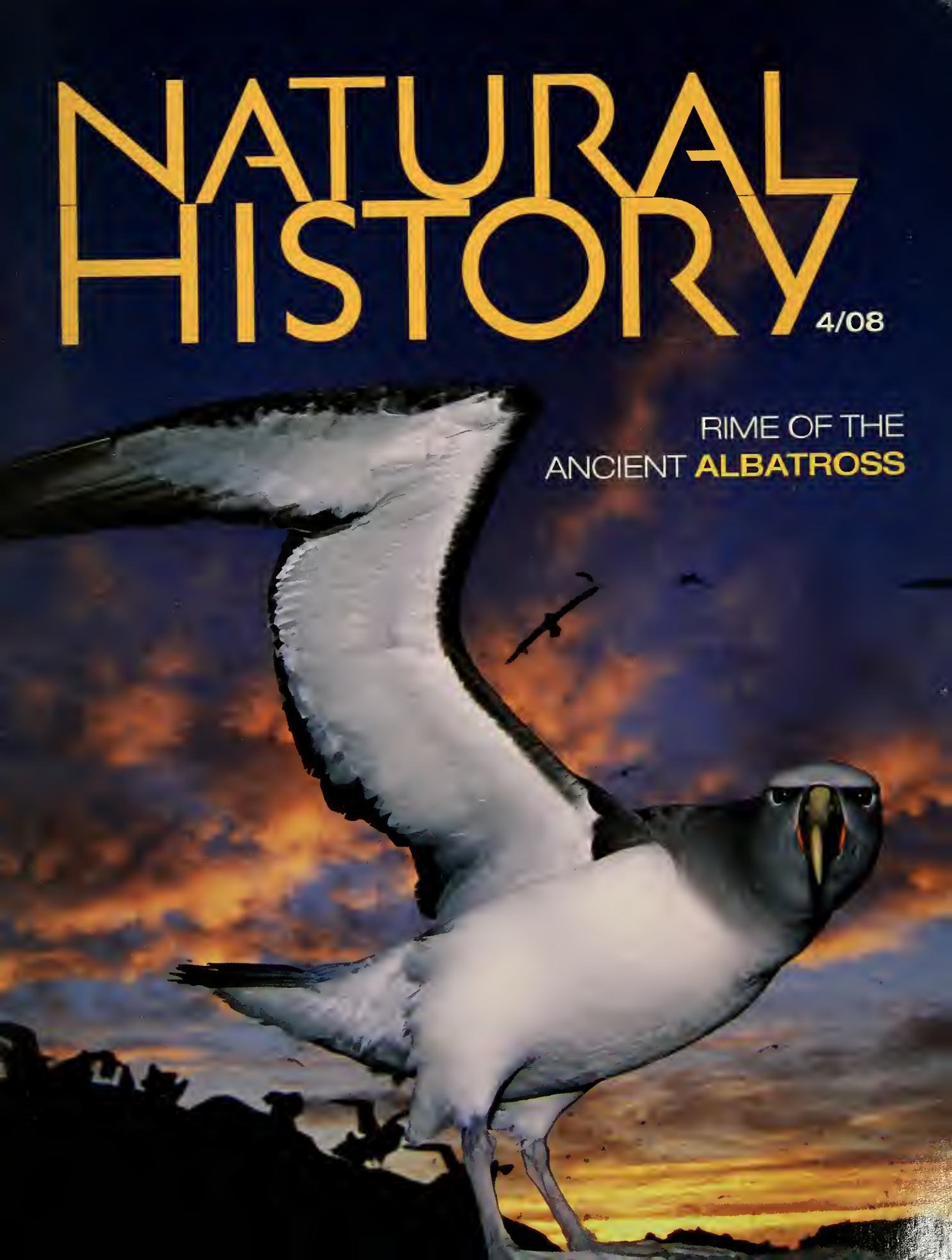
4/08



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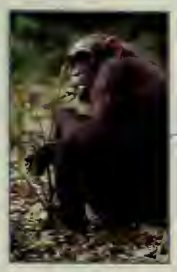

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THE NATURAL MOMENT

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THE NATURAL EXPLANATION BY ERIN ESPELIE

"Once in a great while you witness one of those rare moments where everything comes together: subject, location, light, and—in this case—dead calm."

That's how photographer David Chauvin describes the windless scene he found at a watery reserve in southeastern Louisiana. A green lynx spider, dangling by a few strands of silk lassoed around a leaf, went to work—as Chauvin did—before sunrise. With a little help from gravity, the spider slipped out of its old skin, leg spines and all, at first light.

Chauvin often photographs in the Bonnet Carré Spillway, a twelve-square-mile reserve about ten miles northwest of New Orleans. Alligators, coots, dabbling ducks, marsh rice rats, minks, nine-banded armadillos, and swamp rabbits are just a few of the creatures that live there. Once a decade or so, the area gets doused when the Mississippi River, to the west, is shunted through Bonnet Carré to ease flooding.

The spillway was completed in 1929, two years after a catastrophic river flood displaced more than 700,000 people. Now the spillway's gates can be opened to divert water into Lake Pontchartrain and from there into the Gulf of Mexico. Bonnet Carré protects Louisianans from floods in other, indirect ways, too: silt and sand from certain areas of the reserve are currently being mined for landfill and levees in nearby parishes, as counties there are called.

The green lynx spider, *Peucetia viridans,* doesn't weave a stationary web, vulnerable to floods. As its name suggests, it actively stalks and pounces on prey. If provoked, it can even shoot venom. Only occasionally does it get tied down to one spot—when it molts, for instance, as shown here. Or, when family life calls: mothers tether their egg sacs to vegetation and keep vigil for weeks, sometimes starving to death without the freedom to hunt.

DAVID CHAUVIN

Bonnet Carré Spillway

Southern farmers can reap significant benefits from green lynx spiders' hunting skills. The arachnids eat pests such as bollworm, cotton leafworm, and cabbage looper moths and their larvae. Unfortunately green lynxes will also nab honeybees, which are desperately needed to pollinate some of the same crops.

And, you might ask, what's with those lethal-looking leg spines? Are they combat spurs? No, they probably help the spiders scramble across uneven terrain. Biomimicry engineers certainly think so, and have recently been building spiny-bottomed robots to prove it.

David Chauvin grew up with the Mississippi River at his front door and the bayous of Lac des Allemands—southeast of Lake Pontchartrain—at the back. After several decades of traveling extensively for his photography, Chauvin returned and now lives nearby in Laplace. More of his work can be seen at davidchauvinphotography.com.

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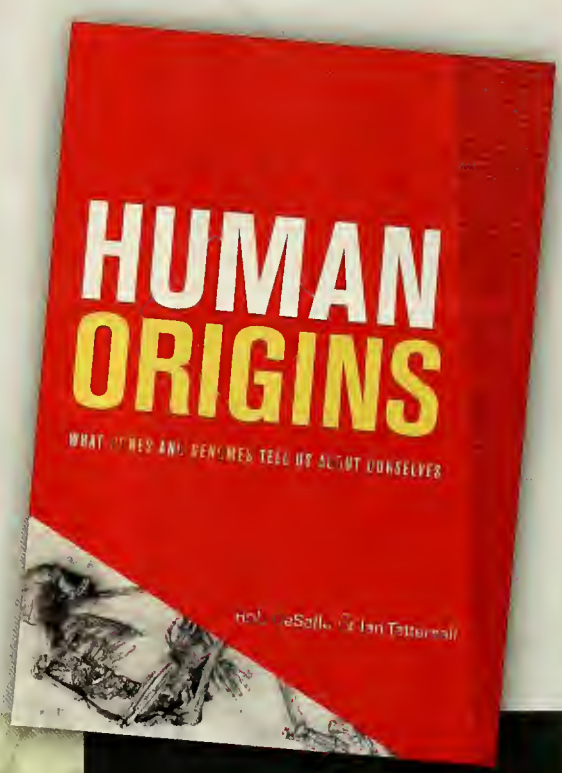

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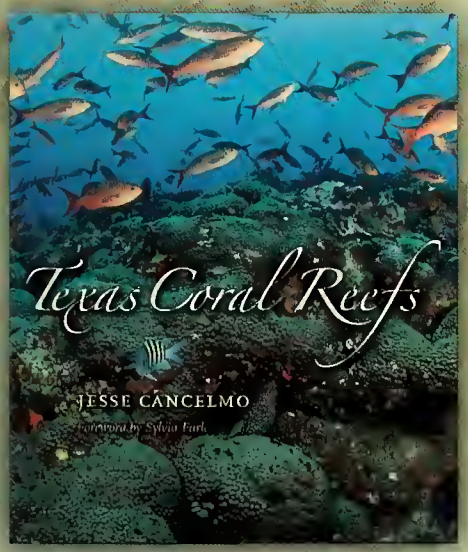

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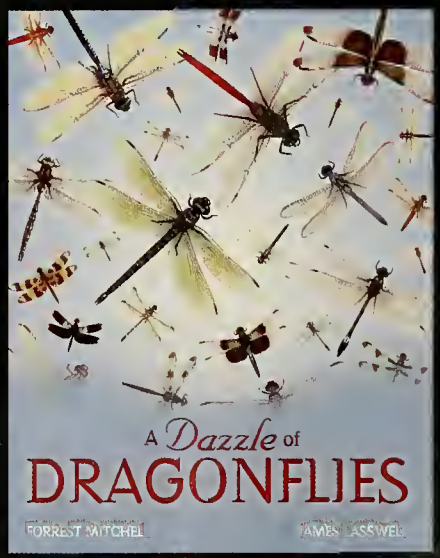

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Pet Peeve

I was disappointed by Josie Glausiusz's "Far From the Forests of the Night" [2/08], which implies that everyone interested in owning an exotic animal would raise it on Cheetos in their twelve-year-old's bedroom. The article fails to mention the thousands of responsible exotic-pet owners whose animals are in danger of being seized from their homes without trial and possibly euthanized. Sensationalized news reports of attacks perhaps lead people to believe that the only answer is to ban exotic-animal ownership. Unless Americans want a life completely cut off from the rest of the animal kingdom, blanket legislation is *not* the answer. Instead we should enforce existing laws and promote responsible, informed ownership.
Alyssa Elkins
East Brunswick, New Jersey

JOSIE GLAUSIUSZ REPLIES: I do not doubt that there are responsible owners of exotic cats who take good care of their animals—indeed, I quoted one of them, Matt Joseph, in my article. However, in my extensive reporting of this story, and in multiple interviews with both proponents and opponents of private ownership, I encountered many instances of tigers, lions, and other exotic felines being abandoned, abused, starved, tied up, or killed when owners could not (or would not) continue to care for them. Even those cats sheltered in the best conditions—in spacious enclosures where they are fed adequately and offered proper medical treatment—do not experience anything close to their natural habitat, where they may roam hundreds of square miles in search of prey. There is something rather sad, to my mind, about watching a magnificent wild beast pace back and forth behind a wire mesh, waiting hungrily for the highlight of its day—a dead chicken tossed over the fence, which it can neither hunt nor kill. Americans have many opportunities to interact with the animal kingdom, whether on farms, in zoos, at national parks and animal reserves, or at home with cats and dogs domesticated for millennia.

Something Fishy

It was with great interest that I read

"I recommend plenty of liquids."

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Neil Shubin's article "Fish Out of Water" [2/08]. As a pediatrician, I often deal with the evolutionary consequences of our fishy origins: inguinal hernias, blocked airways, and ear infections are just some of the anatomical hazards that my little patients face. Luckily, the evolution of human anatomy was accompanied by changes in behavior and society. Since we took to land, our fishy brains have evolved the intellectual ability to solve these problems and the emotional capacity to care.
Gabriel Berson, M.D.
Seattle, Washington

The course of the spermatic ducts in the human male is indeed complicated, but not so complicated as in the diagram that accompanies "Fish Out of Water." They join inside the pelvis, and the urethra downstream passes beneath the pubic bones. Get your ducts in a row!
Bart Saxbe
Williamstown, Massachusetts

THE EDITORS REPLY: We regret the error, which was not the author's. A corrected diagram is shown above.

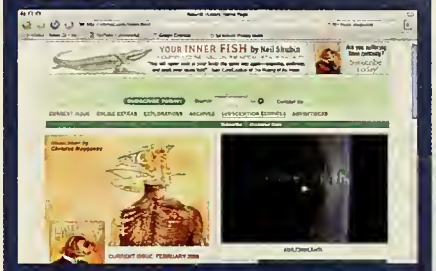
A Parasitic Moment

I was fascinated by Erin Espelie's description of the blow fly laying her eggs in the carrion flower *Stapelia gi-*

Continued on page 58

nature.net by robert anderson

CLASS ACT



ONE OF THE GREAT PROMISES of the Internet is that it provides schooling opportunities. Although face-to-face contact with teachers and fellow students may be lacking, age, location, and mobility are no barriers to access. For instance, my eleven-year-old son, who enjoys math and science, now takes calculus online from Stanford University. Formal enrollment in such programs isn't cheap. But more and more universities are putting some of their course content on the Web for free—minus the supervision and course credit. Please go to *Natural History*'s Web site (www.naturalhistorymag.com), where this month I review Internet sites offering college science courses from biology to physics.

ROBERT ANDERSON is a freelance science writer who lives in Los Angeles.

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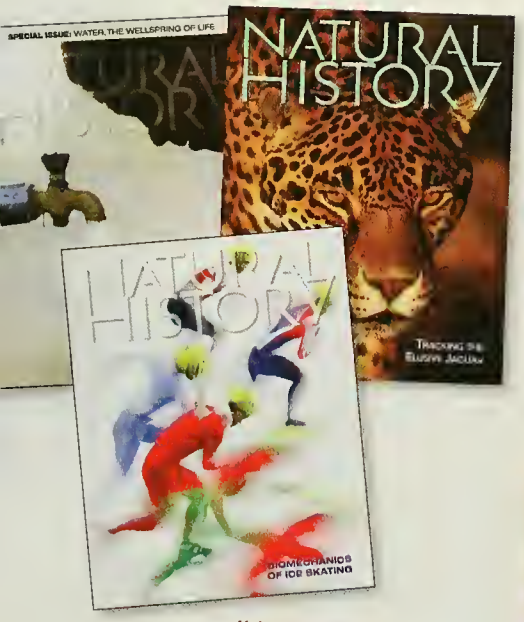

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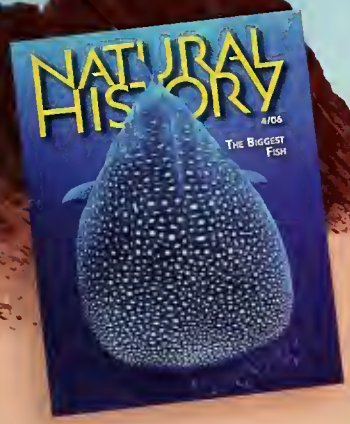

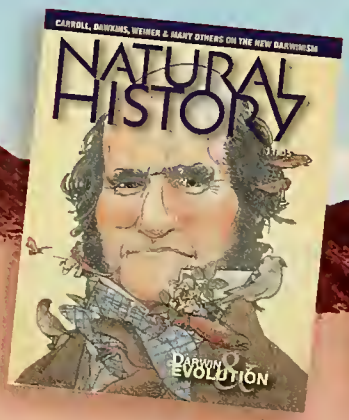

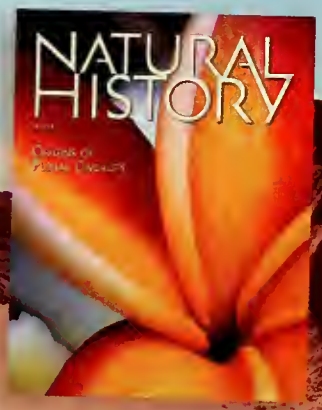

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FRANCESCO BLOISI–ELSEVIER/J. OF ARCHAEL. SCIENCE

Ancient sign at Herculaneum

The Roman town of Herculaneum in Italy was destroyed nearly two millennia ago, yet it still displays a relevant public-service announcement. The ancient sign, inked on plaster at the base of a city water tank, was deciphered in 1938 by the archaeologist Matteo Della Corte: "Anyone who wants to discharge dung in this place is warned that it is forbidden. If someone will denounce such behavior, free citizens will pay a fine and slaves will be lashed on place."

A memorable edict—but that wasn't all. Della Corte could see intriguing signs of an older message beneath it. He chipped away the plaster to reveal the hidden text, but without much success (and to the chagrin of future scholars, he obliterated the original).

Fast-forward to 2007. A team led by Lidia Falcone and Francesco Bloisi of the University of Naples Federico II turned to a more sophisticated, nondestructive method called near-infrared reflectography, which art historians use to detect drawings underneath paintings. Amazingly, the technique—never before applied to an archaeological site—revealed the destroyed text. It also exposed enough of the underlying inscription to deduce the meaning. It's more of the same: No dung, or else!

Such repetition makes good hygienic sense, since excrement and water supplies shouldn't mingle. Of course, volcanoes don't heed "No Dumping" signs. In 79 A.D., Mount Vesuvius buried Herculaneum and its neighbor, Pompeii, under layers of lava, mud, and ash, thus preserving the towns for future archaeologists to explore. (*Journal of Archaeological Science*) —*Stéphan Reebs*

STEVE VAN WINK

Cephalotes atratus *ants, one normal (left), the other parasitized (right)*

Caught Red-Bellied

Parasites are wicked little things. They can transform the appearance and behavior of their hosts, on occasion so radically that the infected hosts resemble an entirely different organism. But such extreme cases are exceptionally rare, and biologists who encounter them are fortunate indeed.

Stephen P. Yanoviak of the University of Arkansas at Little Rock and three colleagues recently made such a discovery. While studying black *Cephalotes atratus* ants in Panama, they spotted individuals with unusually bright-red abdomens, which the insects held high up in the air as they walked. The effect was dramatic: the red ants looked just like moving berries.

The investigators thought they had encountered intruders in the colony—ants previously described as a different species. Actually, however, they had discovered a new species altogether—not of ant, but of roundworm. Dissection revealed that the red ants were ordinary black *C. atratus* ants whose abdomens were jam-packed with hundreds of eggs of an undescribed parasitic roundworm. (The team named it *Myrmeconema neotropicum*.)

Yanoviak thinks the conspicuous berry-like abdomens make infected ants attractive to fruit-eating birds, which, after plucking them, become unwitting hosts and dispersers of the parasites. When worker ants feed bird droppings to their larvae, the young are infected and soon develop the berry-like abdomen, closing the cycle. (*The American Naturalist*) —*Graciela Flores*

Teen-Eggers

As modern birds and reptiles do, dinosaurs laid eggs. But in the timing—if not the packaging—of their reproduction, they seem to have been more like large mammals: a new study suggests they grew fast and bred early.

Andrew H. Lee and Sarah Werning, at the time both graduate students at the University of California, Berkeley, were counting growth lines in the fossil leg bones of a *Tenontosaurus* (a plant-eater) and an *Allosaurus* (a meat-eater), when they found medullary bone. A calcium-rich tissue that in female birds develops before ovulation to supply minerals for eggshells, medullary bone had been found in dinosaurs only once before—in a *Tyrannosaurus rex*.

The growth lines of the *Tenontosaurus*, *Allosaurus*, and *Tyrannosaurus* females revealed that at death they were just eight, ten, and eighteen years old, respectively, and at half their full size, they were still growing rapidly. Yet, as the medullary bone showed, they were sexually mature. That made them mere adolescents, considering their species lived to about age thirty.

Modern reptiles grow slowly and mature sexually before they reach full size; birds grow fast and reproduce only when they're done growing. Dinosaurs, it now appears, took neither approach. Rather, they resembled humans and other large mammals in their rapid growth and precocious sexual maturity—a strategy that indicates high death rates in babyhood and adulthood. (*PNAS*) —*G.F.*

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11. From RNA to Protein
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14. Mendel and His Pea Plants
15. How Sex Leads to Variation
16. Genes and Chromosomes
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The Dog's Meow

Humankind's two best friends don't always fight like cats and dogs, a new study shows. When living under the same roof, the alleged antagonists often get along swimmingly, in fact—especially if they're introduced at a young age.

Neta-li Feuerstein and her graduate advisor, Joseph Terkel of Tel Aviv University, surveyed 170 Israeli households with both a cat and a dog as pets. Two-thirds of the households reported an amicable relationship between the species. Indifference prevailed in a quarter, and less than a tenth reported fighting. Interspecies harmony was most likely if the cat was adopted before the dog and if the animals were introduced when the cat was younger than six months and the dog younger than a year.

What's more, Feuerstein and Terkel found that the animals learned to understand each other's body language—even those signals that convey opposite meanings for the two species. When a dog averts its head, for example, it normally expresses submission; but a cat's averted head can signal aggression. From video recordings of cat–dog interactions in forty-five of the households, Feuerstein and Terkel found that four times out of five, each animal reacted to its companion's behavior according to the other's native code. (*Applied Animal Behaviour Science*)

—*S.R.*

Hold the Crust

The Pacific is the biggest ocean on Earth, but it's getting smaller every day. Australasia and the Americas are inching closer together, and in about 350 million years the Pacific will effectively close. That's when plate tectonics—the process driving all that slow motion, and one that geologists have assumed to be continuous—may grind to a halt.

Plate tectonics is the movement of enormous sections of Earth's crust—the plates. New crust forms where plates separate on the seafloor, and existing crust sinks into the mantle when a neighboring plate overrides it at what's called a subduction zone. Today, most subduction zones are in the Pacific, and they'll vanish along with that ocean. Contrary to widespread opinion, others are unlikely to replace them elsewhere, say Paul G. Silver of the Carnegie Institution of Washington and Mark D. Behn of Woods Hole Oceanographic Institution in Massachusetts. That would stop plate tectonics worldwide—at least for a geological while.

Silver and Behn point to the Tethys Ocean, an ancient sea that shrank to nothing when squeezed by Africa and India drifting against Eurasia. The disappearing act spawned no new local subduction zones, showing that once lost, the zones aren't readily replaced.

Plate tectonics may have already taken a global hiatus 900 million years ago, when several continents collided to form the supercontinent Rodinia. The team says various geological indicators suggest that during Rodinia's 140-million-year existence, the world's plates were at a standstill. (*Science*) —*S.R.*

LANNA CHENG

Oceanic sea skater eats a fly in the lab.

Six Feet Under

Of the million-plus insect species alive today, only 1,400 or so—less than a quarter of 1 percent—inhabit the ocean. Of those, just five species, sea skaters of the genus *Halobates*, live on the high seas; the rest are coastal. That insects, otherwise remarkably successful and versatile creatures, have failed to gain much of a foothold in the rich marine environment has long puzzled biologists. In fact, the lack of footholds in the ocean may be precisely the problem.

Of the numerous explanations put forward over the years, the most convincing has been that the architecture of insects' breathing organs prevents them from diving deep to hide from predatory fish, as most small marine animals do. But Graeme D. Ruxton of the University of Glasgow and Stuart Humphries of the University of Sheffield in England disagree. A few freshwater bugs do survive at depth, they say, and many insects have evolved other effective anti-predator tactics, such as toxins.

Ruxton and Humphries propose instead that the lack of solid stuff in the open ocean is what has kept insects at bay. Most aquatic insects require surfaces—a rock, a stem, a blade of grass—as anchors for their eggs or places to dry their wings. But at sea, *Halobates* (which are wingless) must compete fiercely to lay eggs on even the odd scrap of flotsam. Insects simply seem to need more structure in their lives than the marine environment provides. (*Marine Ecology*)

—*Rebecca Kessler*

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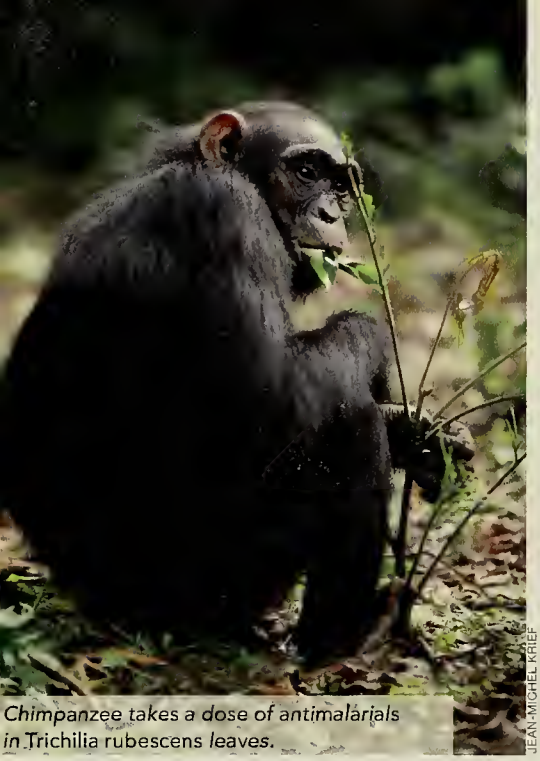

JEAN-MICHEL KRIEF

Chimpanzee takes a dose of antimalarials in Trichilia rubescens *leaves.*

SAMPLINGS

Take Once a Day, with Dirt

Many animals eat dirt once in a while—a practice called geophagy—but the chimpanzees of Kibale National Park in Uganda are unusually methodical about it. They down a small handful of soil almost every day, typically just before or after eating leaves of the tree *Trichilia rubescens*. Sabrina Krief, Noémie Klein, and François Fröhlich of the National Museum of Natural History in Paris knew that the leaves contain antimalarial compounds. But, they wondered, why add dirt?

To find out, the team exposed batches of crushed *T. rubescens* leaves, both with and without soil, to homemade digestive fluids in the lab. Then they tested the resulting mixtures against *Plasmodium falciparum*, the protozoan responsible for human malaria and a cousin of *P. reichenowi*, which similarly afflicts chimpanzees. The mixture with soil was nearly twice as potent as the leaves alone at killing the protozoans, they discovered. Krief, Klein, and Fröhlich think soil particles stick to the antimalarial compounds from the leaves and thus concentrate them in the digestive tract for better absorption.

The soil in the park may have medicinal properties on its own, too, because it contains kaolinite, a mineral that helps control diarrhea. (Indeed, the local village's traditional healer prescribes soil as a remedy for the condition.) But the French team says the antimalarial explanation is more persuasive: the chimps eat dirt almost daily, regardless of their digestive health. (*Naturwissenschaften*) —*S.R.*

THE WARMING EARTH

Want Ice in Your Water?

Ice is in retreat worldwide as glaciers melt, Arctic ice floes vanish, and Antarctic ice shelves break apart. Will all of it eventually disappear as the globe warms?

Not necessarily, say André Bornemann of the University of Leipzig in Germany and several colleagues. From sediment cores drilled out of the Atlantic seafloor, they retrieved fossils of tiny, shell-encased marine organisms called foraminifers that lived 91 million years ago during the Cretaceous Thermal Maximum, when tropical seas were about 12 Fahrenheit degrees warmer than they are today. The fossils' shells contained a high proportion of oxygen-18, an isotope that increases in the ocean relative to oxygen-16 when water evaporates from the sea and gets trapped on land as ice. The isotope data suggest that even during the hot spell, an ice sheet half the size of the current Antarctic ice cap existed—but where?

It couldn't have been near the North Pole, which the fossil record shows was then home to heat-loving crocodiles. Instead, Bornemann thinks the ice cap covered high mountain ranges near the South Pole. The warm weather prevailing elsewhere would have injected plenty of moisture into the air to fall as snow on high altitudes way down south.

But make no mistake. Compared with today, a lot of ice was missing back then, and sea levels were much higher—a history that seems to be on the verge of repeating itself. (*Science*) —*S.R.*

DR. ANDRE BORNEMANN

Fossil foraminifer magnified 220x

Protein Shake-up

Among the subtler effects of rising levels of carbon dioxide (CO_2) is that the crops of tomorrow won't be as nutritious as today's: high CO_2 concentrations reduce the protein yield of crop plants (for reasons that are still unclear).

A number of studies have examined the problem, but not always with the same experimental protocols or results. So Daniel R. Taub of Southwestern University in Georgetown, Texas, and two undergraduate students quantitatively analyzed the results of forty-four of those studies to determine the overall trend. They found that the CO_2 levels projected for the year 2100—roughly double what they are now—cause barley, rice, wheat, and potatoes to contain 10 to 15 percent less protein than they do today. Of the five crops the team considered, only soybeans will remain relatively unaffected, losing about 1 percent.

High CO_2 levels may already be causing plant-protein shortfalls. A few studies have reported lower protein levels in today's crops than in the crops of the 1950s and 1960s. Simply a characteristic of modern cultivars selected for high yields rather than nutritional content? Perhaps, but Taub's group suggests that mounting atmospheric CO_2 may share some of the blame. (*Global Change Biology*) —*S.R.*

Terraced rice fields grow in Japan.

Distinctive Destinations

TAKE A TRIP THIS YEAR TO FIND a tranquil refuge on a pastoral island, to combine outdoor adventure with memorable cuisine, or to delve into the past. On *Prince Edward Island*, you're invited to join a birthday party celebrating the island's famous fictional heroine Anne of Green Gables. Visit *Washington State* and follow up a trek through a rain forest with a meal of fresh seafood accompanied by a fine local wine. In *Delaware*, you can experience the First State's remarkable history through special archaeological exhibits and events. Take a journey to the West to find natural wonders and evocative reminders of the wild frontier.

Prince Edward Island

Prince Edward Island

Green Gables National Historic Site

The Gentle Island celebrates Anne's birthday and welcomes travelers to country pleasures and seaside relaxation

MANY TRAVELERS TO Prince Edward Island may have first been attracted to the pastoral charms of the "Gentle Island" as youngsters by reading the beloved classic Anne of Green Gables, set on the rolling farmland on the island's north central coast. This year, the island is celebrating the 100th anniversary of L.M. Montgomery's famous novel with tours, fairs, and other special events all around the island. Everyone is invited to Anne's year-long Centennial birthday party.

Time seems to stand still in Anne's Land, as that fabled part of the island is known, with its dreamy vistas of fields, orchards, and cozy farmhouses near the sea. You can stop at farmers markets or farmstands to buy apples or pears fresh from the orchards or even pick your own strawberries.

Green Gables, the simple farmhouse that inspired Montgomery, is now part of Prince Edward Island National Park, where there is something to do for everyone, from golf, birding and sea kayaking to strolling along its sandy beaches or taking a dip in the surprisingly warm coastal waters. Even the dunes here seem a bit otherworldly. On the Greenwich peninsula are large, mobile parabolic dunes that are rare in North America.

Finding your way around the island is part of the fun. You can kayak your way from inn to inn around the island or pedal your way by bicycle along the island's scenic country roads and follow up a day of adventure with some of the island's famous seafood. The oysters of Prince Edward Island are coveted by top restaurateurs, and the appellation P.E.I. is a guarantee of delicious shellfish.

The hustle and bustle of city life fall away, as the island begins to work its magic. Families with children will enjoy renting a cottage and trying out the many activities designed for children that abound here. Couples who want to get away from it all will find romantic inns and B&Bs, where the sea breezes and the sound of the waves soothe away any cares. Things haven't changed since L. M. Montgomery evoked the way the island touched a young girl. She wrote, "The beauty of it all thrilled Anne's heart."

Go to www.gentleisland.com/natural for more information.

Top: kayakers prepare to explore the Island's coast; fresh-picked vegetables at the farmers market

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Washington State

Jim Poth/Washington State Tourism

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Finding the best blend of scenery, culture and cuisine, from the cities and wild places of Washington state's Pacific coast to the wine country

THERE AREN'T MANY places in the world where you can follow a walk in the wilderness, a day of whale watching or a hike in a rain forest with a meal to remember. Washington state balances beautiful scenery with the civilized pleasures of food and drink. Whether they've just reached a mountaintop or plied the coastal waters, travelers are never far from great food and wine. And they're never far from a view.

Old growth timber in the Olympic Rain Forest

Even its cities are surrounded by mountain vistas. The Puget Sound region, the most populous part of the state, is an urban naturalist's paradise. With the Olympic Mountains to the west and the Cascades to the east, Seattle and the other cities of the region offer a unique combination of world-class scenery, culture and cuisine. Within easy reach are hiking, skiing, wildlife viewing, bicycling, and boating. Seattle, the Emerald City, is set on the waterfront, with snow-capped Mt. Rainier looming in the distance. Savor the local flavors prepared by some of the country's leading chefs and sample the city's cultural offerings as well by going to the opera, theater, ballet, symphony—or a ball game.

Over the Cascade Mountains to the east is the heart of Washington's wine country, where you'll find eight of the state's nine wine-growing regions. The names of these regions resonate with the area's history, its landscape and its vintages: Columbia Valley, Yakima Valley, Red Mountain, Walla Walla, Horse Heaven Hills, Wahluke, Rattlesnake Hills and Columbia Gorge. There is something rather thrilling in exploring the scenery of a region—its hills, mountains and valleys—and then partaking of the namesake fruits of its vines.

Jutting out from the northwest corner of the state is the Olympic Peninsula, a UNESCO Heritage site. More than ten rivers course through the peninsula, where rafters can watch otters playing in the current. Stretches of its coastline are among the wildest and most dramatic in North America, with panoramic mountain views and tidal pools. To the south is one of the world's few temperate rain forests, with its towering, moss-draped Sitka spruce and Western hemlocks. Complementing the peninsula's wild, natural beauty are the comforts of cozy lodges and Olympic Coast cuisine, with its famous Dungeness crab specialties.

You'll find that combination of outdoor adventure and comfort as well in the San Juan Islands, a sunny archipelago lying in protected waters between the western coast of Washington and Canada's Vancouver Island. Only a short trip from the cities of Puget Sound, the islands offer some of the best wildlife viewing and outdoor sports anywhere. It's difficult to choose between sea kayaking, bicycling, boating, scuba diving, mountain climbing and fishing. The Strait of Juan de Fuca, which borders the islands to the south, is considered the best place in the world to watch orcas in the wild. And you'll see bald eagles as well. And then, after a full day of adventure, enjoy the islands' waterfront restaurants and wine tastings.

Orca pod swimming in the San Juan Islands

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Delaware

The First State celebrates its archaeological heritage with special events and year-round exhibits at its museums and historic sites

History buffs can dig deep into Delaware's rich history and heritage this year at museums, festivals and on-site excavations. From early Native American life and fledgling European colonies to rip-roaring seafaring days and the federalist era, the First State has put its archaeological history on display.

In May, the state celebrates Delaware Archaeology Month, with special exhibits and events. (Go to **www.delawarearchaeology.org** for more information.) And all year round, the Delaware Archaeology Museum in Dover, the state capital, highlights more than 11,000 years of human habitation.

Just a short drive away toward the Delaware shore, in historic Lewes, is the Zwaanendael Museum, which showcases artifacts from the 1631 Dutch settlement predating the town, from the bombardment of the area in the War of 1812, and from an 18th century Royal Navy shipwreck. (Admission is free.)

Still more of Delaware's maritime past is on display at the nearby DiscoverSea Museum. The museum's collection of recovered artifacts from shipwrecks around the world is one of the largest in the Mid-Atlantic region. The items on display include gold and silver coins and china used aboard early sailing ships.

For a down-to-earth demonstration of the basics of archaeology, visit Greenbank Mills, northern Delaware's 300-year-old gristmill and 19th-century farm. Visitors can participate in a hands-on excavation at Greenbank's prepared archaeological site and work in an on-site archaeological lab.

Consult **www.VisitDelaware.com** or call 866-284-7483 for more information on visiting the First State.

Top: The rugged cast iron Delaware Breakwater Lighthouse in Lewes; right: Explore Delaware's rich history at the Delaware Archaeology Museum

The Journey West

Travel to the timeless West and follow in the footsteps of legendary Native American warriors, cowboys, outlaws, frontier lawmen, and explorers

In Montana's Missouri River Country, follow the trail of Lewis and Clark through a wild unspoiled landscape where herds of elk and antelope still roam. Then follow in the tracks of T-Rex or imagine a Triceratops lumbering along in Dinosaur Country.

Few places convey the legacy of the Wild West better than Cody Country, Wyoming, which is also the eastern gateway to Yellowstone Park. William F. "Buffalo Bill" Cody left his mark here, and you can still experience the traditions he showcased, including a Plains Indian Powwow.

In Arizona, you can envision what it was like when fearless explorer John Wesley Powell embarked on his epic journey through the Grand Canyon, emerging to tell the world of its glories and the rhapsodic music he heard from the Colorado River's rippling current.

Head south to Tucson, where the tall Saguaro cacti haunt the desert like signaling bandits. Pick up the trails of such legendary figures as Wyatt Earp, Pancho Villa and the great chief Cochise. You can imagine yourself an eye witness at OK Corral or a weary traveler finding refuge at graceful Mission San Xavier del Bac.

The magic of the West is that your sense of place keeps expanding into the distance, even as your sense of time seems to plunge back centuries and then eons, so that you're immersed in the vast sweep of history and grand vistas that surround you.

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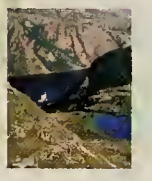

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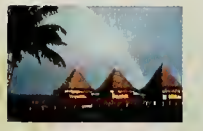
Japan & China aboard *Clipper Odyssey*	Apr 2009
North India aboard *New Palace on Wheels*	Sep 2009
Cambodia & Vietnam aboard *Mekong Pandaw*	Nov 2008
Indonesia aboard *Orion*	Oct 2009
Himalayan Kingdoms	Oct 2009



The Pacific

New Zealand aboard *Clipper Odyssey*	Jan 2009
Circumnavigation Australia by Plane	May 2009

World

Around the World by Private Jet	Feb 2009
Second Departure	Nov 2009
Vanishing Cultures by Private Jet	Sep 2009

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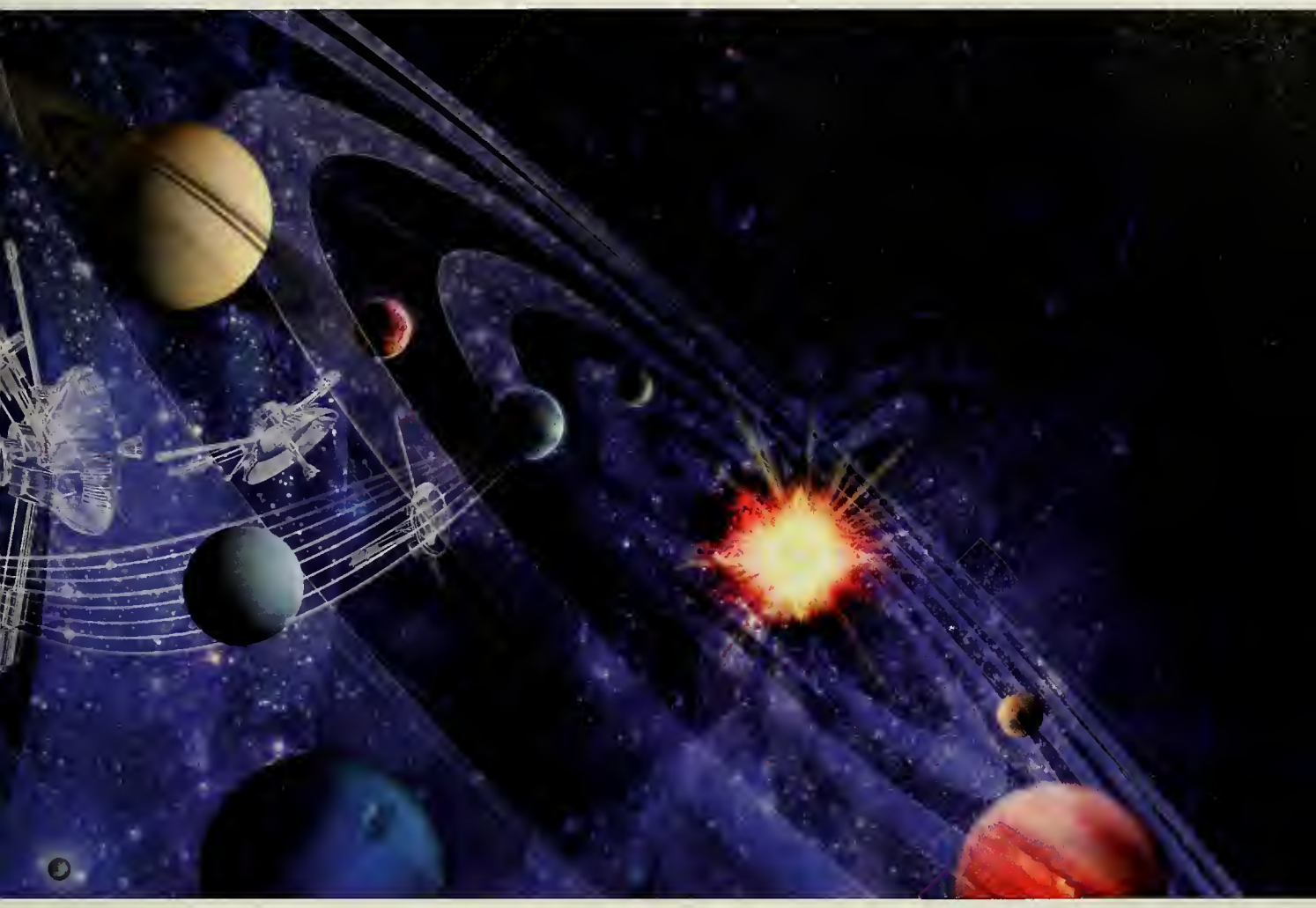
Spacecraft Behaving Badly

Something unexpected has been happening to a pair of distant space probes. Could strange new physics be the cause?

There's no sweeping it under the rug. NASA's twin *Pioneer 10* and *Pioneer 11* space probes, launched in the early 1970s and headed for stars in the depths of our galaxy, are both experiencing a mysterious, continuous force that is altering their expected trajectories. Calculations say the *Pioneers* should each be in a particular place, but the probes themselves have told us they're each someplace else—as much as a quarter million miles closer to the Sun than they're supposed to be.

That mismatch, known as the Pioneer anomaly, first became evident in the early 1980s, by which time the spacecraft were so far from the Sun that the slight outward pressure of sunlight no longer exerted significant influence over their velocity. Scientists expected that Newtonian gravity alone would thenceforth account for the pace of the *Pioneers*' journey. But things seemingly haven't turned out that way. The extra little push from solar radiation had been masking an anomaly. Once the *Pioneers* reached the point where the sunlight's influence was less than the anomaly's, both spacecraft began to register an unexplained, persistent change in velocity—a sunward force, a drag—operating at the rate of a couple hundred-millionths of an inch per second for every second of time the twins have been traveling. That may not sound like much, but it eventually claimed thousands of miles of lost ground for every year out on the road.



Contrary to stereotype, research scientists don't sit around their offices smugly celebrating their mastery of cosmic truths. Nor are scientific discoveries normally heralded by people in lab coats proclaiming "Eureka!" Instead, researchers say things like "Hmm, that's odd." From such humble beginnings come mostly dead ends and frustration, but also an occasional new insight into the laws of the universe.

Once the Pioneer anomaly revealed itself, scientists said, "Hmm, that's odd." So they kept looking, and the oddness didn't go away. Serious investigation began in 1994, the first research paper about it appeared in 1998, and since then all sorts of explanations have been proffered to account for the anomaly. Contenders that have now been ruled out include software bugs, leaky valves in the midcourse-correction rockets, the solar wind interacting with the probes' radio signals, the probes' magnetic fields interacting with the Sun's magnetic field, the gravity exerted by newly discovered Kuiper Belt objects, the deformability of space and time, and the accelerating expansion of the universe. The remaining explanations range from the everyday to the exotic. Among them is the suspicion that in the outer solar system, Newtonian gravity begins to fail.

The very first spacecraft in the Pioneer program—*Pioneer 0* (that's right, "zero")—was launched, unsuccessfully, in the summer of 1958. Fourteen more were launched over the next two decades. *Pioneers 3* and *4* studied the Moon; *5* through *9* monitored the Sun; *10* flew by Jupiter; *11* flew by Jupiter and Saturn; *12* and *13* visited Venus.

Pioneer 10 left Cape Canaveral on the evening of March 2, 1972—nine months before the Apollo program's final Moon landing—and crossed the Moon's orbit the very next morning. In July 1972 it became the first human-made object to traverse the asteroid belt, the band of rocky rubble that separates the inner solar system from the giant outer planets. In December 1973 it became the first to get a "gravity assist" from massive Jupiter, which helped kick it out of the solar system for good. Although NASA planned for *Pioneer 10* to keep signaling Earth for a mere twenty-

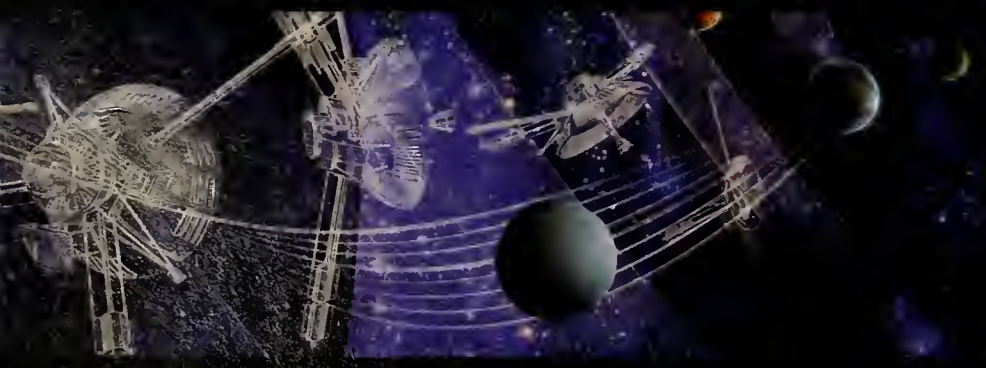
one months, the craft's power sources kept going and going—enabling the fellow to call home for thirty years, until January 22, 2003. Its twin, *Pioneer 11*, had a shorter signaling life, with its final transmission arriving on September 30, 1995.

At the heart of *Pioneers 10* and *11* is a toolbox-size equipment compartment, from which booms holding instruments and a miniature power plant project at various angles. More instruments and several antennas are clamped to the compartment itself. Heat-responsive louvers keep the onboard electronics at ideal operating temperatures, and there are three pairs of rocket thrusters, packed with reliable propellant, to help with alignments and midcourse corrections en route to Jupiter.

Power for the twins and their fifteen scientific instruments comes from radioactive chunks of plutonium-238, which drive four radioisotope thermoelectric generators, sensibly abbreviated RTGs. The heat from the slowly decaying plutonium, with its half-life of eighty-eight years, yielded enough electricity to run the spacecraft, photograph Jupiter and its satellites in multiple wavelengths, record sundry cosmic phenomena, and conduct experiments more or less continuously for upwards of a decade. But by April 2001 the signal from *Pioneer 10* had dwindled to a barely detectable billionth of a trillionth of a watt.

The probes' main agent of communication is a nine-foot-wide, dish-shaped antenna pointed toward Earth. To preserve the antenna's alignment, each spacecraft has star and Sun sensors that keep it spinning along the antenna's central axis in much the way that a quarterback spins a football around its long axis to stabilize the ball's trajectory. For the duration of the dish antenna's prolonged life, it sent and received radio signals via the Deep Space Network, an ensemble of sensitive antennas that span the globe, making it possible for engineers to monitor the spacecraft without a moment's interruption.

The famous finishing touch on *Pioneers 10* and *11* is a gold-plated plaque affixed to the side of the craft. The plaque includes an engraved illustration of a naked adult male and female; a sketch of the spacecraft itself, shown in correct proportion to the humans; and a diagram of the Sun's position in the Milky Way, announcing the spacecraft's provenance to any intelligent aliens who might stumble across one of the twins. (I've always had my doubts about this cosmic calling card. Most people wouldn't give their home address to a stranger in the street, even when the stranger is one of our own species. Why, then, give our home address to aliens from another planet?)



Space travel involves a lot of coasting. Typically, a spacecraft relies on rockets to get itself off the ground and on its way. Other, smaller engines may fire en route to refine the craft's trajectory or pull the craft into orbit around a target object. In between, it simply coasts. [*See "Universe" for June 2005, "Fueling Up," and July–August 2005, "Heading Out."*] For engineers to calculate a craft's Newtonian trajectory between any two points in the solar system, they must account for every single source of gravity along the way, including comets, asteroids, moons, and planets. As an added challenge, they must aim for where the target should be when the spacecraft is due to arrive, not for the target's current location.

Calculations completed, off went *Pioneers 10* and *11* on their multibillion-mile journeys through interplanetary space—boldly going where no hardware had gone before, and opening new vistas on the planets of our solar system. Little did anyone foresee that in their twilight years the twins would also become unwitting probes of the fundamental laws of gravitational physics.

Astrophysicists do not normally discover new laws of nature. We cannot manipulate the objects of our scrutiny. Our telescopes are passive probes that cannot tell the cosmos what to do. Yet they can tell us when something isn't following orders. Take the planet Uranus, whose discovery is credited to the English astronomer William Herschel and dated to 1781 (others had already noted its presence in the sky but misidentified it as a star). As observational data about its orbit accumulated over the following decades, people began to notice that Uranus deviated slightly from the dictates of Newton's laws of gravity, which by then had withstood

a century's worth of testing on the other planets and their moons. Some prominent astronomers suggested that perhaps Newton's laws begin to break down at such great distances from the Sun.

What to do? Abandon or modify Newton's laws and dream up new rules of gravity? Or postulate a yet-to-be-discovered planet in the outer solar system, whose gravity was absent from the calculations for Uranus's orbit? The answer came in 1846, when astronomers discovered the planet Neptune just where a planet had to be for its gravity to perturb Uranus in just the ways measured. Newton's laws were safe . . . for the time being.

Then there's Mercury, the planet closest to the Sun. Its orbit, too, habitually disobeyed Newton's laws of gravity. Having predicted Neptune's position on the sky within one degree, the French astronomer Urbain-Jean-Joseph Le Verrier now postulated two possible causes for Mercury's deviant behavior. Either it was another new planet (call it Vulcan) orbiting so close to the Sun that it would be well-nigh impossible to discover in the solar glare, or it was an entire, uncataloged belt of asteroids orbiting between Mercury and the Sun.

Turns out Le Verrier was wrong on both counts. This time he really did need a new understanding of gravity. Within the limits of precision that our measuring tools impose, Newton's laws behave well in the outer solar system. However, they break down in the inner solar system, where they are superseded by Einstein's general relativity. The closer you are to the Sun, the less you can ignore the exotic effects of its powerful gravitational field.

Two planets. Two similar-looking anomalies. Two completely different explanations.

Pioneer 10 had been coasting through space for less than a decade and was around 15 AU from the Sun when John D. Anderson, a specialist in celestial mechanics and radio-wave physics at NASA's Jet Propulsion Laboratory (JPL), first noticed that the data were drifting away from the predictions made by JPL's computer model. (One AU, or astronomical unit, represents the average distance between Earth and the Sun; it's a "yardstick" for measuring distances within the solar system.)

By the time *Pioneer 10* reached 20 AU, a distance at which pressure from the Sun's rays no longer mattered much to the trajectory of the spacecraft, the drift was unmistakable. Initially Anderson didn't fuss over the discrepancy, thinking the problem could probably be blamed on either the software or the spacecraft itself. But he soon determined that only if he added to the equations an invented force—a constant change in velocity (an acceleration) back toward the Sun for every second of the trip—would the location predicted for *Pioneer 10*'s signal match the location of its actual signal.

Had *Pioneer 10* encountered something unusual along its path? If so, that could explain everything. Nope. *Pioneer 11* was heading out of the solar system in a whole other direction, yet it, too, required an adjustment to its predicted location. In fact, *Pioneer 11*'s anomaly is somewhat larger than *Pioneer 10*'s.

Faced with either revising the tenets of conventional physics or seeking ordinary explanations for the anomaly, Anderson and his JPL collaborator Slava Turyshev chose the latter. A wise first step. You don't want to invent a new law of physics to explain a mere hardware malfunction.

Because the flow of heat energy in various directions can have unexpected effects, one of the things Anderson and Turyshev looked at was the spacecraft's material self—specifically the way heat would be absorbed, conducted, and radiated from one surface to another. Their inquiry managed to account for about a tenth of the anomaly. But neither investigator is a thermal engineer. A wise second step: find one. So in early 2006 Turyshev sought out Gary Kinsella, a JPL colleague who until that moment had never met either him or a *Pioneer* face to face, and convinced Kinsella to take the thermal issues to the next level. Last spring, all three men came to the Hayden Planetarium in New York City to tell a sellout crowd about their still-unfinished travails. Meanwhile, other researchers worldwide have been taking up the challenge too.

Consider what it's like to be a spacecraft living and working hundreds of millions of miles from the Sun. First of all, your sunny side warms up while the unheated hardware on your shady side can plunge to 455 degrees below zero Fahrenheit, the background temperature of outer space. Next, you're constructed of many different kinds of materials and have multiple appendages, all of which have different thermal properties and thus absorb, conduct, emit, and scatter heat differently, both

Clockwise starting top left: Caño Negro Wildlife Refuge; Tortuguero Park Canal Cruise; White Faced Monkey; Keel Billed Toucan; Manuel Antonio Park; Rainforest Hike

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within your various cavities and outside to space. In addition, your parts like to operate at very different temperatures: your cryogenic science instruments do fine in the frigidity of outer space, but your cameras favor room temperature, and your rocket thrusters, when fired, register 2,000 degrees F. Not only that, every piece of your hardware sits within ten feet of all your other pieces of hardware.

The task facing Kinsella and his team of engineers was to assess and quantify the directional thermal influence of every feature on board *Pioneer 10*. To do that, they created a computer model representing the spacecraft surrounded by a spherical envelope. Then they subdivided that surface into 2,600 zones, enabling them to track the flow of heat from every spot in the spacecraft to and through every spot in the surrounding sphere. To strengthen their case, they also hunted through all available project documents and data files, many of which hail from the days when computers relied on punch cards for data entry and stored data on nine-track tape. Without emergency funds from the Planetary Society, by the way, those irreplaceable archives would shortly have ended up in a dumpster.

For the simulated world of the team's computer model, the spacecraft was placed at a test distance from the Sun (25 AU) and at a specific angle to the Sun, and all the parts were presumed to be working as they were supposed to. Kinsella and his crew determined that, indeed, the uneven thermal emission from the spacecraft's exterior surfaces does create an anomaly—and that it is indeed a continuous, sunward change in velocity.

But how much of the Pioneer anomaly can be chalked up to this thermal anomaly? Some. Perhaps even most. But not all. The team's thermal model was based solely on the trajectory and hardware data from *Pioneer 10*, which displays a smaller anomaly than that of *Pioneer 11*. Not only that, the researchers have yet to calculate how the thermal anomaly varies with *Pioneer 10*'s (let alone *Pioneer 11*'s) distance from the Sun.

So what about the as-yet-unexplained "not all" portion? Do we sweep it under the cosmic rug in hopes that additional Kinsellan analysis will eventually resolve the entire anomaly? Or do we carefully reconsider the accuracy and inclusiveness of Newton's laws of gravity, as a few zealous physicists have been doing for a couple of decades?

Pre-*Pioneers*, Newtonian gravity had never been measured—and was therefore never confirmed—with great precision over great distances. In fact, Slava Turyshev, an expert in Einstein's general relativity, regards the *Pioneers* as (unintentionally) the largest-ever gravitational experiment to confirm whether Newtonian gravity is fully valid in the outer solar system. That experiment, he contends, shows it is not. As any physicist can demonstrate, beyond 15 AU the effects of Einsteinian gravity are negligible. So, at the moment, two forces seem to be at play in deep space: Newton's laws of gravity and the mysterious Pioneer anomaly. Until the anomaly is thoroughly accounted for by misbehaving hardware, and can therefore be eliminated from consideration, Newton's laws will remain unconfirmed. And there might be a rug somewhere in the cosmos with a new law of physics under it just waiting to be uncovered.

Astrophysicist NEIL DEGRASSE TYSON *is the Frederick P. Rose Director of the Hayden Planetarium at the American Museum of Natural History. In 2007* Time *named him one of the world's 100 most influential people.*

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SWEETDREAMS

IN WHICH AN **AMERICAN BIOLOGIST** FOLLOWS THE TRAIL OF **HONEY ANTS** TO AUSTRALIA AND **MEETS PEOPLE** WHO CAN TEACH HIM ABOUT AN **ANCIENT TREAT**.

BY JOHN R. **CONWAY**

Storage ants, known as repletes, hang within a carefully exposed chamber of a honey-ant nest. Their distended abdomens contain sugars, water, and other nutrients collected by workers in the colony, to be regurgitated in times of shortage.

IN THE 1970S, WHEN I WAS JUST A graduate student in biology at the University of Colorado in Boulder, my Ph.D. advisor offhandedly mentioned he needed some preserved honey ants to trade to ant specialists in other parts of the world. Some readers of this magazine may have previously encountered photographs of the bloated storage ants called *repletes,* and may even have heard that in some traditional cultures they are considered a delicacy. But back then I knew none of that. "What is a honey ant?" I asked.

I was quickly informed that honey ants store nectar, just as honeybees do (indeed, both ants and bees are members of the order Hymenoptera). But honey ants store their nectar in the living bodies of repletes, worker ants that hang from the ceilings of domed chambers in the underground nest and are filled with nectar collected by other workers in the colony. The organ that serves as a transport vessel for the collectors as well as a storage jar in the repletes is the crop, a part of the foregut that can expand to fill most of the gaster, the bulbous part of the abdomen. In a normal ant the gaster is covered by overlapping plates of exoskeleton, but in a replete the gaster swells to the size of a grape, and the plates appear as small islands on a membranous sea [*see photograph on opposite page*].

During times of scarcity, repletes regurgitate nectar to colony members, an especially valuable asset in arid environments. There are at least six genera of honey ants in the world, including four with less extreme kinds of repletes, and the indications are that the adaptation arose among them independently. My naïve question, "What is a honey ant?" launched me into investigating a North American honey ant with the impressive name *Myrmecocystus mexicanus hortideorum* McCook. The genus name means "cyst- or sac-like ant," the species name refers to its distribution in Mexico and the southwestern United States, and the subspecific name is Latin for Garden of the Gods, a park near Colorado Springs for which Rev. Henry McCook named the subspecies in 1882. Later I shifted my research to the Southwestern Research Station of the American Museum of Natural History, near Portal, Arizona, where several other species of *Myrmecocystus* can be found. And intrigued by accounts of similar ants in the Northern Territory of Australia, I traveled there to study the black honey ant, *Camponotus inflatus*. That species was first described in 1880 by the English naturalist John William Lubbock from specimens sent to him from Australia.

One reason I was drawn to study honey ants in Australia was to learn what Aboriginal peoples of that continent knew about the insects, and to see if and how they used the "honey." Historical records tell us that native peoples in North America consumed honey ants. The Aztecs, for example, who called the honey ant *nequazcatl,* dug up repletes and nipped off the honey-filled gasters with their teeth. The Aztecs and other Mexican peoples reportedly also pressed repletes, and used the honey to sweeten food, to treat diseases, or to make a fermented alcoholic drink for religious ceremonies. But the opportunities to observe traditional uses in North America are now past.

TO ME AUSTRALIAN HONEY ANTS SEEM A BIT SWEETER THAN AMERICAN ONES, BUT BOTH TASTE LIKE MOLASSES WITH AN OCCASIONAL TOUCH OF FORMIC ACID.

ON MY FIRST VISIT TO CENTRAL Australia, I camped in the outback with an Aboriginal family near Alice Springs, and they showed me how they locate not only honey ants, but also other bush foods such as monitor lizards, witchetty grubs, and water-holding frogs. Later I benefited from the guidance of other experts knowledgeable in Australian honey-ant biology and Aboriginal ethnography. Among my most memorable experiences was leading three Earthwatch expeditions, on each of which some twenty-five enthusiastic volunteers paid their way to assist in scientific field research.

The first two Earthwatch groups worked on the Hamilton Downs cattle station thirty miles from Alice Springs, mapping the distribution of black honey ant nests, excavat-

Repletes of the black honey ant, Camponotus inflatus, a species of central Australia, are helpless when their nest is exposed.

ing one of them, and observing how the ants foraged in a mulga grove. (A variable species of *Acacia*, mulga grows as a shrub or small tree; it is well adapted to arid conditions.) Excavated ants were counted, measured, and weighed in our makeshift field lab. The volunteers became familiar with the pungent odor of formic acid sprayed by angry worker ants and the molasses-like smell of repletes unlucky enough to burst when dislodged by our digging. The second expedition excavated a colony of another species as well, the red honey ant, *Melophorus bagoti,* in Alice Springs. Repletes of that species are smaller and more mobile. The third expedition excavated a second *C. inflatus* nest, and an unexpected bonus was finding, at its periphery, a nest of a third type of honey ant, *Plagiolepis squamulosa,* with very small, turgid repletes. The third group of volunteers also devoted much of the time to working with Aboriginal women from the Mutitjulu community in Uluru–Kata Tjuta National Park to learn how they locate and excavate nests (Uluru is the Aboriginal name for what Westerners called Ayers Rock, which is now known as Uluru/Ayers Rock).

The expeditions provided the means to compare Australian *C. inflatus* honey ants with their North American counterparts, *M. mexicanus,* an ocean away. They are, in fact, broadly similar. In comparison with other honey-ant species, both have large repletes. Repletes, which may make up as much as a fifth or more of a nest population, usually develop from workers two weeks after they emerge from pupae, and for a long time it was believed that only such young workers had exoskeletons pliable enough to undertake the job. But repletes can also form from mature workers. They usually develop from the largest workers in a colony, which has the evolutionary advantage of minimizing the number of workers taken away from other tasks. In experiments with laboratory colonies, other investigators have found that when all repletes are removed, new ones rapidly develop from the next largest workers.

When fully distended, repletes of both species do not fit through passageways and are imprisoned in the nest for life. If they are dislodged from their perches, they burst or lie on the floor, legs flailing helplessly in the air. Both Australian and American honey-ant colonies may also contain repletes that are not fully distended—some still in the process of expanding, others whose flaccid, misshapen gasters show they have recently been drained of their precious liquid.

The color of repletes ranges from dark amber to nearly clear, apparently indicating differences in the products stored, and the percentages of different-colored repletes vary from nest to nest. The honey in dark amber American repletes is rich with glucose, fructose, and traces of sucrose, while the liquid in clear ones (which we found make up from 0.2 to 2 percent of the replete population) is more dilute, and sucrose is the main sugar. Opaque, milky-colored repletes, which accounted for 12.4 percent of the replete population in one Arizona nest, contained higher concentrations of protein and lipids, likely stored from consumption of insects. *M. mexicanus* commonly scours its territory for dead insects and other arthropods and occasionally attacks small insects to feed its larvae. Although we did not observe that behavior in the Australian ant, Aboriginal women said the ants gather grubs on mulga leaves and feed them to the larvae.

***M. MEXICANUS* USUALLY NESTS ON TOP** of ridges or mesas, which in the Colorado Springs area fall between about 5,500 and 7,100 feet. *C. inflatus* excavates its nests at lower elevations, such as on the flat red

sandy plains where mulga trees grow. The trees provide nectar, insect prey, and shelter from high temperatures and evaporation, but one mystery is why honey ants seem to be concentrated in certain patches of mulga—typically mature ones—and not others. Perhaps those are undisturbed stands where a mutualistic relationship has progressed. Australian ants commonly feed on nectaries at the base of the mulga tree's needlelike "leaves" (which are modified petioles). In many plants such nectaries attract ants, which reciprocate by defending the plant from herbivorous insects and other animals.

IF THE STORAGE ANTS, KNOWN AS REPLETES, ARE DISLODGED FROM THEIR PERCHES, THEY BURST OR LIE ON THE CHAMBER FLOOR, LEGS FLAILING HELPLESSLY.

Entrances to American and Australian nests are quite different. The *M. mexicanus* entrance, often found in a small clearing, is usually a single round opening in the crater of what looks like a miniature gravel volcano. Australian nests lack the volcanic cone, and have either a single hidden entrance or multiple entrances in thatch under the canopy of mulga trees. Full excavations of two nests from each species suggest *M. mexicanus* colonies are somewhat larger, with populations of 4,968 and 5,029 compared with 1,063 and 4,019 for *C. inflatus* colonies. The Australian nests extended farther horizontally, however—more than seven feet in one case compared with two feet or less for the American species. The chambers in Australian nests were likewise scattered over a larger area and radiated from several vertical passages, not from one as in the American species. The maximum nest depths of our excavated nests were similar (about five and a half feet), though other investigators have reported depths up to thirteen feet for *M. mexicanus,* and similar depths may yet be found in Australia. In both species, the chambers for repletes, with rough arched ceilings to anchor the pendulous honeypots, lay at least seven or eight inches under the surface, providing protection along with stable temperature and humidity.

Both species gather nectar from a variety of sources. American honey ants feed on almost any nectar-producing plant in their habitat, but in Colorado they feed primarily on nonfloral sources such as scrub oak galls.Those are sugar-secreting growths on trees obligingly triggered by a fellow hymenopteran, the gall wasp [*see photograph on next page*]. Occasionally the ants also collect honeydew from aphids on yucca capsules. The gasters of the foraging workers often become so distended after feeding that they have to waddle home with their burden. Australian ants

North American honey ants of the species Myrmecocystus mexicanus are native to Mexico and the Southwest of the United States. The clear abdomens in these two specimens suggest they contain mostly water, a crucial resource in their arid habitat.

feed on the mulga nectaries and on lerp, a red, sugary scale that is produced as a protective cover by a sap-sucking insect known as a psyllid.

Both American and Australian honey ants seem to be subordinate competitors in the ant world. Other ant species chased Australian honey ants away from bee honey we placed close to their nest entrances. In Arizona, observers have reported seeing ants of the species *Conomyrma bicolor* prevent honey ants from foraging by surrounding the nest and dropping stones into the entrance! Colonies of the North American honey ant *M. mimicus,* which feeds on termites, often have overlapping foraging grounds, and they conduct ritualized confrontations to defend their turf. The adversaries communicate their strength by assembling in force and by engaging in various postures and nonlethal contact, such as pushing. When one colony is stronger, the "tournament" ends and the weaker colony is raided—the first reported example of within-species slavery in ants.

M. mexicanus worker feeds on a scrub oak gall, a nectar-secreting tree growth whose development is triggered by the gall wasp.

ALTHOUGH AT LEAST THREE SPECIES of honey ant live in central Australia, only repletes of the black honey ant reach maximum plumpness and are commonly used by Aboriginal people. Several tribal groups, including the Anmatyerre and the Alyawarre, have names for *C. inflatus,* but *yerrampe,* the name used by the Aranda, is probably the most common. Women at Uluru National Park, most of whom are members of the Pitjantjatjara tribe, taught me various terms that show their awareness of the ant's castes and life cycle. Women at Uluru reported in detail the sources of nectar stored in repletes: corkwood blossoms, yellow mulga flowers, red *Eremophila latrobei* flowers, and lerp. Nevertheless, in some respects their knowledge proved incomplete or inaccurate. For example, although some understood that repletes regurgitate to nourish workers, others thought that workers bite the swollen gasters. Uluru women also believed workers start new nests and did not seem to know that only queens produce eggs. Confusion between workers and queens is understandable, since in this species the queens resemble large workers. That may also explain why the women never appeared concerned that excavation of the nests might deplete the resource, since workers would always be left to carry on.

It is usually the women who locate and excavate nests, and young girls learn the skill from older, more experienced women. Equipped with digging sticks, shovels, and wooden dishes, a small group of women with their children will spread out in a mulga grove, scanning the ground and moving aside leaf litter to search for the nest entrance or worker ants. Once a nest is found, one or two women will excavate it. Sometimes inserting a stick in the entrance as a guide, the excavator clears the ground to one side of the entrance and digs a pit. Feeling and smelling the soil and noting its color, she examines the opened nest for clues to the location of repletes, then delicately scrapes away earth with the digging stick to expose a chamber. Excavating from the side avoids breaking into a chamber from above and destroying the hanging repletes. She then removes repletes carefully with a twig or her fingers, so that few are damaged.

When the supply at one nest dwindles, a woman will search for another. This probably helps preserve the species, since queens and workers carrying brood usually retreat deep into the nest when the colony is disturbed. They can then rebuild and repopulate the nest. In the Anmatyerre view one cannot come to the "end" of a honey-ant nest, because it extends to the very heart of the Earth. Other Aborigines may be afraid to dig too deep because they believe the queen is a snake at the bottom of the nest.

Usually repletes are eaten one by one as a sweet delicacy: formerly they were one of the few sweet wild foods in the desert. The number of repletes recovered from excavations varies. One report said there were not enough to provide one for each person in the group, but my guide, Jakamara, said each person might eat fifty repletes. It is

A dish of M. mexicanus *repletes provides a concentration of sugars, much as bee honey does. Such a natural resource was highly prized in some traditional cultures.*

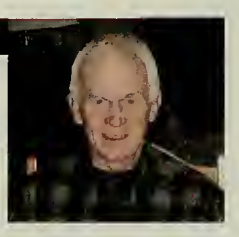
usually done by holding the head and thorax between two fingers and biting off the grape-size gaster. It has been reported that Aborigines prefer dark repletes to light ones. To me Australian repletes are somewhat sweeter than the American kind, but both taste like cane molasses with an occasional touch of formic acid.

Others report Aborigines using replete honey to sweeten seed cakes or to make a sweet dough for bread. According to one investigator, young women decorated their hair with bloodwood seeds sealed with honey. Aborigines have also been recorded to make a drink called *ilpirla* by mixing the honey with water in their shields. Now that modern sweets are available, Aborigines view honey-ant digging more as a picnic with a purpose, an opportunity for a mother to teach her children their way of life and customs.

Nevertheless, honey ants still figure prominently in the mythology of some Aboriginal groups. The Dreamtime is the mythic time of creation, an era filled with the adventures, discoveries, and explorations of such creator beings as Kangaroo, Shark, Honey Ant, Emu, and so on. All animals, plants, and topographical features result from the activities of these spirit ancestors. Each plant and animal has a Dreaming—the story of its creation and its importance in the lives of the people. Songs and myths record the place where the food is found and the correct time for collection. Elaborate ceremonies were performed in some tribes of central Australia to ensure an abundance of honey ants in the coming season. I was told honey-ant ceremonies, rituals, and paintings are still practiced at localities not far from Alice Springs.

Aborigines have depicted honey ants for thousands of years in their ground mosaics (large ground paintings incorporating decorated mounds and standing sacred objects), cave paintings, and body paintings. And in the early 1970s, Geoff Bardon, a teacher at Papunya, a government settlement for displaced Aborigines west of Alice Springs, encouraged men to re-create ground mosaics on canvas using acrylic paints in traditional colors. Such paintings have attained wide appreciation. Each clan can depict Dreamtime stories associated with its totemic ancestors. Most of the art is abstract and geometric, with circles, arcs, lines, dots and animal tracks predominating. Although symbols may have a multiplicity of meanings, those for particular ancestors, such as the honey ant, are widely recognized. Today Aboriginal paintings, T-shirts, and postcards depicting honey-ant dreaming are sold to tourists. But above all, the designs, along with ceremonies, foods, and stories, link Aboriginal peoples to each other and to the native sweetness of their homeland—the honey ant.

Aboriginal portrayal of honey ants



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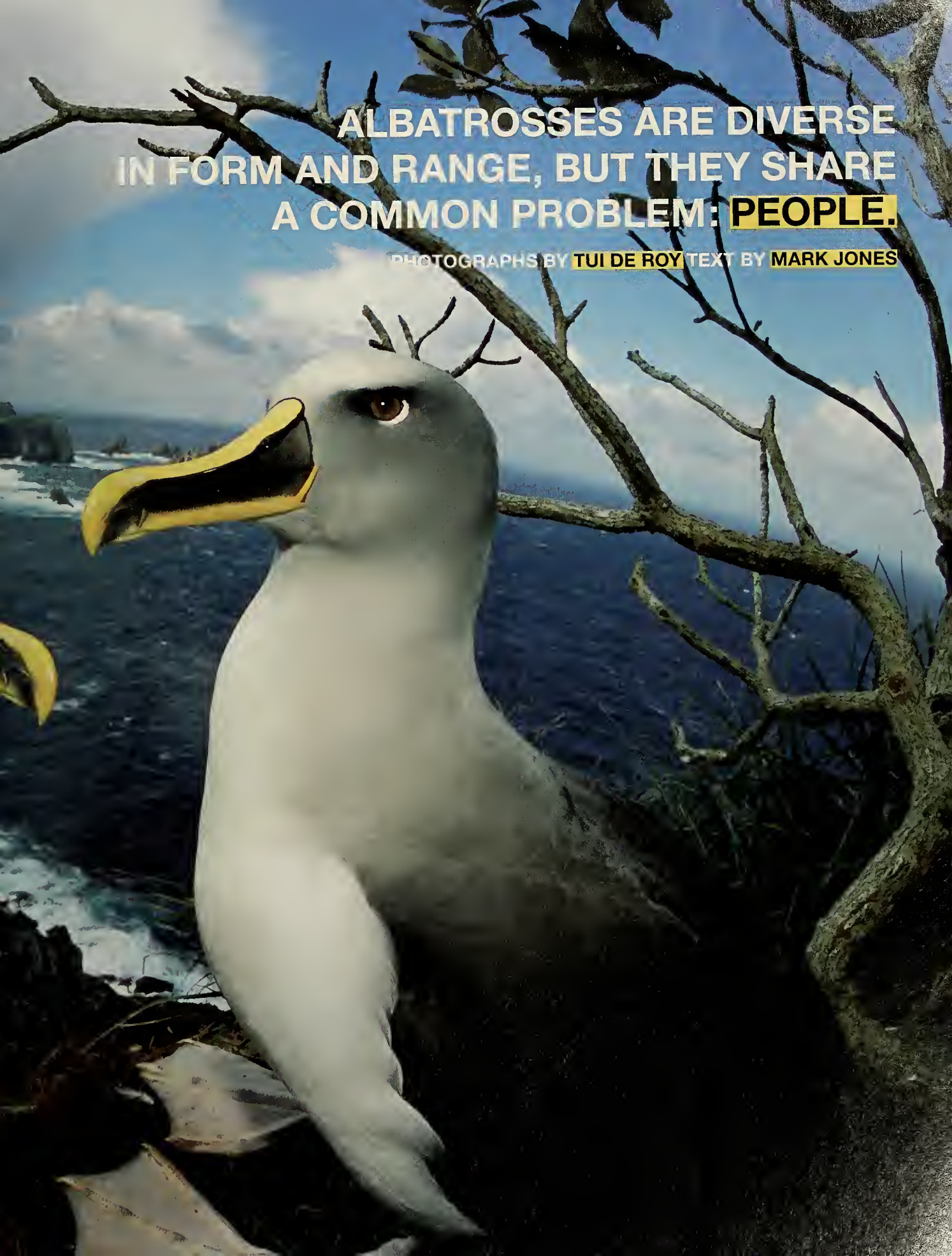
AROUND THEIR NECKS

Mated pair of Buller's albatrosses (Thalassarche bulleri) nest on the cliffs of an island in the Snares archipelago, about 120 miles south of mainland New Zealand. The birds usually choose a mate when they're eight years old or so, and stay with their partner for life—several decades more.



ALBATROSSES ARE DIVERSE IN FORM AND RANGE, BUT THEY SHARE A COMMON PROBLEM: PEOPLE.

PHOTOGRAPHS BY TUI DE ROY TEXT BY MARK JONES

No self-respecting birdwatcher should mistake an albatross for a pelican, right? Yet etymologists can trace the word *albatross* back through the annals of early seafarers' logbooks—*albitross . . . algatross . . . alcatrass*—to a Portuguese word, *alcatráz*, which was used for a variety of large seabirds. And alcatráz, a word now famous as the name of the old island prison in San Francisco Bay, probably came from an Arabic term, *al-câdous,* or "bucket"-mouthed bird—the pelican. Pelicans, though, never venture far beyond the coasts and live to perhaps twenty years of age. Albatrosses live forty to sixty years and are adapted to the open ocean—with special salt-excreting glands that enable them to drink seawater; well-developed olfaction for tracking down food; and superb navigation skills that guide them back to isolated specks of land for breeding.

Although a pelican and an albatross can hardly be confused, even the sophisticated birdwatcher may find it a challenge to distinguish among all twenty-two albatross species (the number currently recognized by the World Conservation Union, also known as the IUCN). Those species fall into four genera that fly the gamut in size, appearance, distribution, and population: the great albatrosses (*Diomedea*, six species); the mollymawks (*Thalassarche*, ten species); the North Pacific albatrosses (*Phoebastria*, four species); and the sooty albatrosses (*Phoebetria*, two species). Since the mid-1990s ornithologists have been using molecular data for further classification, but haven't yet reached a consensus. What is certain, however, is that people have taken a toll on the entire family, the Diomedeidae. Every species of albatross is currently included on the IUCN Red List of Threatened Species, with ten facing the highest risk of extinction in the Endangered and Critically Endangered categories.

Courtship display of waved albatrosses (Phoebastria irrorata) on Española Island in the Galápagos involves elaborate sequences of gaping, bowing, bill-fencing, and sky-pointing, accompanied by loud screams, moans, and sighs. Averaging seven to nine pounds, this mid-size albatross species is critically endangered. Estimated at 35,000 individuals in 2001, the population appears sharply on the decline, with recent studies indicating a drop in the birds' average life expectancy.

Long before our forebears were naming them or having any effect on them, albatrosses were riding the winds and waves. The earliest fossils of recognizable albatrosses and their closest kin, the petrels, date back some 32 million years, and come from places as disparate as modern-day South Carolina and Germany. At least 9 million years ago, genera very similar to living species were ranging over the Southern Ocean, the North Pacific, and the North Atlantic.

Albatrosses are found today throughout the southern oceans, but in the Northern Hemisphere they are limited to North Pacific waters. Fossil evidence suggests that most species may have disappeared from the North Atlantic during the time period when the North and South American continents became connected by the Isthmus of Panama, about 3.7 million years ago. These days when southern individuals occasionally stray into North Atlantic skies they can get stranded there, in confusion.

The majority of albatross colonies are located far south of the equator, on the remotest islands in the inhospitable, uninhabited reaches of the Southern Ocean. Colonies in the tropical and subtropical latitudes of the North Pacific, though, are more easily accessible to people and have been greatly impacted by that exposure. Around the turn of the twentieth century, an international demand for plumes fuelled major depredations on three species inhabiting Japanese and Hawaiian islands—the short-tailed, black-footed, and Laysan albatrosses. During boom years, crews of as many as 300 men and women worked their way from one colony to another. The term "featherweight" took on a different meaning as 383 tons of feathers were exported in the peak years of 1908 to 1911. Over a period of three decades at least 5 million short-tailed albatrosses were killed.

Fowling, such as it was known, was banned by Japan in 1906, yet it continued illegally in Japanese waters—and elsewhere—for many years afterward. The birds have also succumbed to less deliberate assaults. In the late 1930s, Midway, a sandy atoll in the Hawaii archipelago, was bulldozed and partly paved over with concrete to become a U.S. naval air base, which would be crucial for transpacific wartime flights. The atoll was an important nesting ground for the Laysan albatross [*see photograph at right*], and collisions between birds and planes became a major hazard

Raising at most one hatchling each year, albatrosses intensively nurture their offspring for several months. If even one parent is killed at sea during that time the chick will starve. Top: Grey-headed albatross (Diomedea chrysostoma) feeds its chick on Campbell Island, 400 miles south of mainland New Zealand. Middle left: A young black-footed albatross (Phoebastria nigripes) nibbles on a typical meal of a fish's egg sac, regurgitated by its parents. Middle right: Chatham albatross chick (Thalassarche eremita) sits atop its mud nest tucked in a crevice on "The Pyramid," a four-acre island east of mainland New Zealand that is their only breeding site, the smallest of any species. Bottom: Laysan albatross pair (Phoebastria immutabilis) guard their chick on Midway Atoll in the Hawaii archipelago.

Male and female Gibson's wandering albatross (Diomedea gibsoni) gather in a so-called gamming group to choose mates on Adams Island in subantarctic New Zealand. These adults have wingspans of more than ten feet—the largest of any living bird.

for aviators and albatrosses alike. More recently, since the atoll was made a National Wildlife Refuge in 1988 and the Navy departed in the 1990s, the U.S. Fish and Wildlife Service and armies of volunteer conservationists have been fighting battles of a different kind on Midway, combating introduced plants that choke prime nesting habitat. Even the aging buildings are proving deadly: albatross chicks unlucky enough to hatch near them get poisoned when they eat chips of the peeling lead-based paints. Plastics, too, picked up at sea by parents and fed unwittingly to chicks, are wreaking havoc.

The greatest overall threat to albatross survival, however, whether in the north or in the south, is the world's ever-expanding appetite for seafood. According to the United Nations Food and Agriculture Organization, an international fishing fleet of about 4 million vessels supplies every person on Earth with an average of thirty-five pounds of seafood annually. More than 60 percent of all that fish and shellfish is wild caught in marine waters. No part of the world's oceans, the albatrosses' far-reaching fishing ground, is untouched.

Albatrosses and petrels range far and wide precisely because catching prey is not easy. Their access to the ocean's bounty is limited to the depth they can reach from the surface, and as far as we know, only a few albatross species can dive deeper than a few feet. When vessels ply the oceans to catch fish and squid, they bring to the surface large quantities of the same elusive resource that large seabirds strive to capture. And so birds have been using men to fish for them since whaling ships first took to the sea. Ocean sailors like Coleridge's Ancient Mariner encountered albatrosses not only because the birds spent most of their lives flying far out at sea, but because they followed ships for days, hoping for a bonanza of fish offal, bait, or food scraps.

With the invention of modern methods of longline fishing and trawling, this otherwise rewarding habit has turned deadly. A baited longline hook will float astern of a vessel until the weight of the rig drags it down, and during that floating period, from a seabird's point of view it is an irresistible morsel, indistinguishable from any other.

Longlines, used to catch tuna, swordfish, and other prized open-ocean species, can be as much as ninety miles long, bearing thousands of hooks baited with squid and fish. Hungry albatrosses take the bait, get hooked, and are dragged to their deaths. Annual kill estimates are hotly debated in both science and fishing forums, but no one disputes a toll at least in the many tens of thousands, and some estimate a rate of up to 100,000 a year. Recently, scientists have been surprised to discover that accidental collisions with the steel cables, or "warps," of bottom-trawling ships are just as deadly to albatrosses.

In recent years, huge advances have been made in devising and deploying methods to reduce the incidental killing of birds—though the challenge is to convince all fishing fleets to apply the techniques. Birds can be discouraged from lingering in danger zones by the use of tori lines, a bird-scaring device consisting of an array of dangling streamers or wands. With the incentive of lucrative prizes and international awards like the World Wildlife Fund's "Smart Gear Competition," a number of ingenious and effective devices are being developed, tailored to the requirements of different fisheries. But while scaring birds away is partially effective in mitigating kill figures, a key issue is to avoid attracting birds into the vessels' wakes with tempting baits and discarded offal. Paradoxically, despite the high mortality rate, there is evidence that some albatross populations are growing as they increase their reliance on fisheries' discards.

Salvin's albatrosses (Thalassarche salvini) soar above their crowded nesting colony on Proclamation Island in the Bounty Islands of subantarctic New Zealand, their main breeding site. The species ranges at sea from New Zealand and Australian waters across to South Africa and as far east as the coast of South America, where the birds dive for fish and squid.

On a positive note, most albatross colonies today are among the most rigorously protected and intensely managed lands in the world. Six island groups where albatrosses breed are World Heritage Sites: the Galápagos; Gough and Inaccessible islands in the South Atlantic; the New Zealand Subantarctic Islands; Macquarie, between Australia and Antarctica; Heard and McDonald, between Madagascar and Antarctica; and Mewstone and Pedra Branca, included in Tasmania's Wilderness Area. Legacies of alien species, such as the carnivorous house mouse on Gough Island—which has evolved to more than twice the size of its stowaway ancestors—may still undermine some conservation measures. Gradual successes, however, such as the eradication of rats from New Zealand's subantarctic Campbell Island, give promise of success in safeguarding breeding sites worldwide.

"I now belong to a higher cult of mortals, for I have seen the albatross!" So exulted American ornithologist and conservationist Robert Cushman Murphy, on a 1912 voyage to the Southern Ocean. Let us hope that we can preserve the birds for future mariners, and so boast in our own way, "We now belong to a higher cult of mortals, for we have helped *save* the albatross!"

Based in New Zealand, nature photographers and writers **Tui De Roy** and **Mark Jones**, seen here aboard their specially outfitted high-seas yacht *Mahalia*, have spent the last six years documenting all the world's albatross species. Their work will appear in *Albatross: Their World, Their Ways* (Firefly, fall 2008). Visit www.ilcp.com to learn more about De Roy and her partnership with the International League of Conservation Photographers.

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BY MICHIO KAKU

A device that renders objects truly invisible

IN *STAR TREK IV: THE VOYAGE HOME*, the crew of the *Enterprise* hijacks a Klingon battle cruiser. In case you're not a die-hard trekkie, that was quite a feat for a Federation starship. Usually the Klingon ships are the ones ambushing with impunity, thanks to a secret "cloaking device" that renders them invisible to light or radar.

Is such a device really feasible? Invisibility has long been one of the marvels of science fiction and fantasy, from H.G. Wells's *The Invisible Man* to the *The Lord of the Rings* to the Harry Potter series. Yet physicists have doggedly dismissed such vanishing acts as impossible, claiming that escaping detection violates the laws of optics and does not conform to the known properties of matter.

But today the impossible may become possible. New advances in "metamaterials"—man-made materials that can, in a sense, control the movement of light—are forcing a major revision of optics textbooks. Working prototypes of such materials have actually been built in laboratories, sparking intense interest from the media, industry, and the military, eager to know how the visible could someday become invisible.

e commonplace within the next few decades.

MODERN OPTICS TRULY BEGAN with work done by James Clerk Maxwell, a Scottish physicist, in the mid-nineteenth century. At Cambridge, where Isaac Newton had worked two centuries earlier, Maxwell excelled as a student of what would now be called mathematical physics. Calculus—an invention of Newton's that uses equations to describe how objects move in space and time—armed Maxwell with the mathematical tools to explore the nature of electromagnetism.

Maxwell began with physicist Michael Faraday's discoveries that electricity could generate magnetism, that magnetism could generate electricity, and that each could be thought of as a force field. Maxwell rewrote Faraday's depictions of force fields in the precise language of calculus, producing eight fierce-looking differential equations—one of the most important series of equations in modern science. (Every physicist and engineer in the world has to sweat over them when mastering electromagnetism in graduate school.)

Next, Maxwell asked himself a fateful question: if changing magnetic fields create electric fields and vice versa, what happens if those fields are constantly generat-

ing each other in a never-ending pattern? Maxwell found that electric-magnetic fields behave much like ocean waves—for example, in the way they undulate through space. He calculated the speed of the waves and to his astonishment, found it to be the speed of light! Upon discovering this fact in 1864, he wrote prophetically: "This velocity is so nearly that of light that it seems we have strong reason to conclude that light itself . . . is an electromagnetic disturbance."

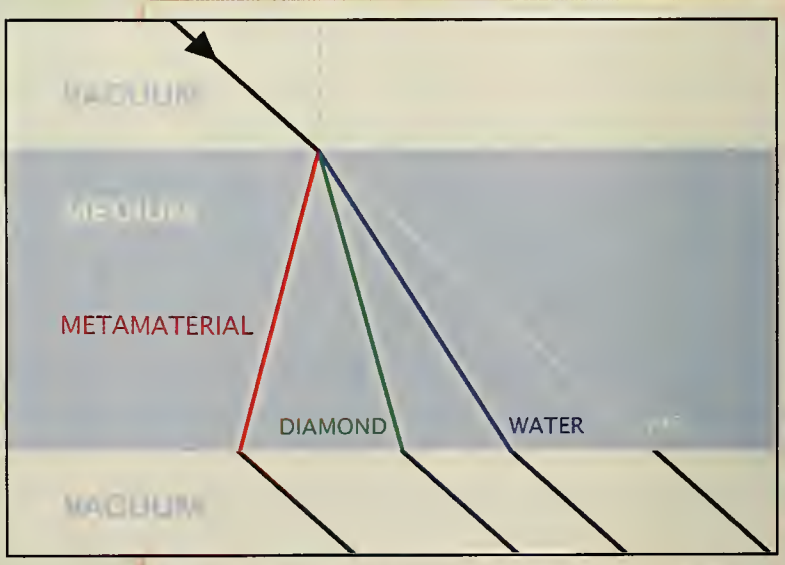
It was perhaps one of the greatest discoveries in human history. For the first time the secret of light was revealed. Maxwell suddenly realized that the brilliance of the sunrise, the blaze of the setting sun, the dazzling colors of the rainbow, and the stars in the firmament could all be explained in terms of waves. Today we realize that the entire electromagnetic spectrum—from radio waves, including broadcast frequencies and radar, through microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays—can all be described by Maxwell's wave theory of light.

Maxwell's theory of light, paired with the insight that all matter is made up of atoms, provides simple explanations for the phenomena of optics and lays the foundation for invisibility. Most solids, for example, are opaque because light rays, traveling as waves, cannot pass through the dense matrix of atoms. Many liquids and gases, by contrast, are transparent because the wavelengths of visible light can pass more readily through the larger spaces between their loosely arranged atoms. Diamonds and other crystals are something of an exception: they are both solid and transparent. That's because the atoms of a crystal, while tightly packed, are arrayed in a precise lattice structure that offers many straight pathways for a light beam to take.

Invisibility is a property that would clearly have to arise at the atomic level, via Maxwell's equations, and hence would be exceedingly difficult, if not impossible, to duplicate using ordinary means. To make a solid boy like Harry Potter invisible, you would have to liquefy him by boiling, crystallize him, heat him again, and then cool him, all of which would be quite an accomplishment, even for a wizard.

A "METAMATERIAL" CAN PERFORM FEATS THAT WOULD HAVE SEEMED MIRACULOUS A FEW DECADES AGO.

OF COURSE, SHORT OF changing someone or something's atomic structure, there are other optical options. At the heart of current invisibility research is the manipulation of something called the "index of refraction." When you put your hand in water, or look through the lenses of your glasses, you'll notice that water and glass distort and bend the path of ordinary light—that's refraction. Light slows down when it enters a dense, transparent medium, but in a pure vacuum the speed of light always remains the same. The index of refraction of any given material is obtained by dividing the speed of light by the slower speed of light inside the medium. Since the speed of light divided by itself equals 1, a natural material's index of refraction is always greater than 1. It is also ordinarily a constant: a beam of light bends at a particular angle when it enters a given substance, such as



Light traveling from a vacuum (upper left) into a denser transparent medium slows down, and as a consequence changes direction: its path bends, or becomes refracted. The denser the material, the more the light slows down, and thus the greater the degree of bending. So light bends more in a diamond than in water, and hardly bends at all in air. In natural mediums, light never angles backward beyond an imaginary line (dotted line) perpendicular to the surface where it crosses into the medium. To do so, the medium would have to have what is known as a negative index of refraction. That barrier has been broken by exotic man-made materials, called metamaterials, that bend light far more than once thought theoretically possible.

glass, and then keeps going in a straight line [*see illustration on opposite page*].

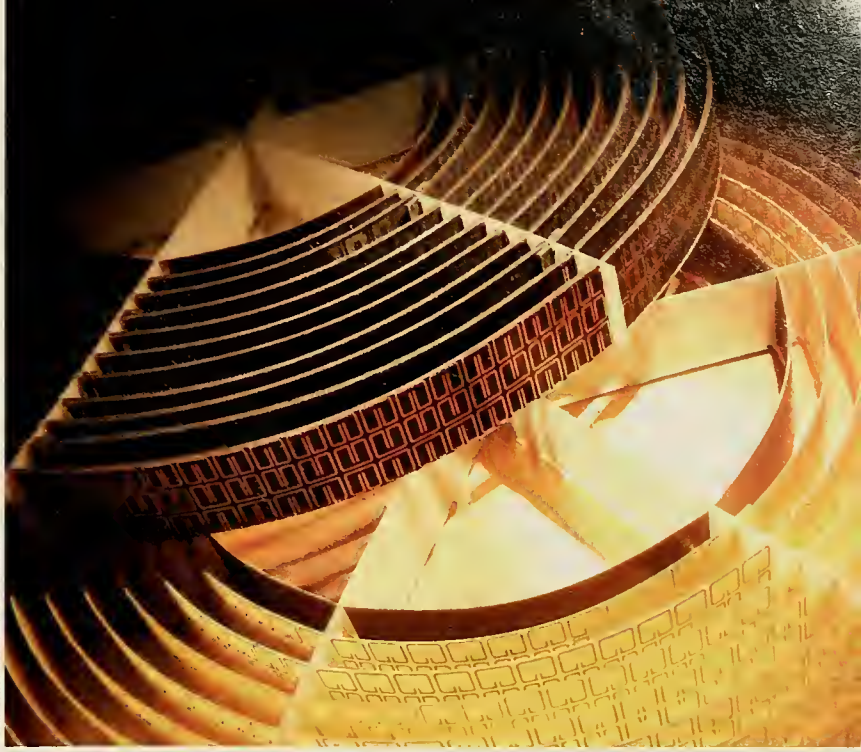
But what if you could control the index of refraction at will, so that, for instance, it changed continuously from point to point in the glass? If a beam of light could create its own path—slithering around an object's atoms like a snake—and exit the material along the same line it entered, then the object could be invisible. To do this, however, the object would need to bend light in unorthodox ways, which would require using a medium with a *negative* index of refraction, and that's exactly what every optics textbook for decades said was impossible. Yet in 2006, researchers at Duke University's Pratt School of Engineering in Durham, North Carolina, and at Imperial College London successfully defied conventional wisdom and made objects that were "invisible" to microwave radiation—by manipulating refraction.

The scientists designed a kind of metamaterial: a substance that has optical properties not found in nature. Nathan Myhrvold, former chief technology officer at Microsoft, says metamaterials "will completely change the way we approach optics and nearly every aspect of electronics. . . . [They] can perform feats that would have seemed miraculous a few decades ago."

The metamaterial, made by the Duke University engineers, relied upon tiny implants that forced electromagnetic waves to bend in unorthodox ways. Tiny electric circuits were embedded in a concentric series of bands arranged rather like the coils of an electric oven [*see photograph above right*]. Those implants—a mixture of ceramic, Teflon, fiber composites, and metal—made it possible to channel the path of microwave radiation in a specific way around the device. A small copper cylinder inside the device was undetectable to microwave radiation. But it did cast a minuscule shadow. True invisibility requires eliminating all reflections and shadows.

To visualize how the radiation bends around the device, think about the way a river flows around a boulder. Because the water quickly wraps around the boulder, the rock is undetectable downstream. Similarly, metamaterials can continuously alter and bend the path of microwaves so that they flow around a cylinder, for example, essentially making everything inside the cylinder invisible to microwaves [*see illustration on next page*].

In general, the internal structures implanted inside such a metamaterial must be smaller than the wavelength of the radiation to be redirected. For example, for a metamaterial to bend the path of microwaves with a wavelength of three centimeters, it must have tiny implants embedded in it that are smaller than three centimeters. But to make an object invisible to green light, with a wavelength of 500 nanometers (nm), the metamaterial must have structures embedded within it that are only about 50 nm long. (One nanometer is a billionth of a meter in length. Approximately five atoms fit within a single nanometer.) Building such atomic-scale structures requires advanced nanotechnology at the very limits of modern engineering. Pushing those limits is perhaps the key problem engineers face in their attempts to create a true invisibility cloak.



DUKE UNIVERSITY PHOTOGRAPHY

Two versions of a cloaking device created by Duke University engineers, using metamaterials, that makes invisibility possible at microwave frequencies. Each is one centimeter high and about ten inches across. Tiny electric circuits embedded in their concentric rings bend the path of microwave radiation in such a way that the electromagnetic waves flow around the cloaking device, making both it and an object placed in the center undetectable.

THE RACE IS ON—just as it is in the computer-chip industry—to use nanotechnology to achieve better performance at smaller scales. Ever since the announcement that metamaterials have been fabricated in the laboratory, there has been a stampede of activity in this area, with new insights and startling breakthroughs coming every few months. And the goal is to create metamaterials that can bend visible light, not just microwaves.

Advances made in the semiconductor industry have spurred the creation of new metamaterials. A technique called "optical lithography" enables engineers to place hundreds of millions of tiny transistors onto a silicon wafer no bigger than your thumbnail. Scientists use ultraviolet radiation to "etch" tinier and tinier components onto a silicon chip. At present, the smallest components that one can create with this etching process are about 30 nm (or about 150 atoms) across. With the etching technology, a

group of scientists created the first metamaterial that operates in the visible range of light: scientists in Germany and at the U.S. Department of Energy (DOE) announced in late 2006 that, for the first time in history, they had fabricated a metamaterial that worked for red light.

How did they achieve the "impossible"? Physicist Costas M. Soukoulis of the DOE's Ames Laboratory in Iowa joined forces with Gunnar Dolling and Martin Wegener of the University of Karlsruhe and Stefan Linden of the Karlsruhe Research Institute in Germany. They started with a glass sheet, and then deposited a thin coating of silver, followed by magnesium fluoride and another layer of silver, forming a fluoride "sandwich" that was only 100 nm thick. Next, using standard etching techniques, they made a large array of microscopic square holes, 100 nm wide, in the sandwich to create a grid pattern resembling a fishnet. Then they passed a red light beam with a wavelength of 780 nm through the material and measured its refractive index, which was −0.6. (Previously, the smallest wavelength of radiation bent by a metamaterial was 1,400 nm, which put it outside the visible light spectrum, in the range of infrared.)

Physicists foresee many applications of this invisibility technology. Metamaterials "may one day lead to the development of a type of flat superlens that operates in the visible spectrum," says Soukoulis. "Such a lens would offer superior resolution over conventional technology, capturing details much smaller than one wavelength of light." Breakthrough applications of such a "superlens" would include the photographing of microscopic objects, such as the inside of a living human cell, with unparalleled clarity; it could make possible the early diagnosis of diseases in a developing baby inside the womb. Ideally, one would be able to take photographs of a DNA molecule without having to use clumsy X-ray crystallography.

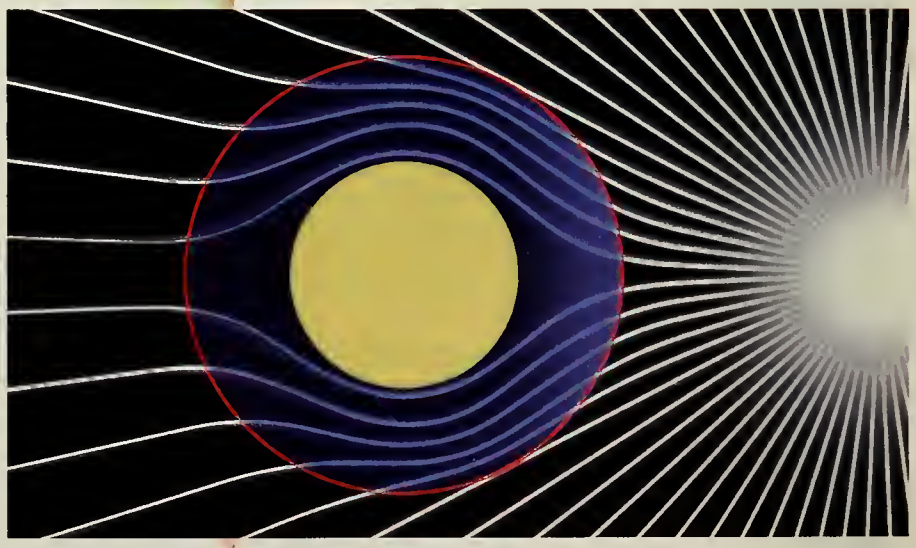
So far, Soukoulis's group has only been able to manipulate red light. The next step would be to create a metamaterial that would bend red light entirely around an object, rendering it invisible to that light.

IN THE RUNNING FOR future developments, another area of invisibility research shows promise: light transistors. The goal of "photonic crystal" technology is to create a chip that uses light, rather than electricity, to process information. That entails using nanotechnology to etch and mold tiny components on a wafer, such that the index of refraction changes with each component.

Light transistors have several advantages over those using electricity. For example, there is much less heat loss in photonic crystals. (Advanced silicon chips generate enough heat to fry an egg. Thus chips must be continually cooled down or they will fail, and keeping them cool is very costly.) Not surprisingly, the science of photonic crystals is ideally suited for metamaterials, since both technologies involve manipulating the index of refraction of light at the nanoscale.

Not to be outdone, yet another group announced in mid-2007 that they created a metamaterial that bends visible light using an entirely different technology, called "plasmonics." Physicists Henri J. Lezec, Jennifer A. Dionne, and Harry A. Atwater at the California Institute of Technology had developed a metamaterial that had a negative index for the more difficult blue-green region of the visible spectrum of light. Unlike photonic crystals, which use light beams trapped inside crystals, plasmonics uses electrons synchronized with a light beam. (Electrons also behave like waves, as photons do.)

The goal of plasmonics is to "squeeze" light's rapid information-carrying capacity into nanoscale spaces, especially on the surface of metals. The reason metals conduct electricity is that electrons are loosely bound to metal atoms, so they can move freely along the surface of the metal. The electricity flowing in the wires in your home is nothing more than loosely bound electrons flowing smoothly on the wires' metal surface. But under certain conditions, a light beam colliding with the metal surface can create wavelike motions of the electrons on that surface, called plasmons. The wavelike motions of the plasmons vibrate in unison with the original light beam. More important, one can "squeeze" the plasmons so that



White lines show the path that light rays from a source at right take toward a hypothetical metamaterial cloaking device (blue ring). Blue lines show how the rays are rerouted around the cloaked object (yellow circle) by the device's metamaterial; a viewer at left would not know that the light did not arrive directly from the light source. A viewer at right would also not detect the object, because it will not reflect the light or cast a shadow.

while they still have the same frequency as the original beam (and hence carry the same amount of information), they have a much smaller wavelength. In principle, one might then cram the squeezed waves onto nanowires. As with photonic crystals, the ultimate goal of plasmonics is to create computer chips that compute using light and electricity, rather than electricity alone.

The Caltech group built their metamaterial out of two layers of silver, with a 500 nm silicon-nitrogen insulator in between, interrupted by a nanoscale prism of gold and silver layers. The prism was separated by only 50 nm of silicon nitride, which acted as a "waveguide" that could redirect the plasmonic waves. Laser light enters and exits the team's cloaking apparatus via two slits carved into the metamaterial. By analyzing the angles at which the laser light is bent as it passes through the metamaterial, one can verify that the light is being bent with a negative index.

THANKS TO THE INTENSE interest in creating light transistors, progress in metamaterials will only continue to accelerate. Research in invisibility can therefore "piggyback" on the ongoing research in photonic crystals and plasmonics. Already hundreds of millions of dollars are being invested in the two fields with the goal of creating smaller, faster, and cooler replacements for silicon chip technology, and newer and better metamaterials will inevitably be spun off.

With breakthroughs occurring in this field every few months, it's not surprising that some physicists see a practical invisibility shield of some kind emerging from the laboratory in the not so distant future. Scientists are confident, for example, that in the next few years they will be able to create metamaterials that can render an object totally invisible for one frequency of visible light, at least along a two dimensional plane. To do this would require embedding tiny nano implants not in regular arrays, but in sophisticated patterns, so that light would bend smoothly around an object.

The next challenge will be to create metamaterials that can bend light in three dimensions, not just on flat two-dimensional surfaces. Photolithography has been perfected for making flat silicon wafers, but creating three-dimensional metamaterials will require stacking wafers in a complex fashion.

After that, scientists will face the problem of creating metamaterials that can bend not just one frequency of light, but many. That will be perhaps the most difficult task, since the tiny implants that have been devised so far bend light of only one precise frequency. Scientists may have to create metamaterials in layers, with each layer bending a specific frequency. The solution to this problem is not clear.

This article was adapted from *Physics of the Impossible: A Scientific Exploration into the World of Phasers, Force Fields, Teleportation, and Time Travel*, by Michio Kaku, ©2008. Reprinted with permission of Doubleday, a division of Random House, Inc. All rights reserved. On sale in bookstores now.

WHEN WILL AN INVISIBILITY cloak be ready for the market? Sci-fi fans will have to wait. And even then, the first one may be a clunky device. Harry Potter's cloak was made of thin, flexible cloth that rendered anyone draped in it invisible. But for that to be possible, the index of refraction of the cloth would have to be constantly changing in complex ways as it fluttered, which is impractical. More than likely, the first true invisibility cloak would be made of a solid cylinder of metamaterials. That way the index of refraction could be fixed. More advanced versions could eventually incorporate metamaterials that are flexible and can twist and still make light flow within them on the correct path. In this way, anyone inside the cloak would have some freedom of movement.

And, as some die-hards have pointed out, there is an inherent flaw in the invisibility shield: anyone inside would not be able to look out without becoming visible. Imagine Harry Potter being totally invisible except for his eyes, which appear to be floating in midair. Any eyeholes in the cloak would be clearly visible from the outside. To be totally invisible, Harry Potter would have to be sitting blindly beneath his cloak. (One possible solution to the problem might be to insert two tiny angled glass plates near the location of the eyeholes. The glass plates would split off a tiny portion of the light hitting the plates, and direct that light into the eyes. So most of the light hitting the cloak would still flow around it, rendering the person invisible; only a tiny amount would be diverted to allow the person to see.)

As daunting as those difficulties are, scientists and engineers are optimistic that a real-life invisibility shield of some sort, worthy or not of the Klingons, can be built within two or three decades. In the meantime, there is still a lot of imagining that can be done, from the pages of a book to the intricate, ever-smaller designs of exotic materials.

Michio Kaku is a world-renowned theoretical physicist and best-selling author. His goal in life is to complete Einstein's quest for a "theory of everything" that can unify all physical laws into a single equation. He is the co-founder of string field theory, a division of string theory; the latter is a leading contender for that title. Kaku's popular books on the frontiers of physics include *Hyperspace*, *Parallel Worlds*, and *Visions*. After graduating summa cum laude from Harvard, Kaku received his Ph.D. from the University of California at Berkeley and taught at Princeton University. He has been Henry Semat Professor of Theoretical Physics at the City University of New York for more than twenty-five years. His nationally syndicated weekly radio program airs in 130 cities across the United States.

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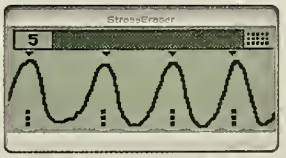

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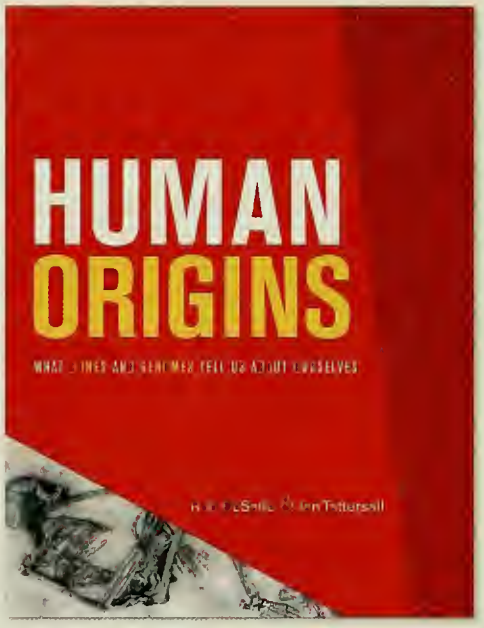
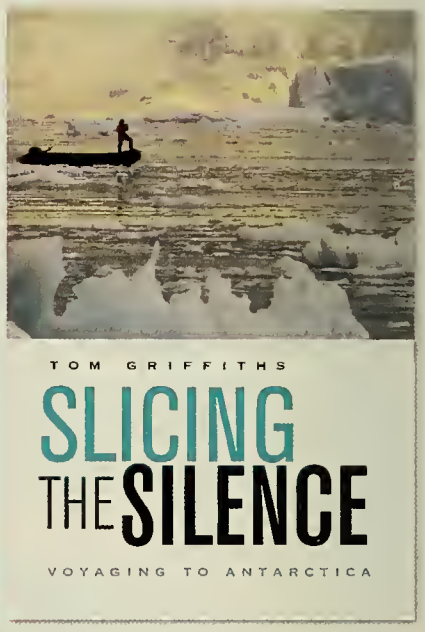




To readers jaded by the deluge of nonfiction about vanishing species, the title *Last Flight of the Scarlet Macaw* portends one more tale of woe, even as *One Woman's Fight* in the subtitle promises a hopeful glimmer of human interest. Nature writer Bruce Barcott's book is a sympathetic saga of eco-activism with a cast of unforgettable characters. Yet it is also an instructive account of the dilemmas faced by environmentalists in developing nations, where competing social, political, and commercial interests turn otherwise clear-cut issues of right and wrong into a rat's nest of difficult choices.

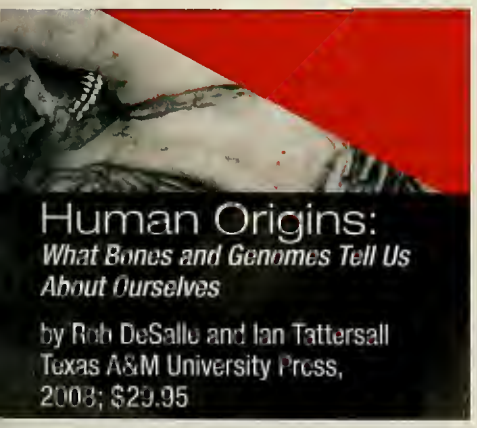
Barcott's book manages to cover so much territory because it takes place in an extremely small place, Belize, a sliver of land about the size of Massachusetts, just south of Mexico's Yucatan Peninsula. Belize City, home to about a quarter of the nation's 300,000 inhabitants, has the air of a seedy beach colony, with stilt houses lining a maze of narrow streets. Beyond the coastal swampland, two-thirds of the country is jungle, overgrown and undeveloped since Great Britain exhausted most of its usable timber and turned the place (then called British Honduras) back to the local residents. Novelist Aldous Huxley, who visited in the 1930s, described it as the ultimate backwater: "If the world had any ends, British Honduras would certainly be one of them." Except for a name change at independence in 1981, Belize hasn't changed significantly since then.

One avenue for development might be the tourist trade, of course. Belize has two advantages in this regard: proximity to the United States and vast tracts of wild country in which macaws, jaguars, tapirs, and monkeys flourish. What stands in the way, however, is the lack of a reliable source of electricity, which Belize currently purchases from neighboring Mexico. The country has no coal, no refineries to process its small deposits of oil and natural gas, no capital to construct nuclear generating plants. But it does have plenty of rivers and streams in the interior. And so the local electric company, Belize Electricity Limited (BEL), looks primarily to hydroelectric generation to provide power.

In the late 1990s, BEL began making plans to build a dam across Belize's Macal River. The 150-foot-tall structure would create a reservoir to provide a steady year-round flow of water, dry season or wet, to an existing generating plant downstream, while adding another six megawatts to the nation's power grid. If the power company's figures were to be believed, it was a commendable project that would

provide cheap electricity to a poor country without consuming fossil fuels or adding to global warming.

But to Sharon Matola, the director of the Belize Zoo and the protagonist of Barcott's fast-paced narrative, the dam spelled disaster. It would flood one of the largest remaining stretches of wild country in Central America and destroy the only local breeding ground of the scarlet macaw. A single letter of protest she wrote to the prime minister in 1999 blossomed into a strident campaign, a polarizing national debate, the involvement of international environmental groups, and a series of lawsuits that eventually wound up before Queen Elizabeth's Privy Council in London. As the central character in this book, Matola is a journalist's dream: straight-talking, thoughtful, and full of lovable quirks. She's been an Air Force survival specialist and a tiger tamer in a circus, and she commutes through the jungle on a motorcycle. It's not giving anything away to say that Matola comes across as eccentric but often admirable, that the power companies and politicians come across as deceitful and greedy but occasionally well-intentioned, and that the scarlet macaw is still in plenty of trouble. Beyond that, I can only say to jaded souls, this is a book well worth reading.



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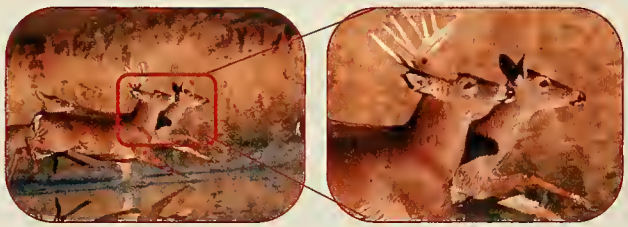

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the image of a khaki-clad paleontologist, in the mold of Richard Leakey, scrabbling for bones in an African landscape. Great progress in tracing out the human family tree has indeed been made in this fashion, but over the last few decades remarkable advances in several disciplines—molecular biology and genetics most of all—have revolutionized the way we regard the human past. The conventional wisdom of paleoanthropology has been sometimes challenged, sometimes supported, and most often sharpened by the precision of the new molecular techniques. Appropriately, the American Museum of Natural History (AMNH) recently decided that it was time to mount a new permanent exhibition on human origins, incorporating diverse fields of study. The exhibit's companion book, written by geneticist Rob DeSalle and paleoanthropologist Ian Tattersall, both on the museum's staff, is an accessible and authoritative summary of the major insights of the new synthesis.

Molecular biology has, first of all, made it possible to refine our understanding of the relationships among species, living and extinct. Relying on fossils alone was always a chancy enterprise. Nowadays we can look at similarities in sequences of DNA to trace out the details of animal family trees, often with unanticipated results that challenge commonsense conclusions based solely on appearance. Whales turn out to be the closest kin of hippos; mushrooms are more closely related to armadillos than they are to oak trees; and, closer to us, primates seem to be second cousins to bats and tree shrews.

It's not just living animals whose DNA is accessible, either. Genomic detectives are beginning to sequence the mitochondrial genome of *Homo neanderthalensis*, using shavings from fossils, and it already seems clear to the authors that those hominids never interbred with Cro-Magnons, *Homo sapiens*, though they coexisted. The disappearance of Neanderthals can't be attributed to intermarriage, then; it seems increasingly likely that they were wiped out, not assimilated, by the Cro-Magnons.

Now that DNA analysis has become cheaper, faster, and better understood, it's even possible to compare the coding sequences of large populations of individuals. That enables scientists to trace routes of human migration back into the past by looking for certain "marker" genes, which are passed on, virtually unaltered, from parent to child. The similarity in genes between natives of central Siberia and natives of South America, for instance, pretty much squelches Thor Heyerdahl's *Kon-Tiki* theory that the first Americans came on rafts across the Pacific, and supports the view that they walked across an isthmus or an ice bridge that once spanned today's Bering Strait.

Molecular biology may even shed light on perhaps the greatest puzzle of human origins: how our ancestors leaped the gap separating smart apes from *Homo sapiens*. How did we become creatures with the ability to think in symbols, to use language, and to create works of art, music, and literature? If you share the optimism of the authors, the answer will come from identifying the genes that give us the ability to distinguish color, to perceive changes in pitch, to memorize and calculate, and a host of other faculties, some of which we are not yet even aware we possess. Granting the remarkable advances we're already making, it's not clear whether genetic reductionism will ultimately unravel the deeper meaning of our unique form of consciousness. Readers of this book and viewers of the new AMNH hall may marvel at how much we've learned about the human past in the last few decades, yet wonder still at what it means to be human.

Slicing the Silence:
Voyaging to Antarctica

by Tom Griffiths
Harvard University Press, 2008; $29.95

On the 17th of December, 2002, Tom Griffiths, an environmental historian at the Australian National University in Canberra, sailed south from Tasmania aboard a ship bringing supplies and a fresh crew to Antarctica's Casey Station. It was hardly the kind of heroic expedition that characterized trips to the frozen continent a century earlier, and judging from the journal entries in *Slicing the Silence*, not much out of the ordinary happened on the voyage. But as lovers of polar literature know full well, even an ordinary trip to Antarctica is extraordinary.

And this is an extraordinary book, as notable as that of Griffiths's antipodal fellow traveler Barry Lopez (whose 1986 best seller, *Arctic Dreams,* won a National Book Award). Griffiths turns otherwise humdrum shipboard jottings into starting points for inspired ruminations on the meaning of the Antarctic experience. Although he has never ventured into the interior, he seems to have read virtually everything published on the discovery, exploration, and exploitation of the southern continent, along with a host of unpublished diaries and station logs.

Best of all, he relates what he has learned in prose that is both thoughtful and luminous:

> Antarctica has an aura. I don't just mean its mystery, its magical otherworldliness, its implacable grandeur, and its capacity to haunt all who have visited it. I also mean that this land over the South Pole, which is covered by a single mineral, actually emanates ice, water and air well beyond its geographical boundaries. . . . Antarctica is like a giant,

breathing organism clamped to the base of the globe. Every winter as the southern hemisphere tilts away from the sun, so much sea ice forms that the size of the white continent appears to double, only to shrink again in the summer, like a billowing creature rhythmically expanding and contracting.

You may recognize a few of the names and places on the book's pages: Ernest Shackleton, leading five men across 800 miles of storm-tossed sea in a small whaling boat after their ship was splintered by ice floes; Robert Falcon Scott and his party, beaten to the pole by Amundsen, freezing and starving to death in a canvas tent just eleven miles short of a major depot of food and fuel. But there are many other unfamiliar and astonishing stories. One essay, based on the journals of Robert Cushman Murphy, who went south to collect specimens for the AMNH in 1912, provides a window into the long-vanished world of southern whaling. Down among the floes and roaring winds on South Georgia island, Murphy discovered a surprising outpost of civilization—a mansion owned by a wealthy whaling captain, complete with a cook and butler, a billiard room, canaries, and a conservatory planted with flowers and palm trees.

Few of us will ever visit Antarctica, even though cruise ships now bring several tens of thousands of high-rolling tourists to its coasts each year. Readers, I am sure, will come away from this book agreed that fewer is better, because Griffiths makes it clear just how special this land is, and, for all its ruggedness, how fragile. Better to leave Antarctic travels to a select few scientists, adventurers, and support staff. And, from time to time—for those of us who stay at home—eloquent writers like Tom Griffiths.

Laurence A. Marschall is W.K.T. Salm Professor of Physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.

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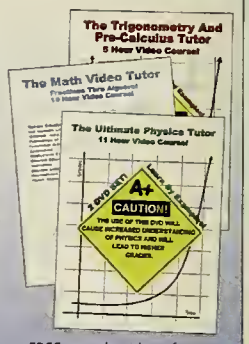

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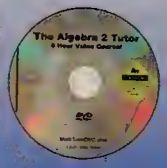

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WORD EXCHANGE

Continued from page 7

gantea ["Vegetarian Carrion," 2/08]. Espelie describes the way in which *S. gigantea* acts as a parasite on the reproductive efforts of the blow fly, benefiting from pollination while the hatching eggs suffer early deaths. I know that the famed large-flowering parasitic plant *Rafflesia keithii*, which parasitizes jungle vines for its physiological needs, also secretes the smell of rotting flesh to attract flies for pollination. Perhaps *R. keithii* is parasitizing the reproductive efforts of those flies in the same manner as *S. gigantea*? If so, that would make it doubly parasitic!

David Zeigler
The University of North Carolina at Pembroke
Pembroke, North Carolina

MENNO SCHILTHUIZEN OF THE UNIVERSITY OF MALAYSIA SABAH REPLIES: *Rafflesia keithii*, like all members of that genus, is indeed a double parasite. First of all, the plant lacks chlorophyll, so it parasitizes *Tetrastigma* vines, living a near-invisible life as threadlike filaments within the host's tissues and feeding on its nutrients. Only when *R. keithii* reproduces does it emerge with a splash: its spectacular flowers are famous for being not just the world's largest, but also among the world's smelliest. The smell attracts flies, as well as many other insects, such as dung beetles, that normally feed on rotting materials. As those insects travel in frustration from flower to flower, they take care of the plant's pollination. And even if the flies and beetles realize their mistake before laying any eggs, the plant still parasitizes on their time and energy. So indeed, *Rafflesia* is one of the plant kingdom's biggest scroungers.

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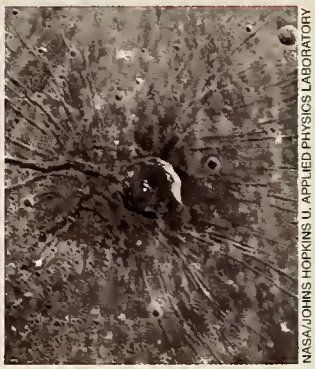
SKYLOG BY JOE RAO



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Twenty-five-mile-wide crater, center, overlies a spidery pattern of troughs discovered on Mercury.

This past winter, observers were treated to close-up imagery of the planet Mercury courtesy of a space probe known by the acronym MESSENGER (**ME**rcury **S**urface, **S**pace **EN**vironment, **GE**ochemistry, and **R**anging). In Roman mythology, of course, Mercury was the messenger of the gods. The only probe to visit Mercury previously was *Mariner 10*, which swept past it three times in the 1970s. Launched in August 2004, MESSENGER zipped by Mercury in January as part of an elaborate interplanetary dance. It will settle into orbit around Mercury in March 2011 for at least an Earth year's investigation of the rocky little world's geologic history, the chemical composition of its surface, the size and state of its core, the nature of its very thin envelope of gas (known as the exosphere), and the strength and dynamics of its magnetosphere. The first pictures of a previously unexamined region reveal smooth surfaces suggestive of volcanic lava flows, corrugations formed by the planet's shrinking (thanks to its cooling core), and a spidery scar that one scientist said is "unlike anything we've seen anywhere in the solar system."

From an Earthly standpoint, Mercury is in superior conjunction with the Sun (on the opposite side of the Sun) on the 16th of April. It begins to swing into view during the following week, and should be easily observable by the 23rd—shortly after sunset, very low in the west-northwest. This is the start of Mercury's best evening apparition of the year for those of us who live in the mid-northern latitudes, because the planet is moving in orbit north of the Sun's equator even as it moves to the Sun's east (it will be farthest east of the Sun on the evening of May 14th). By the last day of April, Mercury sets as much as 85 minutes after the Sun.

JOE RAO (hometown.aol.com/skywayinc) *is a broadcast meteorologist and an associate and lecturer at the Hayden Planetarium in New York City.*

April Nights Out

1 Saturn, the "Lord of the Rings," is on the local meridian (the line running north to south), and thus as high as it gets in the sky during the night, at about 10:30 P.M. It arrives there four minutes earlier each day thereafter, in excellent position for observers all month.

5 The Moon is new at 11:55 P.M. eastern daylight time (EDT).

8 A thin crescent Moon hovers just above the Pleiades star cluster (distinguishable through binoculars) in the west-northwest sky, about an hour after sunset.

10 Mars forms an isosceles triangle with Castor and Pollux, the brightest stars in the constellation Gemini, the Twins.

11 Appearing to move at roughly its own diameter each hour, the Moon slowly approaches Mars from the lower right.

12 The Moon waxes to first quarter at 2:32 P.M. EDT.

20 The Moon becomes full at 6:25 P.M. EDT.

23 Look for Mercury low in the west-northwest sky about a half hour after sundown, a little to the left of where the Sun has vanished. Binoculars may reveal the Pleiades 4 degrees directly above it.

28 The Moon reaches last quarter at 10:12 A.M. EDT.

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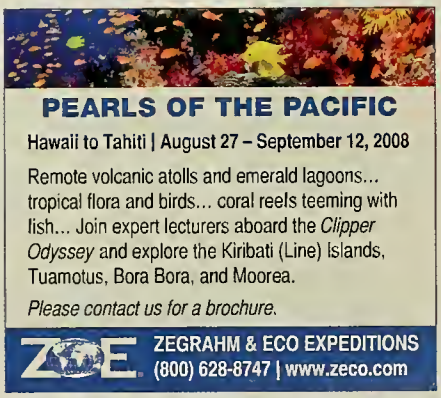

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Biology and Culture: Bridging the Gap

What do the dialects of indigenous peoples in Papua New Guinea, hunting traditions of the Vuntut Gwitchin people of the Northern Yukon, colobus monkeys in Ghana, and the Zanzibar leopard have in common? All are under threat from many of the same forces—a critical link too often overlooked by the very people who have dedicated their lives to preserving these precious resources.

Hoping to address that divide, leading scientists, policymakers, educators, and others will gather from Wednesday, April 2, to Saturday, April 5, for *Sustaining Cultural and Biological Diversity in a Rapidly Changing World: Lessons for Global Policy*, the Center for Biodiversity and Conservation's thirteenth annual Spring Symposium.

Organized by the CBC with IUCN-The World Conservation Union/Theme on Culture and Conservation and with Terralingua, the symposium is informed by a recognition that fragmented approaches have not been successful in arresting the growing erosion of the world's biodiversity or the rich diversity of human knowledge and practices—and that what is urgently needed is a multidimensional approach to public policy and outreach.

Among the symposium participants are natural and social scientists, conservation and development practitioners, members of indigenous, tribal, and local communities, representatives of governmental and nongovernmental organizations, United Nations agencies, universities and research institutions, funding organizations, educators, students, and others versed in relevant fields. Events include the presentation of background papers, panel discussions, posters, and musical and spoken-word performances.

The public is encouraged to attend the Mack Lipkin Man and Nature Series evening panel on Thursday, April 3, "The Culture of Nature, the Nature of Change," moderated by Julie Burstein, creator and executive producer of Public Radio International's *Studio 360 with Kurt Andersen*. The panelists will grapple with maintaining the distinctiveness of music, language, art, and nature in the face of the homogenizing pressures of an ever-shrinking world.

Also in conjunction with the symposium, there will be daylong Global Weekend events on Saturday, April 5, celebrating cultural and biological diversity.

This symposium is supported, in part, by grants from The Christensen Fund, The Rockefeller Foundation, and the Wenner-Gren Foundation.

Sustaining Cultural and Biological Diversity in a Rapidly Changing World
Wednesday–Saturday, April 2–5
cbc.amnh.org/biocultural

© AMNH

Cultural and linguistic diversity is inextricably intertwined with biological diversity.

Two Evenings of Darwin

Tuesday and Thursday, May 6 and 8

While a student at Cambridge University, Charles Darwin was so enthralled by the study of plants he took the sole botany course three times. His later work with plants was central to his revolutionary ideas about natural selection. Until the end of his life, he made a habit of rising early to walk in his garden at Down House outside London.

So it is fitting that the symposium *Darwin: 21st-Century Perspectives* begins next month at The New York Botanical Garden through a rare collaboration with the American Museum of Natural History. Generously underwritten by Mr. and Mrs. Coleman P. Burke and Mr. and Mrs. Lewis B. Cullman, two evenings of presentations and panel discussions will explore Darwin and his legacy.

On Tuesday, May 6, The New York Botanical Garden will host "Darwin: Yesterday and Today." On Thursday, May 8, the American Museum of Natural History will present "Human Evolution and the Complexity of Living Organisms." Both sessions will be moderated by world-renowned entomologist E. O. Wilson, two-time Pulitzer Prize winner and professor emeritus at Harvard, and will conclude with questions from the audience.

A complementary exhibition, *Darwin's Garden: An Evolutionary Adventure*, will be on view at the Botanical Garden from April 25 through June 15. *Darwin*, the groundbreaking AMNH exhibition, continues to travel around the world and is currently on view in Tokyo through June 22 and in Toronto through August 5.

Darwin: 21st-Century Perspectives
Tuesday, May 6, at the NYBG
www.nybg.org
Thursday, May 8, at the AMNH
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Or call 800-322-6924 for information and to purchase tickets.

Opens Next Month

The Horse *May 17, 2008–January 4, 2009*

© JAMES TAYLOR

Black Beauty. Seabiscuit. My Little Pony. Mr. Ed. The horse—in fiction and fact, from prehistory to the present—has captured our imagination through books, television, film, and many other media. But there is a compelling backstory to this relationship, as rooted in science as it is in sentiment. This evocative, trailblazing exhibition explores the evolution of this magnificent animal and the enduring bond that shaped human history—transforming hunting, agriculture, transportation, trade, sports, warfare (untold millions of horses died in World War I alone), and many other facets of our life. Spectacular fossils and cultural objects, videos, interactive computer stations, touchable casts, and more tell this amazing story in ways the whole family will enjoy.

The Horse is organized by the American Museum of Natural History, New York (www.amnh.org), in collaboration with Abu Dhabi Authority for Culture & Heritage; Canadian Museum of Civilization, Gatineau-Ottawa; The Field Museum, Chicago; and San Diego Natural History Museum.

The Horse at the American Museum of Natural History is made possible, in part, by the Eileen P. Bernard Exhibition Fund. Additional support has been provided by an anonymous donor.

© THE IFF BY AARON AND CASSANDRA OTT

HYPERBOLIC CROCHET: advanced mathematics, handicraft, a little of both? One thing is clear: it's a dazzling art form being used to great effect (see above) in the service of marine ecology, conservation, and artistic collaboration in the Hyperbolic Crochet Coral Reef, an ongoing project of the Institute for Figuring in Los Angeles. Christine and Margaret Wertheim, codirectors of the Institute—an educational organization that explores the poetic and aesthetic dimensions of math, science, and technology—have called upon artisans around the world to crochet colorful faux coral reefs to draw attention, as nothing else could, to the plight of these fragile ecosystems endangered by global warming, pollution, side effects of tourism, and more.

On April 8, in the Museum's Wallach Orientation Center, Margaret Wertheim, who is also an award-winning science writer, will join with Kate Holmes, an AMNH marine biologist, to discuss both the evolving Hyperbolic Crochet Coral Reef and the current environmental challenges facing real coral reefs, such as the Great Barrier Reef, the world's largest, which stretches along the coast of the Werthheim twins' native Queensland, Australia. Holmes is a Biodiversity Specialist in the Marine Program of the Museum's Center for Biodiversity and Conservation, and has done extensive fieldwork on the complexity of marine life in The Bahamas.

In the ocean, loopy kelps, fringed anemones, crenellated corals, and curlicued sponges are all manifestations of a single mathematical structure known as hyperbolic space. The art of crochet was first used to illustrate hyperbolic space by Daina Taimina of Cornell University—a discovery that astounded the mathematical world. Building on Dr. Taimina's technique, the Wertheims and other project participants have mimicked tightly bunched mounds of brain coral, towering spires of pillar coral, blooms of carnation coral, wavy strands of kelp, and other life forms—often modifying the underlying "crochet code" to create a huge range of hyperbolic crochet "species," just as the marvelous diversity of living species results from variations of a genetic code. The IFF Reef is a quintessentially collaborative project, and anyone who takes up this style of crochet can begin to develop their own woolly "species."

The impact of a group display must be seen to be appreciated. To that end, the Institute has arranged exhibitions across the country including two in Manhattan this month and next, in addition to the evening program at the Museum. For more information about hyperbolic crochet, exhibition locales, and exquisite photos, visit the Institute's Web site at www.theiff.org.

This program is supported, in part, by Kay Allaire and Ruth A. Unterberg.

At the Museum

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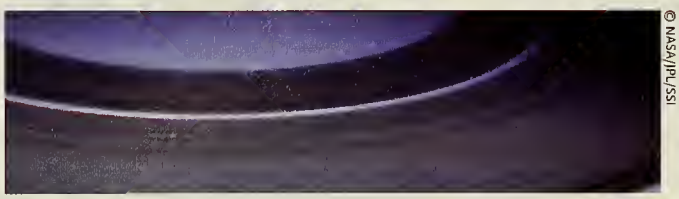

© NASA/JPL/SSI

Saturn's northern hemisphere is presently a serene blue, as seen in this natural-color image from *Cassini*.

EXHIBITIONS

Saturn: Images from the Cassini-Huygens Mission
IMAX Corridor, first floor
Opens April 26, 2008
This new exhibition reveals details of Saturn's rings, moons, and atmosphere with images sent over half a billion miles by the *Cassini* spacecraft. Pictures from the largest moon, Titan, are displayed alongside images of the giant geyser discovered on the smaller moon Enceladus.

The support of the National Aeronautics and Space Administration is appreciated.

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Images of the word "water" in different languages projected on a dramatic fog screen greet visitors as they enter the exhibition *Water*.

Water: H_2O = Life
Through May 26, 2008
Live animals, hands-on exhibits, and walk-through dioramas invite the whole family to explore the beauty and wonder of water and reveal one of the most pressing challenges of the 21st century: humanity's sustainable management and use of this life-giving, but finite, resource.

Water: H_2O = Life is organized by the American Museum of Natural History, New York (www.amnh.org), and the Science Museum of Minnesota, St. Paul (www.smm.org), in collaboration with Great Lakes Science Center, Cleveland; The Field Museum, Chicago; Instituto Sangari, São Paulo, Brazil; National Museum of Australia, Canberra; Royal Ontario Museum, Toronto; San Diego Natural History Museum; and Singapore Science Centre with PUB Singapore.
The American Museum of Natural History gratefully acknowledges the **Tamarind Foundation** for its leadership support of *Water: H_2O = Life*, and the **Johns Hopkins Center for a Livable Future** for its assistance.
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The Museum extends its gratitude to the Panta Rhea Foundation, Park Foundation, and Wege Foundation for their support of the exhibition's educational programming and materials.

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Undersea Oasis: Coral Reef Communities
Through May 2008
Brilliant color photographs capture the dazzling invertebrate life that flourishes on coral reefs.

Beyond
Through April 6, 2008
Exquisite images from unmanned space probes take visitors on a journey through the alien and varied terrain of our planetary neighbors.

The presentation of both *Undersea Oasis* and *Beyond* at the American Museum of Natural History is made possible by the generosity of the Arthur Ross Foundation.

Unknown Audubons: Mammals of North America
Through August 2008
The stately Audubon Gallery showcases gorgeously detailed depictions of North American mammals by John James Audubon, best known for his bird paintings.

Major funding for this exhibition has been provided by the Lila Wallace-Reader's Digest Endowment Fund.

Public programs are made possible, in part, by the Rita and Frits Markus Fund for Public Understanding of Science.

GLOBAL WEEKENDS

Cultural and Biological Diversity
Saturday, 4/5, 1:30 a.m.–5:30 p.m.
For details, visit
cbc.amnh.org/biocultural
Explore the vital link between humanity and the natural world through spoken word, live music, and film. Presented in conjunction with the CBC Spring Symposium; see p. 60.

Global Weekends are made possible, in part, by the City of New York, the New York City Council, and the New York City Department of Cultural Affairs. Additional support has been provided by the May and Samuel Rudin Family Foundation, Inc., the Tolan Family, and the family of Frederick H. Leonhardt.

LECTURES AND TASTINGS

Global Kitchen: Wine and Culture
Three Tuesdays, 4/22–5/6, 7:30 p.m.
With Louisa Thomas Hargrave and Jean-Louis Carbonnier.

FIELD TRIP

Spring Bird Walks in Central Park
Eight weeks starting on 4/8, 4/9, or 4/10.
For tickets and details, visit
www.amnh.org.
Observe the spring migration of birds in Central Park.

FAMILY AND CHILDREN'S PROGRAMS

WATER SUNDAYS
11:00 a.m.–12:30 p.m. (Ages 4–6, each child with one adult) and 1:30–3:00 p.m. (Ages 7–9)
In conjunction with *Water: H_2O = Life*, these hands-on workshops introduce young audiences to the science of water.

ROSE CENTER FOR EARTH AND SPACE
Sets at 6:00 and 7:30 p.m.
Friday, 4/4
Valerie Capers Ensemble

The Properties of Water
Sunday, 4/6

Groundwater and the Water Cycle
Sunday, 4/13

Dr. Nebula's Laboratory: Water Works
Saturday, 4/19, 2:00–3:00 p.m.
In this science-theater adventure for the whole family, Scooter, Dr. Nebula's apprentice, investigates water on our planet and beyond.

Exclusive corporate sponsor for *Water: H_2O = Life* is JPMorgan and Chase.

AMNH ADVENTURES: SPRING CAMPS
Monday–Friday, 4/21–25, 9:00 a.m.–4:00 p.m.
Each session includes hands-on investigations, behind-the-scenes tours, and visits with Museum scientists.

Water Camp
For 4th and 5th graders

Fossils and DNA
For 2nd and 3rd graders

© AMNH/D. FINNIN

Science on a Sphere is one of the highlights of the exhibition *Water*.

HAYDEN PLANETARIUM PROGRAMS

TUESDAYS IN THE DOME
Virtual Universe
The Grand Tour
Tuesday, 4/1, 6:30 p.m.

Celestial Highlights
Carnivores' Corner
Tuesday, 4/29, 6:30 p.m.

These programs are supported, in part, by the Sant'Angelo/Koval Family, Val and Min-Myn Schaffner, and an anonymous donor.

LECTURE
Messenger
Monday, 4/14, 7:30 p.m.
With Sean Solomon.

HAYDEN PLANETARIUM SHOWS

Field Trip to the Moon
Wednesdays, 10:30 a.m.
Guided by a live presenter, children and adults can see a sunrise in space and orbit and land on the Moon.

Cosmic Collisions
Journey into deep space to explore the hypersonic impacts that drive the formation of our universe. Narrated by Robert Redford.

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

IMAX MOVIE

Dinosaurs Alive!
Great dinosaur finds by AMNH scientists past and present come to life with archival and contemporary footage and scientifically accurate, computer-generated images.

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A hula hoop entertains at One Step Beyond.

LATE NIGHT DANCE PARTY

One Step Beyond
Friday, 4/25, 9:00 p.m.–1:00 a.m.
This monthly party in the Rose Center features the biggest names in techno, electronica, hip-hop, and indie rock. Cocktails keep the party going.

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., and Saturday, 9:00 a.m.–4:00 p.m., or visit www.amnh.org. A service charge may apply. All programs are subject to change.

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

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By Anna Marie Roos

The Prince and the Popper

Six years ago, I was looking out the window of a plane bound for England, admiring the sunlight illuminating the slightly pink clouds. My British companion remarked that the clouds were just like candy floss—Britspeak for cotton candy. Those sweet thoughts were rudely interrupted by a small popping noise from within my handbag, then another . . . and another. Unfortunately it wasn't candy. My heart sinking, I discovered that the bottom of my bag was littered with powdered glass. Three of the little Prince Rupert's drops I had so carefully made for a lecture at Oxford University had exploded.

I first came across Prince Rupert's drops when I was reading an early "chymical" text at the British Library. In it the drops were called "Greatricks glasses." After a week of trying to find out who Greatricks was—mostly by reading up on a seventeenth-century faith healer named Valentine Greatrakes—I e-mailed a desperate SOS out to my colleagues. A kind soul informed me that "Greatricks" might have simply meant "great tricks": King Charles II of seventeenth-century England had used the drops as practical jokes after being introduced to them by his nephew, Prince Rupert of Bavaria.

Typical of "virtuosi" of this period, gentlemen who dabbled in everything and excelled at much, Prince Rupert had a varied career as an artist, military officer, and scientist. His scientific curiosity focused on the great-trick glasses: teardrop-shaped beads formed by dropping molten glass into cold water. The bulbous head can withstand hammering on an anvil, but breaking the curved, tapered tail shatters the entire drop into fine powder. The king would have subjects hold the bulb end in their palms, and then he'd break off the tip, startling the victims with a harmless little explosion.

Charles II, the founding patron of the Royal Society, directed its members to explain why the "chymical glasses" exploded. So riveted was the Society by the glasses that in 1663, an enterprising satirist wrote a ballad about the group's obsession:

And that which makes their Fame
ring louder
With much adoe they shew'd the King
To make glasse Buttons turn to powder,
If off the[m] their tayles you doe
but wring.
How this was donne by soe small Force
Did cost the Colledg a Month's discourse.

Robert Hooke, the Society's Curator of Experiments, did the first detailed examinations of the drops: he coated them with a transparent glue, wrapped them in leather, broke off their tails, and then viewed the glass fissures under his microscope. But it was not until 1994 that their secret was fully revealed. Munawar M. Chaudhri of the University of Cambridge, England, and Srinivasan Chandrasekar of Purdue University in Indiana did high-speed photographic analyses of the drops, observing the cracks accelerating from the drop's tail towards the head at more than 4,000 miles per hour.

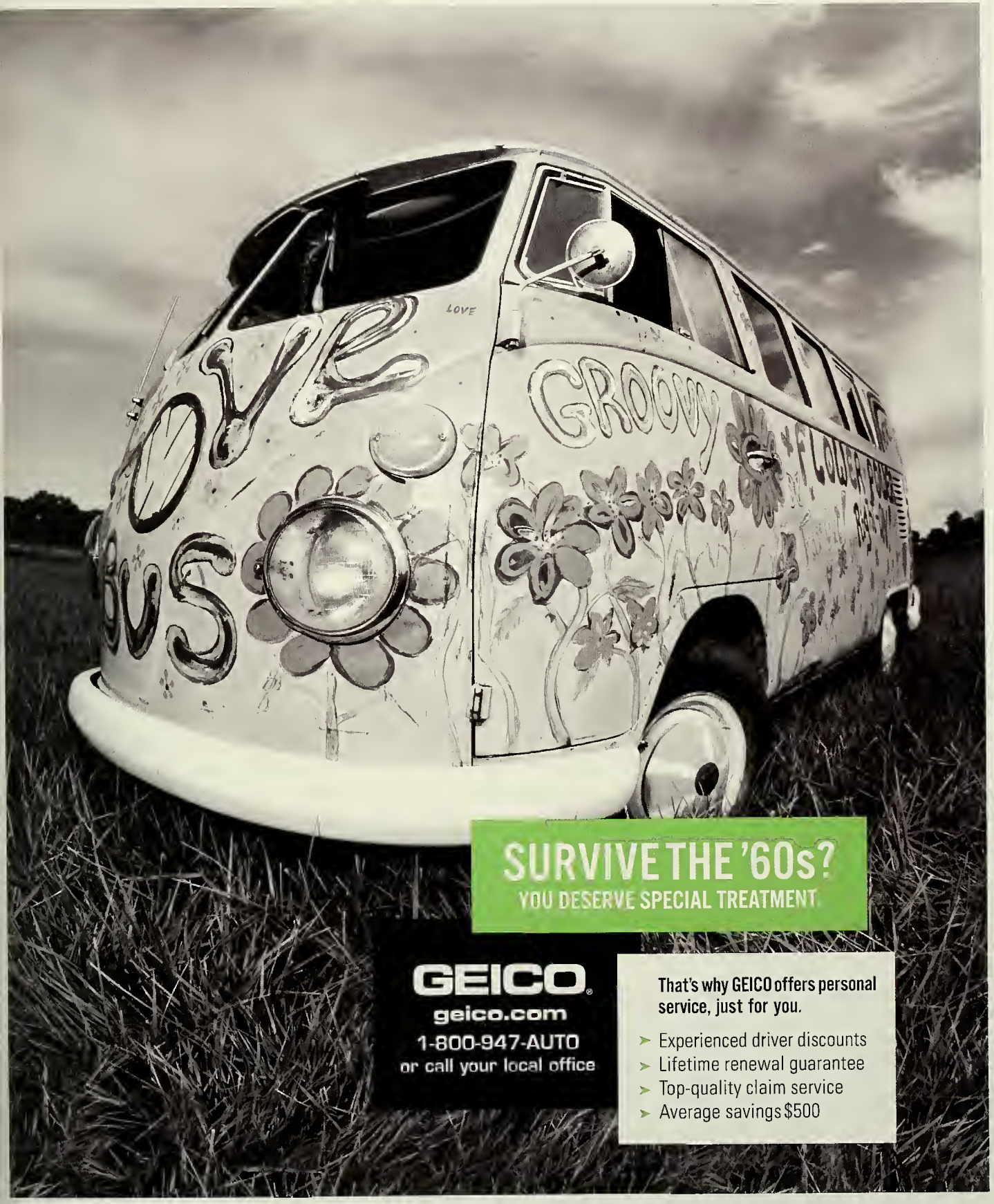
The two engineers realized that when a drop is formed, the cold water rapidly cools and solidifies the molten glass on the outside. The glass within, still hot, then gradually contracts, causing large compressive stresses on the surface as well as interior tension. That inner tension is enough to blow the drop apart at the tiniest crack, making the thin tail vulnerable. But that tension also accounts for the round head's toughness, by pulling the outer layers of the head tight.

Finding some instructions for making Prince Rupert's drops in *The Art of Glass*, written by a Florentine chemist, Antonio Neri, in 1662, I decided to try myself. Neri advised, "The best way of making them, is to take up some of the Metall [molten glass] out of the pot upon the end of an Iron rod, and immediately let it drop into cold water, and there lye till it cool." Using a crème brûlée torch on steroids, I heated up a glass rod, placing it very close to the surface of a beaker of ice water to catch the drops. Some of the glass tears broke when I fished them out of the water, but soon I was armed with a dozen, carefully taped to an index card to take with me for my lecture.

Though a few drops did not endure the plane trip, because a change in air pressure can destabilize the glass, my audience was delighted with those that survived. Recently, a video of exploding drops has even appeared on YouTube. Prince Rupert had discovered a "great trick" indeed to entertain royals and Internet junkies alike.

Anna Marie Roos is a research associate at the Wellcome Unit for the History of Medicine at the University of Oxford; she recently wrote The Salt of the Earth: Natural Philosophy, Medicine, and Chymistry in England, 1650-1750 *(Brill, 2007).*

GLASS AND PHOTOS BY WWW.ROBINMROGERS.COM



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