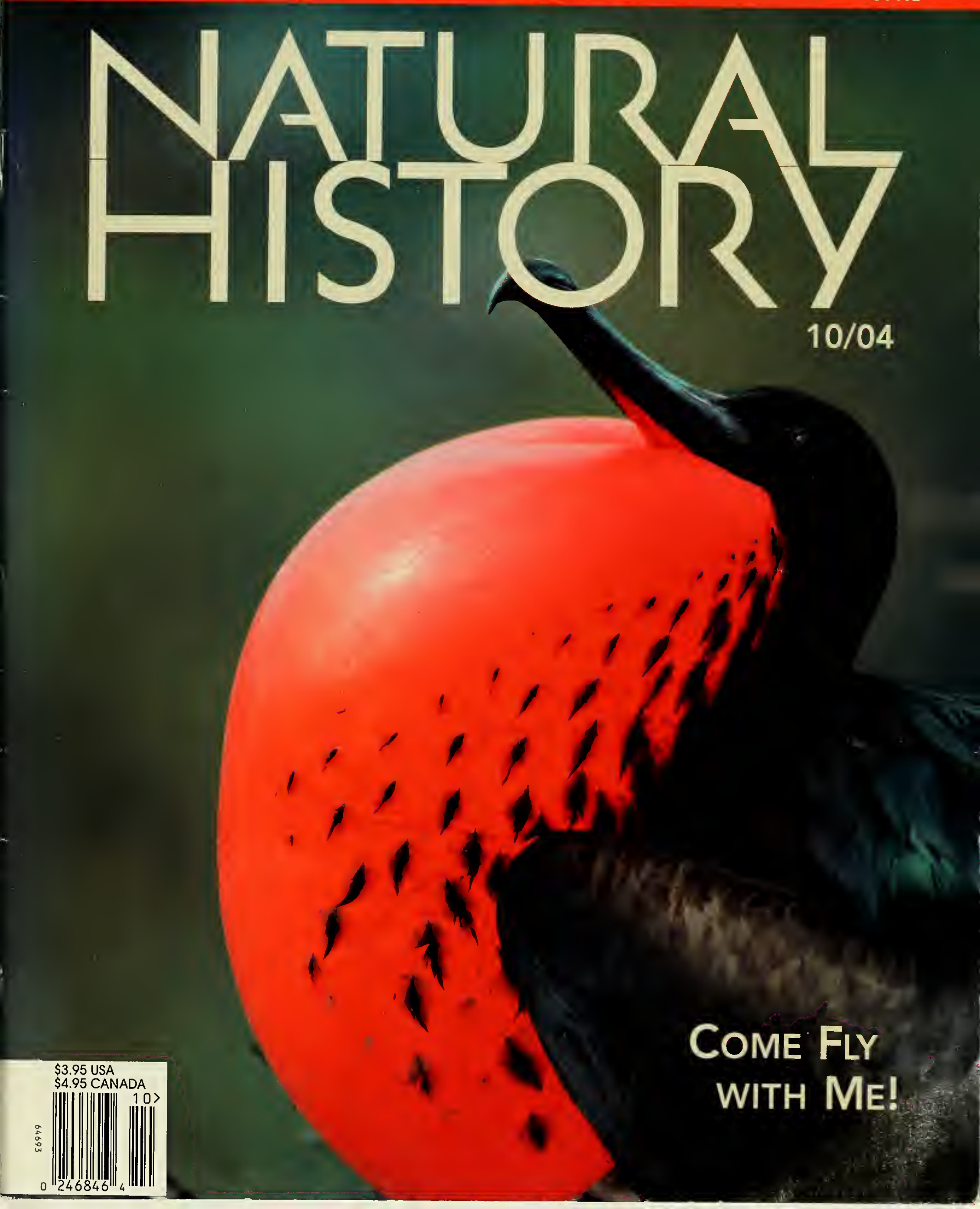
Q&A: Bush v. Kerry • Atoms v. Bits • Slime • Fish that Climb • Ferns

NATURAL HISTORY

10/04



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NATURAL HISTORY

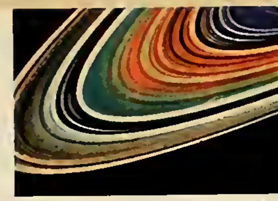
OCTOBER 2004 VOLUME 113 NUMBER 8

FEATURES

CAMPAIGN 2004

ON THE COVER: Great frigatebird *(Fregata minor)* fully inflates its throat pouch during a courtship display.

NATURAL HISTORY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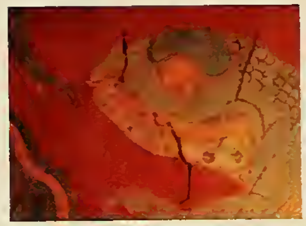
DEPARTMENTS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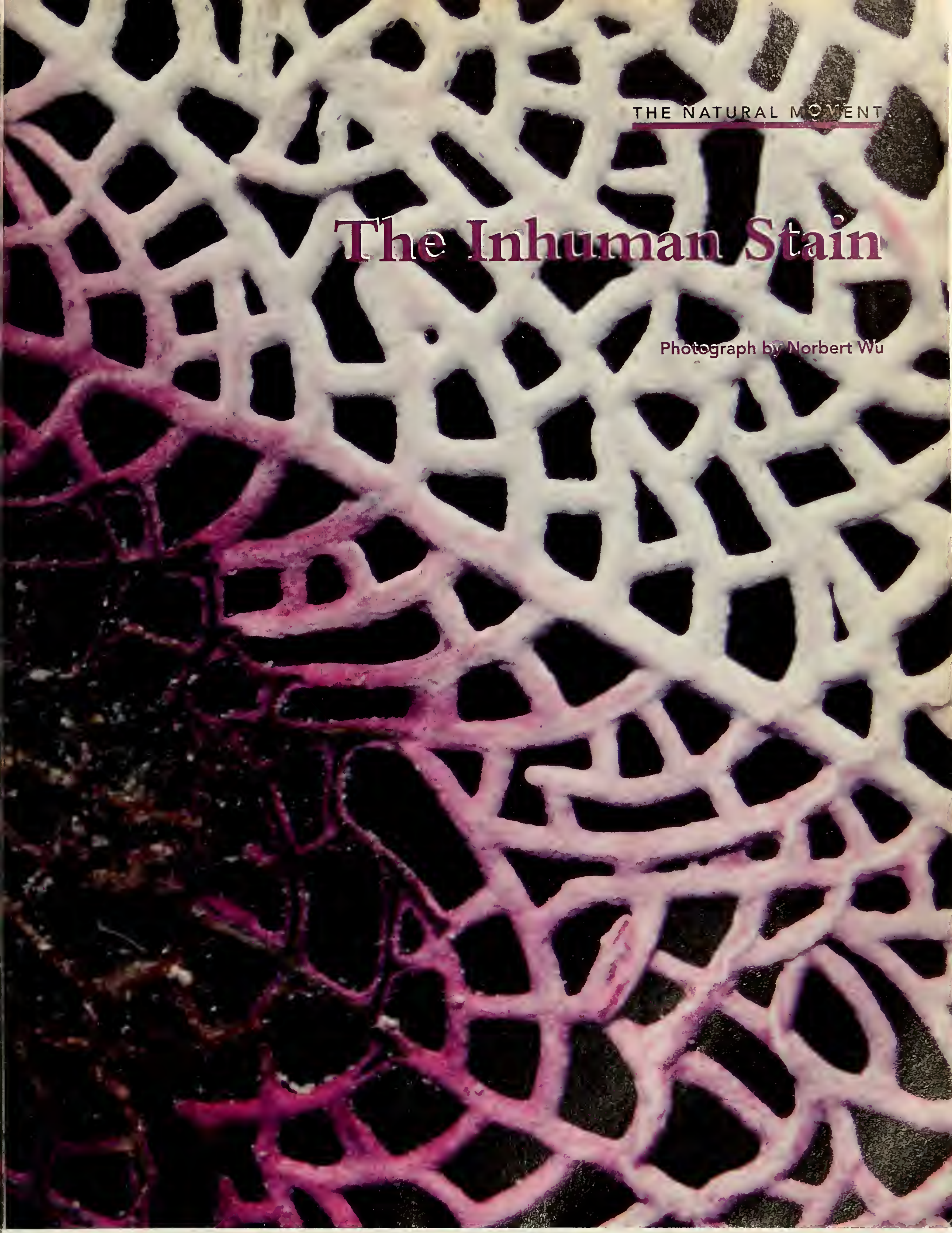
Photograph by Norbert Wu



THE NATURAL MOMENT

◄ *See preceding two pages*

Unlike the smear of goo the land snail leaves in its wake, a swath of purple lesions marks the passage of the flamingo tongue snail *(Cyphoma gibbosum)*, as it munches its way across a *Gorgonia ventalina* sea fan. The carnivorous snail—less than an inch long—masks its plain white shell with a fleshy, leopard-spotted mantle while grazing. Soft corals such as the sea fan are both its feeding ground and its food.

Acting in self-defense, the *G. ventalina* pictured here responded to the flamingo tongue's attack by making a cocktail of protective compounds. The chemicals turned the sea fan bright violet, and helped fend off a number of fungi and bacteria. But according to Jessica Ward, a marine scientist at Cornell University in Ithaca, New York, the holes and black decay in the center suggest that a fungus, possibly *Aspergillus sydowii*, might have broken through the coral's barriers.

A. sydowii was once strictly terrestrial, but since the late 1990s the organism has become epidemic at many underwater sites in the Caribbean. Flamingo tongues—not thought to be lethal by themselves—have been found to carry *A. sydowii* in their gut and, as Ward speculates, may be responsible for spreading the disease.

Photographer Norbert Wu found this ghoulish-looking pair (or trio, if you count the fungus) off the coast of the Caribbean island of Saba.

—*Erin Espelie*

UP FRONT

Our Crowded Niche

Niche, from the Latin word for "nest," means much the same thing in biology as it does in ordinary speech. Your niche is your comfort zone, a familiar place where you can make a decent living. Some creatures find their niche through heroic exertions, like the fish in Peter T. Sherman and Perri K. Eason's story of Hawaiian gobies that reach safety in freshwater pools by scaling sheer, thousand-foot cliffs ("Climb Every Waterfall!" page 33). Some, like the albatrosses and frigatebirds in Henri Weimerskirch's article, "Wherever the Wind May Blow" (page 40), spend most of their days soaring over remote oceans, wandering freely across vast ranges that others can only dream of.

• • •

When you read a magazine, you also tend to share a niche. As a reader of *Natural History*, you probably have more than the average person's curiosity about the environment, natural resources, biodiversity, health, science education, and other issues, such as energy and space, with roots in the natural world. Those issues—"our" topics—are also important matters of national debate. Come election season, our niche seems to attract lots of outsiders.

My colleague Mary Knight took on the job of asking the two major-party presidential candidates about those issues. Her first task was to help draft our questions, but her real challenge was to get the campaigns to respond. A spokesperson for President Bush's campaign suggested she look for the answers online. A spokesperson for Senator Kerry's campaign said they were "working on" the answers—then told Knight the questions had gone to the wrong official.

As our deadline approached, we decided that the only way to move forward was to take the advice of the Bush forces and cull answers from the recent speeches and campaign statements of each candidate. We then sent both sets of our proposed answers, along with our sources, to both campaigns—making it clear to each that we were sending the same materials to the other side. We again urged each campaign to respond to our questions directly or to revise the answers we had assembled. If nothing was changed, we noted, the replies we were suggesting would stand.

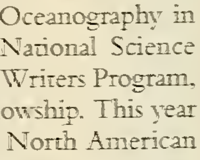
In the end, the Kerry campaign did prepare responses to our questions. Officials with the Bush campaign twice considered our request, then decided not to respond—hence letting stand what we had already sent them. The questions and answers begin on page 46.

• • •

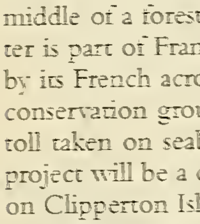
I am sorry to report that, after this issue, Elizabeth Meryman will be leaving her position as art director of *Natural History*. In her two years with us, Liz has made extraordinary contributions to this magazine. Happily, in her new role as a fine-arts consultant, she will still be helping us find just the right images for our pages. But every morning at the office, she will be missed. —PETER BROWN

CONTRIBUTORS

Photographer and cinematographer NORBERT WU ("The Natural Moment," page 6) comes to his studies of marine wildlife from a multiple academic background: before he began his photographic career, Wu majored in electrical and mechanical engineering at Stanford University and pursued doctoral studies at Scripps Institution of Oceanography in La Jolla, California. He has won three National Science Foundation grants for work in the NSF's Antarctic Artists and Writers Program, and in 1999 he was awarded a Pew Marine Conservation Fellowship. This year he was named Outstanding Photographer of the Year by the North American Nature Photographers Association. His photograph of a flamingo tongue snail on a besieged sea fan coral was made in the eastern Caribbean. In cooler waters, Wu gathered the images for his latest book, *Under Antarctic Ice,* which was published last month by the University of California Press.



HENRI WEIMERSKIRCH ("Wherever the Wind May Blow," page 40) has been studying seabirds of the Southern Ocean for twenty-five years and tropical seabirds for the past five. When Weimerskirch, an ecologist and ornithologist, is not working on remote islands, he is a research director at the Chizé Center for Biological Studies field laboratory, in the middle of a forest in southwestern France (the Chizé Center is part of France's National Center for Scientific Research, widely known by its French acronym CNRS). Weimerskirch is an active member of various conservation groups and is working to develop measures that can reduce the toll taken on seabirds by such practices as long-line fishing. His next seabird project will be a comparative study of masked, brown, and red-footed boobies on Clipperton Island, an uninhabited, French-owned coral atoll in the Pacific Ocean, about 800 miles southwest of Mexico.



The author of several books and countless articles on ferns, as well as a frequent contributor to *Fiddlehead Forum,* the newsletter of the American Fern Society, ROBBIN C. MORAN ("Dispatches from the Fern Frontier," page 52) is well prepared to talk about the latest developments in fern research. Moran is the curator of ferns at the New York Botanical Garden, where he investigates the evolution, classification, and ecology of ferns. He also spends several months a year collecting and studying plants in the American tropics, as well as teaching courses in Costa Rica on behalf of the Organization for Tropical Studies. His story in this issue draws on material from his latest book, *A Natural History of Ferns,* which is being published this month by Timber Press. He is also co-author, with Barbara Joe Hoshizaki, of *Fern Grower's Manual* (Timber Press, 2001), a book that illustrates and describes more than 700 known fern species under cultivation in the United States and Canada.

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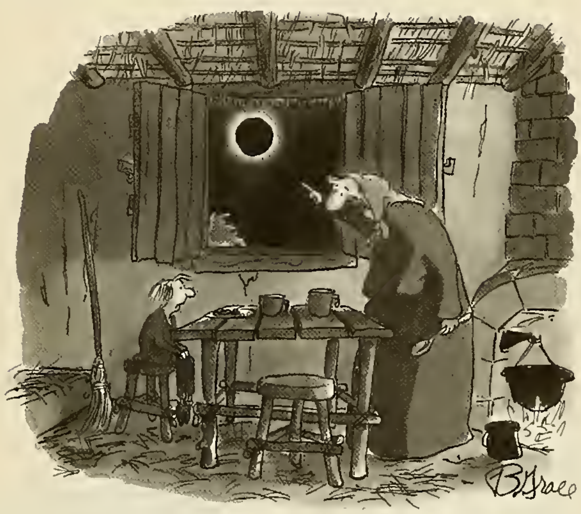
Universal Nonsense?

Speculation about other universes ("The Best of All Possible Worlds," by Donald Goldsmith, 7–8/04) is much like counting how many angels can dance on the head of a pin: it is truly unworthy of your fine magazine. Sure, there may be other universes, but since we cannot sense outside our own universe, it is vacuous to speculate about what they might be like. I am willing to bet a bucket of beer that within our own universe there are as yet undreamt of and undiscovered living systems, maybe even on our own planet. So why publish such nonsense?
Hans J. Berliner
Carnegie Mellon University
Pittsburgh, Pennsylvania

DONALD GOLDSMITH REPLIES: Some cosmologists take the "multiverse" concept seriously because it emerges rather naturally from their basic assumptions. Intriguingly, it is not entirely proven that if other universes exist, we would never have any chance of interacting with them. I rather share Hans Berliner's disapproval (though in a low-key way), and I admire the cosmologist Michael S. Turner's judgment, which I reported, that the anthropic approach is a narcissistic one, not worthy of serious investigation. Nevertheless, because the cosmologist Martin J. Rees and the physicist Steven Weinberg take a more positive attitude toward it, I felt that their eminent reputations entitled them (and it) to some consideration.


"See what you've done? You made the Moon swallow the Sun. Now will you eat your turnips?"

Lost and Found

In her review of Richard C. Francis's book *Why Men Won't Ask for Directions* ("Dad's Not Lost," 7–8/04), Deborah M. Gordon states that evolutionary psychology adheres to the idea that "every characteristic of every species is adaptive—that is, each characteristic has enhanced reproductive success." No responsible evolutionary psychologist would make such an all-inclusive claim. It would immediately be recognized as ridiculous, for some of the reasons Gordon mentions, but primarily because evolution is a process of experiment that leads to many failures (maladaptations) for every success.
Jeff P. Turpin
Canyon Lake, Texas

Another problem with the evolutionary explanation for men's unwillingness to ask directions is that it seems to be a national, not a gender-based trait. When my husband and I were in Italy, I was astonished when, on separate occasions and in different circumstances, two of our male Italian friends unhesitatingly approached strangers on the street to ask directions. The encounters appeared to be a pleasure to both parties, and our friends certainly did not seem to feel that their masculinity was threatened.
Betty Feinberg
Tucson, Arizona

Frogs v. Trout

In his story "Where Have All the Frogs Gone?" (6/04), James P. Collins neglected to mention another possible answer to his question, namely, the losses attributable to predation by the nonnative species of fish intentionally introduced for sport fishing into many lakes. Many western U.S. lakes, for instance, have been stocked with rainbow trout. It is becoming increasingly well documented that such fish prey on the native frogs. The fish thrive, to the delight of the fishermen, but the frogs dwindle, perplexing biologists who are looking for more complicated explanations.
Chris Sherman
St. Louis, Missouri

JAMES P. COLLINS REPLIES: It is the rare situation in which only one factor is responsible for amphibian declines. In most cases, two or more out of six factors are involved. The California red-legged frog illustrates how three causes—commercial exploitation, exotic species, and land-use change—interacted to the detriment of the frogs.

Introducing trout in many western U.S. lakes is a particularly clear example of how exotic species can adversely affect native frogs through predation. But it is worth remembering that even in this seemingly straightforward, single-factor case, the reasons for introducing the fish are, in part, commercial ones (recreation brings tourism), and there is some evidence supporting the concern that introduced trout carry pathogens lethal to amphibians.

I Yam What I Yam

"Supercrop," the title of Marten Sorensen's article (4/04), does not at present fit the neglected yam bean. The one supercrop is maize, the giant of the cereals. The yam bean could be the agronomist's and breeder's dream, however: all it would take is a small amount of "risky" investment. The potential profits—as well as the economic, ecological, and social dividends—could be enormous.

Many features of the yam bean have not even been described in published work. For example, some kinds of yam bean can be processed into a high-protein, easy-to-store product resembling *gari*, a flour that is made from cassava roots. And though yam beans are customarily sown, all yam beans can readily be propagated from cuttings; from one "good" genotype several hundred clones can be developed in one generation.

The various kinds of yam bean can have highly different properties. Although the current assumption is that there are three cultivated species, fertile and vigorous hybrids can be developed between all yam bean species. If the frequency of successful crossings within and between species is tested for equivalence—tests that have not been done to date—I suspect that all cultivated yam beans will turn out to be one species. Agronomists and breeders who experiment with other root crops or beans can only dream of working with such diversity and potential for hybridization.

Wolfgang J. Grüneberg
University of Göttingen
Göttingen, Germany

MARTEN SORENSEN REPLIES: Although the yam bean may not yet be a "supercrop," I do think it promises to be one, given its adaptability, yield potential, and many possible uses for food, fodder, and even nonfood products. Its sustainability is unmatched by any cereal, even maize, and for exactly that reason a number of traditional farming systems cultivate maize and yam bean together.

The taxonomic status of the yam bean is closely related to one's definition of species. Plant breeders and agronomists have, for practical reasons, tended to accept a fairly simple species concept, wherein all plants that produce fertile offspring belong to the same species. In contrast, botanists and taxonomists generally favor a more complex definition, not only weighing morphological and genetic differences, but also taking account of whether cross-fertilization is a naturally occurring possibility. (For example, if two variants do not overlap geographically, or if they flower at different times, that would be an argument for considering them different species.) In the end, however, whether the yam bean should be regarded as one species or as several that can be hybridized is not so important, as long as the different kinds can be manipulated to facilitate cross-pollination.

Natural History *welcomes correspondence from readers. Please send e-mail to* nhmag@naturalhistorymag.com *All letters should include a daytime telephone number, and all letters may be edited for length and clarity.*

Birth of a Salesman

No, this is where the neocortex is.

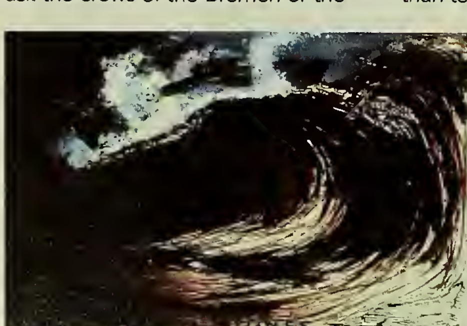
Primatologists have long speculated that, among monkeys and apes, there is a correlation between the brain size of a species—particularly the size of the neocortex—and the species' social skills. But social skills are not easy to define, much less measure directly. Now Richard W. Byrne and Nadia Corp, both psychologists at the University of St. Andrews in Fife, Scotland, have identified a social skill they can count: ordinary acts performed in a way that deceives, and thus manipulates, other animals of the same species, and that benefit the deceiver.

Byrne and Corp synthesized field studies that had reported on the frequency of individual attempts at deception in a total of eighteen species of apes, monkeys, and prosimians. Some of the field investigators had noted, for instance, how often individual troop members hid when they engaged in activity deemed illicit by the dominant animals. Sure enough, when Byrne and Corp matched neocortex size with the number of attempts to deceive, they found that the bigger the neocortex (either in absolute terms, or relative to the rest of the animal's brain), the more deceptions were observed.

It's useful to remember that the size of the human brain is largely the result of its bigger neocortex—a structure that apparently evolved, at least in part, both to deceive and to detect others' attempts at deception. Poker, anyone? ("Neocortex size predicts deception rate in primates," *Proceedings of the Royal Society of London* B 271:1693–99, August 22, 2004) —*Stéphan Reebs*

HIGH SEAS

Sailors' tales of braving bad weather and choppy waters have been standard fare for centuries. But even the crustiest old salt has nightmares about facing a rogue wave, the ultimate in mountainous seas. Just ask the crews of the *Bremen* or the



Victor Hugo, *My Destiny*, 1857

Caledonian Star. Early in 2001, both ships, with hundreds of tourists onboard, were nearly sunk by ten-story-high waves in the South Atlantic.

Until recently, definitive sightings of rogue waves have been rare, but now a team of investigators headed by Susanne Lehner, a marine physicist at the University of Miami in Florida, has not only confirmed their existence, but also discovered that they're disturbingly common. The team recently procured three weeks' worth of radar images of the world's oceans, supplied by European Space Agency satellites, and found more than ten waves whose height from trough to crest was greater than eighty feet.

What causes supersize waves? According to the investigators, currents at the boundary of an ocean gyre—such as the dangerous Agulhas Current at the western edge of the South Indian Ocean, or the Gulf Stream in the North Atlantic—can concentrate and magnify the energy of ordinary waves. By contrast, in regions of open ocean where currents are not a dominant force, prolonged storms, fast-moving fronts, or crossing seas might pump up run-of-the-mill waves to gargantuan proportions. (www.esa.int/esaCP/SEMOKQL26WD_index_0.html)

—*Jordan Paul Amadio*

Hex Wax

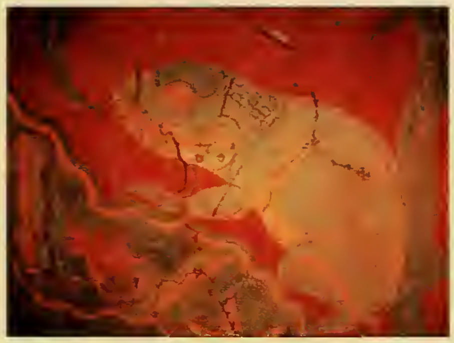
Honeycomb's hexagons: It's the wax, not the bees.

The precise, hexagonal cells of honeybee combs may conjure up visions of bees busily measuring lengths and angles. But a group of entomologists led by Christian W.W. Pirk of the University of Würzburg in Germany recently duplicated the bees' efforts, and found that the process is direct and simple. Wax melts when heated. When wax cylinders are packed together as tightly as possible and then heated, the interstices fill up spontaneously and the cylinders become six-sided. In the case of the honeycombs, the worker bees secrete small flakes of wax and probably surround themselves with the flakes to make the cylinders. Their own metabolism then raises the temperature to 104 degrees Fahrenheit, enough to melt the cylinders into hexagonal tubes. The bees' final touch is to add silk, which prevents the combs from melting further. ("Honeybee combs: Construction through a liquid equilibrium process?" *Naturwissenschaften* 91:350–53, July 2004) —*S. R.*

Red Shifts

Deep inside Earth, at the outer core, electric currents circulate through molten metal, giving rise to the magnetic field that envelops our planet. No doubt because those magnetohydrodynamic currents are complex and unpredictable, the Earth's magnetic poles shift and even flip as time goes by. The changes can be recorded in iron-oxide-bearing minerals on the Earth's surface. At the moment those magnetic minerals solidify, the iron oxides in them are permanently frozen in the direction the geomagnetic field is pointing at that time.

Where can such minerals be found? Among other places, in the red paint of certain pre-Columbian murals in Mexico. Avto Goguitchaichvili, a geophysicist at the Autonomous National University of Mexico, in Mexico City, and several colleagues have determined that the red pigments in murals at four Mexican archaeological sites hold iron-oxide-bearing hematite and magnetite, and thus exhibit "remnant magnetism." Well-dated sites in Europe and the southwestern United States have already provided a 4,000-year historical record of shifts in the Earth's magnetic field, and so investigators can now compare the remnant magnetism of the less well-dated New World sites with the historical record and determine precisely when a mural was created. ("Pre-Columbian mural paintings from Mesoamerica as geomagnetic field recorders," *Geophysical Research Letters* 31:L12607, June 22, 2004) —*T.J. Kelleher*



Mural in Red Temple at Cacaxtla, Mexico (detail), A.D. *600–900*

Before the Invention of Pumpkin Pie

John P. Hart, an archaeologist at the New York State Museum in Albany, has an obsession with gourds. The seeds of the wild squash, ancestor of the pumpkin, have been discovered at archaeological sites from Illinois to Maine, dating to some seven millennia ago, several thousand years prior to the earliest evidence for the domestication of squash.

Familiar pumpkin descended from bitter seeds.

Gourds, as Hart himself has demonstrated, make good fishnet floats, and they obviously also work well as containers. And when dried, their abundant seeds are one-quarter protein, nutritionally similar to sunflower seeds. But one bite into the staggeringly bitter seeds of a modern-day wild squash such as the Ozark gourd *(Cucurbita pepo)* makes clear that if they were eaten, it certainly wasn't raw.

At the suggestion of several attendees at his public lectures, Hart tried the method known to have been used historically by Native Americans to leach tannic acid from acorns and thus make them edible: soaking or boiling the partly crushed materials in water mixed with wood ash. Sure enough, two days of soaking, or just twenty minutes of boiling, removed the bitterness from the gourd seeds. This trick, says Hart, may have enabled the first Americans to harvest the seeds of wild squashes for food, until they stumbled on the nonbitter mutants eventually chosen for cultivation. ("Can *Cucurbita pepo* gourd seeds be made edible?" *Journal of Archaeological Science,* in press) —*S.R.*

A TASTE OF OUR OWN MEDICINE

In football, one team's offense is pitted against the other team's defense, and vice versa. Much the same happens in humanity's battle against bacteria, except that some of our adversaries seem to have cloned our defense to fight our offense.

Bacteria that parasitize other organisms must first break down some of their host's tissues before setting up shop. The bacterial tools of choice are protein-slicers called proteases. Animals retaliate with protease inhibitors. One of the gene families responsible for making protease inhibitors is present in all animals, but absent from all plants, and so biologists have regarded it as an innovation that probably appeared at the dawn of animal evolution.

Imagine the surprise of Aidan Budd of the European Molecular Biology Laboratory in Heidelberg, Germany, when he and his colleagues discovered homologous genes in certain bacterial species. Because those bacteria generally invade the body and, like many bacteria, can collectivize some of their genetic resources, the investigators think that a forerunner of at least one such bacterial species once stole the gene from an animal (an extremely rare event) and shared it with other parasitic bacteria.

What good is the ill-gotten gene to the bacteria? All animal immune systems make their own offensive proteases; perhaps the thieves can now turn the tables and render animal proteases null and void. ("Bacterial α_2-macroglobulins: Colonization factors acquired by horizontal gene transfer from the metazoan genome?" *Genome Biology* 5:R38, May 26, 2004; genomebiology.com/2004/5/6/R38) —*S.R.*

SIT UP WHEN YOU SNOOZE

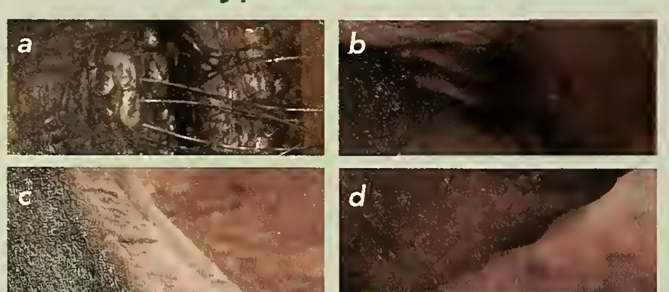
Sloth in sleep mode

Quick, name a mammal that sleeps upside down. If you said bats, take a bow. If you said sloths, you've fallen for a persistent myth. Sloths do travel upside down along tree branches, hanging by all four feet. But when they snooze, they sit. According to Marcus Clauss, a physiologist at Ludwig Maximilians University in Munich, Germany, there's a good reason for that: gravity.

Unlike bats, sloths are herbivores. But they aren't ruminants, and so they don't get a second chance (as, say, cows and sheep do) to process all the fibrous stuff they eat. At any given moment, leaf bits of various sizes are making a slow journey through a sloth's stomach. Because the larger particles are not only harder to digest but also take up space, the best strategy is to get rid of them as soon as possible.

Clauss proposes that in a sitting sloth, those larger bits, which are less dense, rise to the top of the stomach—right near the duct that ushers them into the intestines; meanwhile, the smaller, denser particles sink to the fluid-filled bottom of the stomach and are thoroughly digested. Proper digestion, then, is best achieved in a vertical position. The action of gravity, says Clauss, may account for the resting postures of other herbivores as well—horses, for instance, stand while they sleep. ("The potential interplay of posture, digestive anatomy, density of ingesta, and gravity in mammalian herbivores: Why sloths do not rest upside down," *Mammal Review* 34:241–45, July 2004) —*S.R.*

Cryptic Creatures



Only three of these pictures are close-ups of the same animal. Which one doesn't belong? (Answer on page 37)

Bluer Means Better

Throughout nature, color acts as a signal. Juan Moreno, an ornithologist at the National Museum of Natural Sciences in Madrid, and his colleagues think the bright blue eggs of the pied flycatcher are no exception. But what, and to whom, are the eggs signaling? After all, eye-catching color would seem an open invitation to scavenging predators, yet many of the world's birds lay blue or green eggs. So what's the story?

Moreno and his team recently found evidence that the signal is aimed at Dad. In pied flycatchers, both parents care for the nestlings, but the male needs prodding. Moreno's team noted that the brighter the blue of the eggshells, the larger the eggs and the

For many birds, blueness is a mark of quality.

more food the males brought to the nestlings. The blue color comes from a substance that's taxing to produce but has beneficial, antioxidant properties. Hence, by laying big, azure eggs, the female may—a bit like the cartoon millionaire who lights his cigar with a banknote announcing that she's got resources to burn, and that she's passed plenty of them along to her offspring so they can weather the stresses ahead. That message may help convince Dad to do his bit. ("Egg colouration and male parental effort in the pied flycatcher *Ficedula hypoleuca*," *Journal of Avian Biology* 35:300–304, July 2004)

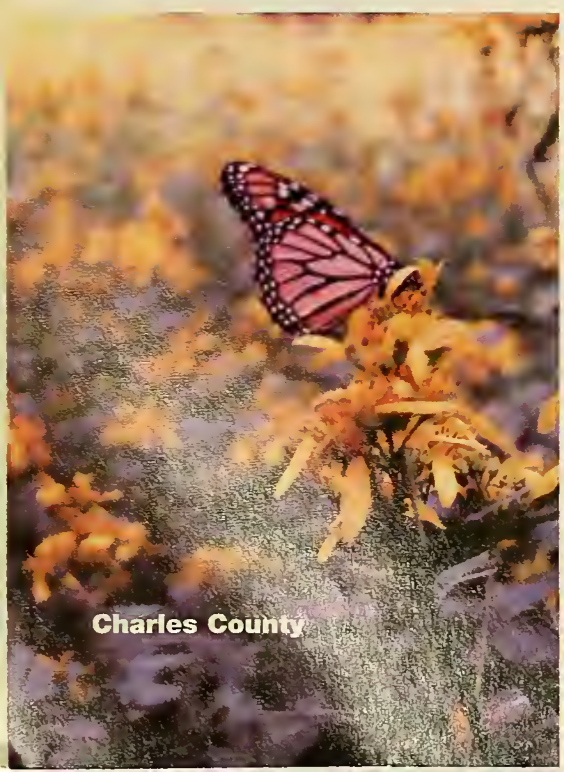
—*Nick W. Atkinson*

THE GREAT OUTDOORS

The Fall/Winter Getaway Guide

Autumn, when Mother Nature is in fall glory, is the perfect setting to embark on an adventure outdoors

Autumn, as the leaves turn color and the landscapes become brilliant, is a perfect time to explore the Great Outdoors. Stay right here in the United States and head to Maryland, Alabama, Georgia, or Pennsylvania, where you can enjoy nature at its peak while you camp, hike, fish, boat, watch birds, or simply relax and enjoy the setting.


Charles County

Start your Maryland adventure in the Capital Region, just outside of Washington, D.C. Pretty **Frederick County**, set amid the Appalachian Mountains and Piedmont Plateau, is dotted with farms, vineyards, and covered bridges. Lilypons Water Gardens (301-874-5503), in Buckeystown, is the largest water garden in the United States, with over 300 acres of lily blossom and lotus blossom ponds. It is also a good place for bird watching; call ahead (800-999-5459) to book a guided bird walk, where you might see tree swallows, red-winged blackbirds, egrets, herons, warblers, purple martins, and mocking birds. From October to February, the gardens are open from Monday to Saturday from 9:30 a.m. to 4:30 p.m.

In **Montgomery County**, hike through the forty-acre Audubon Naturalist Society sanctuary (301-652-9188) in Chevy Chase, which has a self-guided nature trail, pond, wildflower meadow, and butterfly garden. You might also hike or bike on the nearly level towpath in the C&O Canal National Historic Park

Lillypons Water Gardens - Frederick County

and view the Great Falls of the Potomac River. The canal, which operated from 1828 to 1924, follows the route of the Potomac River, and hundreds of original structures, including locks, lock houses, and aqueducts, remain.

Situated on southern Maryland's coastal plain, **Charles County** is surrounded by water: on the east and south by the Potomac River, on the west by the Wicomico River, and on the north by the Mattawoman Creek. Fall is a perfect time to try the new trail at Friendship Farm Park, an excellent place to kayak, canoe, or boat and to spot bald eagles and monarchs amid the autumn foliage.

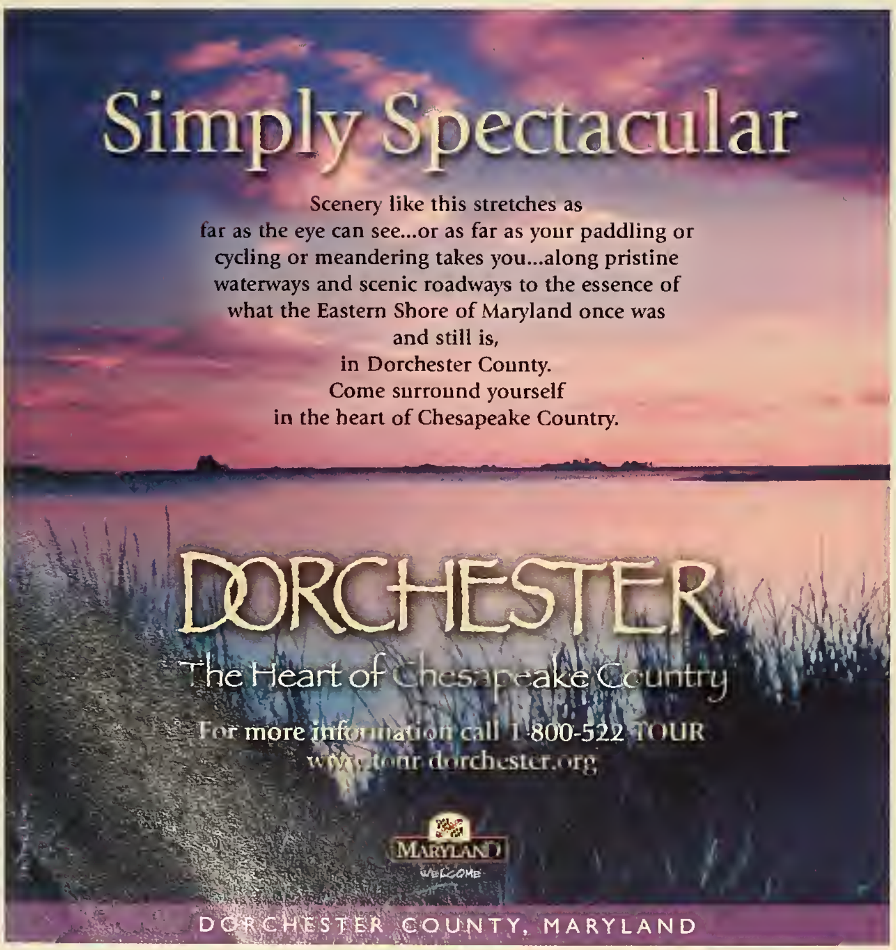
Fish for stripers in the Potomac, look for eagles in the Nanjemoy Creek, kayak through the Blackwater.

Nanjemoy Creek, which winds through miles of scenic marshes abounding with wildlife, has a large population of bald eagles. A free boat ramp, adjacent to deep water, is a designated free fishing zone (no license required by shoreline and pier anglers). Fishing enthusiasts also should explore the Potomac River, home to largemouth and striped bass ("rockfish" to the locals). Stripers, Maryland's state fish, are found year-round here. The main river, as well as its Maryland and Virginia tributaries, can be fished with a Maryland tidal license ($14, or buy a 5-day license for $6).


Kevin Karlson

Nearby **Calvert County** is holding two special events this fall: the Rock 'N The Bay Seafood Festival (October 2, 11:00–7:00 p.m.; tel. 410-535-2577) and the Patuxent River Appreciation Days (October 9–10, 10:00–5:00 p.m.; tel. 410-326-2042). The seafood festival, at Kellam Field in Chesapeake Beach, features entertainment by Deana Bogart, a seafood cook-off, and a host of food vendors. The annual river appreciation days, at the Calvert Marine Museum in Solomons, celebrate Maryland's largest interstate river with boat rides, visits to the Drum Point Lighthouse, music, and children's activities.

Across the Bay, visit **Dorchester County**, in the state's "Lower Shore." Located between the Chesapeake Bay and the Atlantic Ocean, this part of Maryland is known as the "land between the waters." In Cambridge, the Blackwater National Wildlife Refuge is an important nesting and




Kevin Karlson
Red fox kits

feeding area for wild geese, osprey, swans, owls, muskrats, bald eagles, peregrine falcons, and rare Delmarva fox squirrels. The Ninth Annual Blackwater Open House, on October 2 (8:00 a.m. – 4:00 p.m.), would be a wonderful way to become acquainted with the sanctuary, which was founded in 1933.

But for a more contemplative exploration, plan to canoe or kayak through the Blackwater River as it makes its way through open water and marsh (purchase a waterproof paddling map at www.friendsofblackwater.org before you enter a trail). As you explore the tidal marshes and brackish ponds, remember to look upward from time to time: for osprey and terns diving in the sky and bald eagles on top of the tallest pines. In October and November, as many as 50,000 migrating geese, ducks, and tundra swans stop at the refuge during their voyage along the Atlantic Flyway.

Just north of Dorchester is **Talbot County**, also bordering the Chesapeake Bay. Tilghman Island Marina is a perfect place to rent a sailboat, canoe, kayak, crabbing or fishing boat, or even a bicycle. Here, you can book a half-day kayak tour of the Poplar Islands combined with a tour around the Chesapeake Bay shore. The towns of Easton, St. Michaels, Tilghman Island, and Oxford are known for their delectable food: don't leave Talbot without a meal at one of their fine restaurants.

After exploring Talbot, head to Maryland's only ocean-front coun-

Canoeing in Worcester County; least tern and chick

Kevin Karlson

ty: **Worcester**. Here, the Pocomoke River State Park has nature trails through stands of loblolly pine and cypress swamps, indoor exhibits, and areas for bird watching and fishing (you will need to obtain a Chesapeake Bay Sports Fishing License to fish the Pocomoke and nearby creeks). In Snow Hill, the county seat, enjoy Celtic music and Highland culinary delights at the Chesapeake Celtic Festival (October 2–3; admission is $11for adults and $3 for children; tel. 410-632-2032). The festival takes place at the Furnace Town Living Heritage Museum, a nineteenth-century industrial village set in the Pocomoke Forest, with exhibits to view and nature trails to explore.

In **Alabama's Gulf Coast and Orange Beach**, fall brings a migration of monarch butterflies and a burst of vibrantly hued wildflowers. Hikers will enjoy several Alabama wildlife areas where they can gaze at gators and shorebirds. Bon Secour National Wildlife Refuge (251-540-7720), a 6,200-acre refuge with beach access, is a great place to see the large migratory bird stopover in October. Catch bass, bluegill, and bream in the 40-acre freshwater Gator Lake; or cast for trout and flounder or scoop up crabs in the nearby lagoon.

For a deep-sea adventure, take a charter trip for some inshore and offshore saltwater fishing. Go after elusive blue marlin, yellow fin tuna, amberjack, cobia, and red snapper, or take an educational dolphin sightseeing tour.

In Fort Morgan, don't miss the Fall Bird Banding (October 9–23; 251-968-7511), sponsored by the Hummer/Bird Study Group, which will record height, weight, health, and species of the many birds heading south for the winter. The Alabama Coastal Birdfest (October 14–17; 251-990-0420) in Fairhope features birding field trips along the state's Coastal Birding Trail.

October is fishing month on **Little St. Simons**, a privately owned barrier island off the Georgia coast. Each fall, the island's Lodge becomes an angler's paradise as redfish, sea trout, flounder, and other species migrate through its tidal creeks and near-shore waters. Call for the best fishing tides (tel. 888-733-5774). Little St. Simons will feature instruction in both fly-fishing and surf-casting and offer chef-prepared menus loaded with "Today's Catch."

In the fall, the **Pocono Mountains** of Pennsylvania are ablaze with fall colors. And until November 2, leaf peepers can call a twenty-four-hour fall foliage hotline (570-421-5565) telling them exactly when and where to catch peak colors through-

Tim Tadder Photography

Watermen

Learn to fly-fish in Georgia or look for coastal birds alongs trails in Alabama

Sea oats at sunset and historic Fort Morgan - Alabama Gulf Shores

Photos: Alabama Gulf Coast Convention & Visitors Bureau

out the region. The Stourbridge Rail Line, in Honesdale, is offering Fall Foliage Excursions (October 2–3, 9–10, 16–17). These five-hour train rides ($25 adults, $15 for children) let visitors revel in the breathtaking colors along the shimmering Lackawaxen River and view deer, herons, bears, and more.

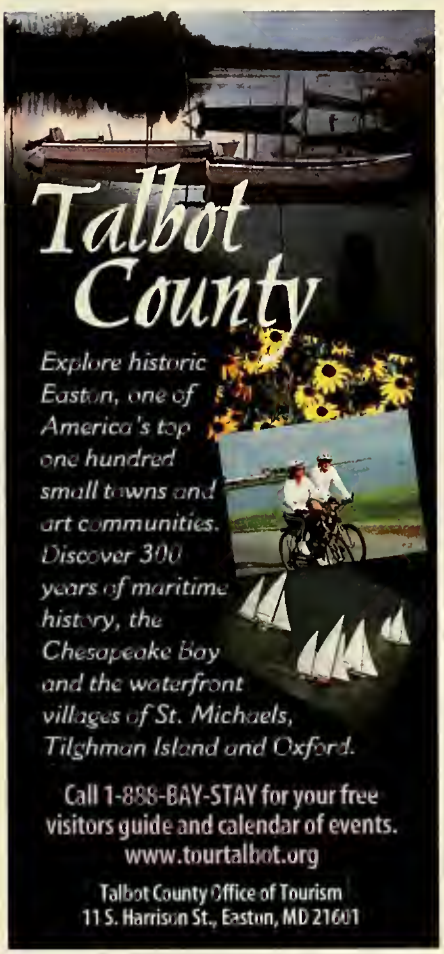
In addition to brilliant colors, the Poconos offers visitors numerous falls festivals. The 20th Annual Shawnee Autumn Balloon Festival (October 15–17, Shawnee Inn & Golf Resort, Shawnee-on-Delaware) includes a balloon glow and fireworks Friday night, hot-air balloon launches Saturday and Sunday (with a spectacular view of the foliage), exhibits, rides, and plenty of fun for the entire family.

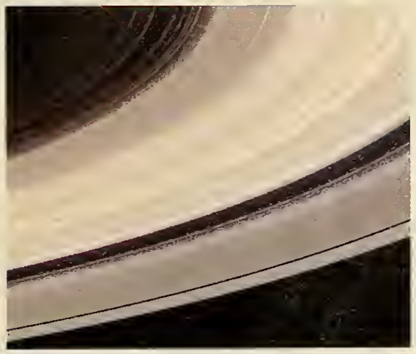
Kevin Karlson

Bobolink; flattop goldenrod in bloom in fall - Little St. Simons Island

Before you embark on any end-of-the-year adventure—whether to Maryland, Alabama, Georgia, or Pennsylvania—pick up a free copy of **L.L. Bean**'s Fall Catalog or the L.L. Bean Guide to Winter Warmth (800-441-5713). You'll find hundreds of great buys, from time-tested classics to a wide selection of new items, to make your autumn and winter adventures easier. Visit llbean.com to browse through a variety of outfits and a full array of hiking gear. The website's "Explore the Outdoors" section offers products that will prepare you for any camping, hiking, cycling, fly-fishing, paddling, or winter sports.

If you are planning a birding trip, first browse www.bigpockets.com or request a catalog (877-247-3758). **BigPockets** is the first company to design and manufacture clothing specifically for birding, and it also carries useful gear for the field. New products recently added to the website include the Going Birding insulated lunch box and a lightweight Daypack-size Dry Sack. This useful and handy sack protects small valuables, such as cameras, from water.

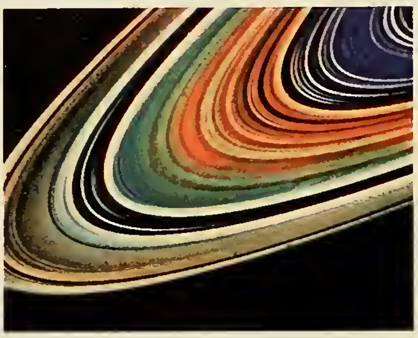




Ringside Seat

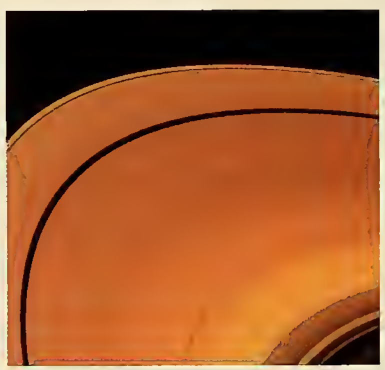
Sometimes, in science as in boxing, you want to be up close; sometimes you want to keep your distance.

By Neil deGrasse Tyson



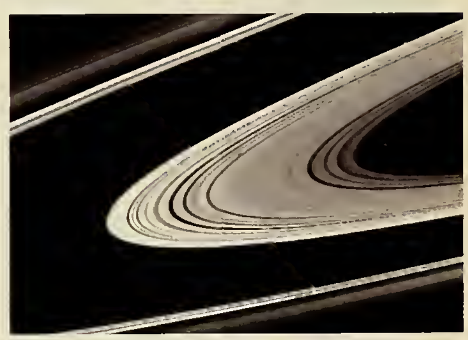
Imagine you're strolling along a boulevard on a crisp autumn day. A block ahead of you is a silver-haired gentleman wearing a dark blue suit. It's unlikely you'll be able to see the jewelry on his left hand. If you quicken your pace and get within thirty feet of him, you might notice he's wearing a ring, but you won't see its crimson stone or the designs on its surface. Sidle up close with a magnifying glass and—if he doesn't alert the authorities—you'll learn the name of the school, the degree he earned, the year he graduated, and possibly the school emblem. In this case, you've correctly assumed that a closer look would tell you more.

Now imagine you're gazing at a late-nineteenth-century French pointillist painting. If you stand ten feet away, you might see men in top hats, women in long skirts and bustles, children, pets, shimmering water. Up close, you'll just see tens of thousands of dashes, dots, and streaks of color. With your nose on the canvas you'll be able to appreciate the complexity and obsessiveness of the technique, but only from afar will the painting resolve into the representation of a scene. It's the opposite of your experience with the ringed gentleman on the boulevard: the closer you look at a pointillist masterpiece, the more the details disintegrate, leaving you wishing you had kept your distance.



Which way best captures how nature reveals itself to us? Both, really. Almost every time scientists look more closely at a phenomenon, or at some inhabitant of the cosmos, whether animal, vegetable, or star, they must assess whether the broad picture—the one you get when you step back a few feet—is more useful or less useful than the close-up. But there's a third way, a kind of hybrid of the two, in which looking closer gives you more data, but the extra data leave you extra baffled. The urge to pull back is strong, but so, too, is the urge to push ahead. For every hypothesis that gets confirmed by more detailed data, ten others will have to be modified or discarded altogether because they no longer fit the model. And years or decades may pass before the half-dozen new insights based on those data are even formulated. Case in point: the multitudinous rings and ringlets of the planet Saturn.

Earth is a fascinating place to live and work. But before Galileo first looked up with a telescope in 1609, nobody had any awareness or understanding of the surface, composition, or climate of any other place in the cosmos. In 1610 Galileo noticed something odd about Saturn; because the resolution of his telescope was poor, however, the planet looked to him as if it had two companions, one to its left and one to its right. Galileo



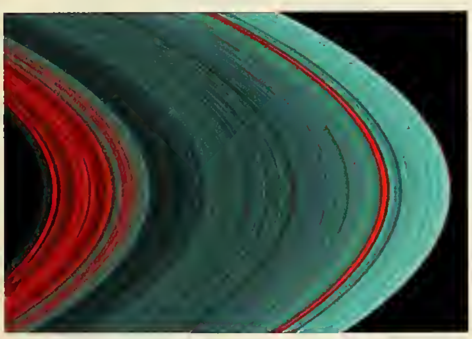
formulated his observation in an anagram, *smaismrmilmepoetaleumibunenugttauiras,* designed to ensure that no one else could snatch prior credit for his radical and as-yet-unpublished discovery. When sorted out and translated

Rings of Saturn, as seen in natural color (top left), backlit (fourth from left), ultraviolet (fifth from left), and false color from the Latin, the anagram becomes: "I have observed the highest planet to be triple-bodied." As the years went by, Galileo continued to monitor Saturn's companions. At one stage they looked like ears or handles; at another stage they vanished completely.

In 1656 the Dutch physicist Christiaan Huygens viewed Saturn through a telescope of much higher resolution than Galileo's, built for the express purpose of scrutinizing the planet. He became the first to interpret Saturn's "ears" as a simple, flat ring. As Galileo had done half a century earlier, Huygens wrote down his groundbreaking but still preliminary finding in the form of an anagram. Within three years, in his book *Systema Saturnium,* Huygens went public with his proposal.

Twenty years later Giovanni Cassini, the director of the Paris Observatory, pointed out that there were two rings, separated by a gap that came to be known as the Cassini Division. And nearly two centuries later, the Scottish physicist James Clerk Maxwell won a prestigious prize for showing that Saturn's rings are not solid, but made up instead of numerous small particles in their own orbits.

By the end of the twentieth century, seven distinct rings, lettered A through G, had been identified. Not only that, the rings themselves turn out to be made up of thousands upon thousands of bands and ringlets. In the most recent photographs available at the time this article went to press—taken this past July by the *Cassini* spacecraft from a mere 4 million miles away—some ringlets look braided, and others have mysterious kinks. Some are opaque; others are translucent. Some are pinkish; others are ivory; still others are gray.

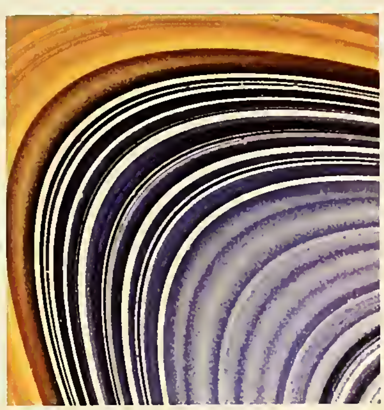


So much for the "ear theory" of Saturn's rings.

Several Saturn flybys preceded the one by *Cassini: Pioneer 11* in 1979, *Voyager 1* in 1980, and *Voyager 2* in 1981. Those relatively close inspections all yielded evidence that the ring system is more complex and more puzzling than anyone had imagined. For one thing, the particles in some of the rings are corralled into narrow bands by the so-called shepherd moons: teeny satellites that orbit near the rings. The gravitational forces of the shepherd moons tug the ring particles in different directions, sustaining numerous gaps between the rings.

Density waves, orbital resonances, and other quirks of gravitation in multiple-particle systems give rise to passing features within and among the rings. Ghostly, shifting "spokes" in Saturn's B ring, for instance—recorded by the *Voyager* space probes and presumed to be caused by the planet's magnetic field—have mysteriously vanished from *Cassini*'s close-up views.

What kind of stuff are Saturn's rings made of? Water ice, for the most part—though there's also some dirt mixed in, whose chemical makeup is similar to that of one of the planet's larger moons. The cosmochemistry of the environment suggests that Saturn might once have had several such moons. The ones that seem to have gone AWOL may have orbited too close for comfort to the giant planet and gotten ripped apart by Saturn's tidal forces.



Saturn, by the way, is not the only planet with a ring system. Close-up views of Jupiter, Uranus, and Neptune—the rest of the Big Four gas giants in our solar system—show that each planet has a ring system of its own. The Jovian, Uranian, and Neptunian rings weren't discovered until the late 1970s and early 1980s, because, unlike Saturn's majestic rings, they're made largely of dark, unreflective substances such as rocks or dust grains.

The space near a planet can be dangerous if you're not a dense, rigid object. Many comets and some asteroids, for instance, resemble piles of rubble, and they swing near planets at their peril [*see "Vagabonds in Space," by Neil deGrasse Tyson, July/August 2004*]. The magic distance, within which a planet's tidal force exceeds the gravity holding together that kind of vagabond, is called the Roche limit—discovered by the nineteenth-century French astronomer Édouard Albert Roche. Wander inside the Roche limit, and you'll get torn apart; your disassembled bits and pieces will then scatter into their own orbits and eventually spread out into a broad, flat, circular ring.

I recently had some upsetting news about Saturn's rings from a colleague who studies them. He noted with sadness that the orbits of their constituent particles are unstable, and so the particles will all be gone in an astrophysical blink of an eye: 100 million years or so. My favorite planet, shorn of what makes it my favorite planet! Turns out, fortunately, that the steady and essentially unending accretion of interplanetary and intermoon particles may replenish the rings. The ring system—like the skin on your face—might be persistent, even if its constituent particles are not.

Other news is carried in the close-up pictures of Saturn's rings sent to Earth by *Cassini*. What kind of news? "Mind-boggling" and "startling," to quote Carolyn C. Porco, the leader of the mission's imaging team and a specialist in planetary rings at the Space Science Institute in Boulder, Colorado. Here and there in all those curves are features neither expected nor, at present, explainable: scalloped ringlets with extremely sharp edges, particles coalescing in clumps, the pristine iciness of the A and B rings compared with the dirtiness of the Cassini Division between them. All these new data will keep Porco and her colleagues busy for years to come, perhaps wistfully recalling the clearer, simpler view from afar.

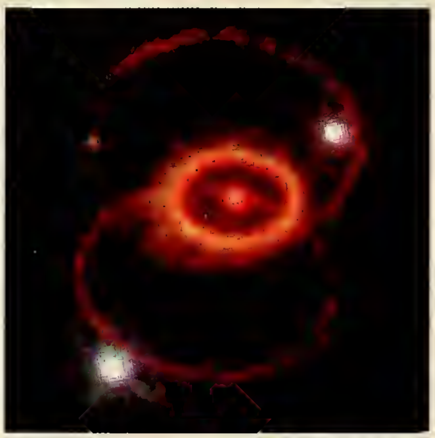
Several years ago, astronomers discovered another, unexpected ring system, nowhere near the solar system and not at all like the rings of a planet. The rings surround supernova 1987A, a former superstar that broadcast its demise not very long ago in a galaxy not too far away.

Supernovas—at least the ones of the same type as 1987A—are massive, brilliant exploding stars that, far from being new (the meaning of the Latin word *nova*), are actually going through their death throes. After chugging along for millions of years, such stars blow themselves to smithereens within days. Your typical supernova becomes as bright as a trillion suns for a few weeks, and then, within months, fades into a barely visible corpse, surrounded by a mildly radiant, gnarly mass of dust known as a supernova remnant.

Models of the birth, life, and death of stars predict that one or two supernovas ought to explode in the Milky Way each century. Yet our galaxy has served up only five in the past thousand years, and not one since 1604. So we're badly overdue.

Supernova 1987A, named for the year that the news of its demise reached Earth, was bright enough to be visible at night to the unaided eye. In recent times, dozens of dim, distant supernovas have been discovered each year, but 1987A was by far the brightest in the era of advanced technology.

Supernovas may be common enough in distant galaxies, but bright ones nearby are rare, memorable, and virtually unpredictable. Two dazzlers appeared in close succession several centuries ago—Tycho Brahe's nova of 1572 and Johannes Kepler's nova of 1604—but both of them took place before Galileo had even built his first telescope. Each one was observed daily by at least one great astronomer, whose only detectors were his eyeballs.



Three rings of Supernova 1987A (the two bright spots on the larger rings are unrelated stars)

The two supernovas afforded disturbing evidence that the celestial realm was not so immutable as the ancients and the faithful had believed.

From the 1920s onward, much effort has gone into classifying and explaining the different kinds of supernovas: Type I's tend to be much more luminous but wane faster than Type II's. Type I's—specifically the fairly common Type Ia—derive from an already dead white dwarf star that explodes because of excess material dumped on it from a bulbous, expanding, red-giant companion star. Type II's derive from a supermassive red giant whose core collapses when it runs out of fuel, and then rebounds in a titanic explosion.

Sounds cut and dried, doesn't it? Twentieth-century astrophysicists had seen plenty of supernovas explode in faraway galaxies, and felt they had more or less accounted for what makes the different types do what they do—the mass, the core, the location, the abundance of hydrogen. But they kept their eyes peeled for something closer, just in case.

Sure enough, on February 24, 1987, at Las Campanas Observatory in the mountains of northern Chile, a Canadian astronomer named Ian Shelton, now at the University of Toronto, was examining a just-developed photograph of the galaxy nearest the Milky Way, known as the Large Magellanic Cloud, which is prominent in the Southern Hemisphere. To Shelton's amazement, the photograph, taken the previous night, included a stunningly bright object that had never been seen before. In disbelief, Shelton dashed outside, looked up, and there it was: the first naked-eye supernova in nearly four centuries.

By the next night, professional and amateur sky watchers alike had turned nearly every southerly telescope on what had formerly been the star Sanduleak –69° 202. Although earthlings watched the poor thing explode in 1987, it had actually blown up about 170,000 years earlier: light takes time to travel, and Sanduleak's home galaxy, the closest one to the Milky Way, lies about 170,000 light-years from Earth.

Shelton happened to catch Supernova 1987A on the upstroke, giving observers a rare opportunity, because the explosion took mere days to rise to peak brightness. Before, during, and after the peak, astrophysicists brought out all the big guns. The most powerful telescopes in the world, spanning all wavelengths of the electromagnetic spectrum, were retooled and reprogrammed to observe the dying star. Coordinated observations around the world tracked its progress from sunset to sunrise, and from time zone to time zone. And even before anybody saw anything, several underground detectors had recorded the arrival of a burst of neutrinos—fast-moving, ghostly particles issuing from the star's collapsed core and darting unimpeded through space.

So we got up close and personal with this one, acquiring the most ex-

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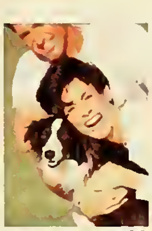
Doubles as a camcorder



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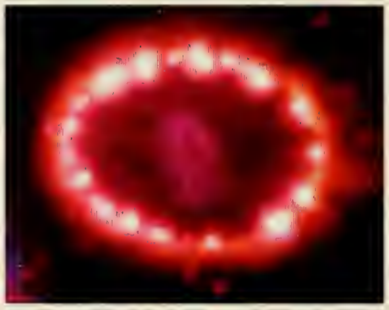
tensive data anyone could have hoped for at the time. And guess what? Supernova 1987A was certainly no Type I event, but it didn't quite look like a Type II supernova either. Some core-collapse predictions more or less held up: the neutrino flash, the approximate energy budget of the entire affair, the signature of some freshly minted elements. But as Dick McCray, a supernova guru at the University of Colorado at Boulder, put it, there were some curveballs as well.

The first anomaly was that Sanduleak, the progenitor star, was a blue supergiant, whereas Type II supernovas supposedly came exclusively from red supergiants. And then there were the rings—three of them. X rays from the explosion lit up the first one in 1989. Soon two other, larger rings came into view [*see photograph of all three on page 30*]. In the next decade the trio faded, but when the awesome shock wave of the initial blast finally hit the central ring, segments of that ring began to reignite, as though luminous pearls were being added to a necklace [*see photograph on this page*].

What was going on? Explosions were supposed to produce spherical messes, not flat rings. Had the star exploded in ways unimagined, or were preexisting gaseous structures in the vicinity of the supernova the real instigators? Suddenly astrophysicists had a whole lot of data in the service of questions no one had ever thought to ask.

Supernova 1987A has become one of the most studied objects in the history of astronomy. Contrary to what you might suppose, the number of research papers on a subject is strongly correlated with the level of our collective ignorance about it. If the object were understood, astrophysicists would quickly publish what they know and shift their attention to the next problem. With that disclaimer, I offer the current best guess about the origin and structure of this three-ring circus.

The size and growth rate of the central ring suggests it was ejected about 20,000 years before the explosion. Its luminous "pearls" occupy less than 1 percent of the ring's total mass, and may simply be the inner edge of a region of gas extending well beyond the visible ring itself. The delay of almost three years between the explosion and the ring-lighting ceremony was simply the time it took for the remains of the explosion, traveling at a million miles an hour, to cross the evacuated inner regions of the space around the original star and overtake the slower-moving ejected gas.



Central ring of Supernova 1987A as it looked on November 28, 2003, shocked into luminescence by the supernova blast wave

Why the pearls? Some parts of the ring trail closer to the explosion than do others, and so they get slammed first. By 2002, more than a dozen hotspots of visible light had appeared, but McCray expects that within a few more years the entire ring will be ablaze, illuminating the rest of the gas in its midst and revealing the evolving structure of the entire supernova remnant.

As for the two larger rings, they may well be the inner surfaces of an even larger envelope of gas, not yet glowing from shock waves but shining instead because of high-energy radiation emitted by the inner ring. The whole thing is a work in progress, and astrophysicists are getting the chance to watch it happen, both with large ground-based telescopes and with top-shelf orbiting telescopes such as the Chandra X-ray Observatory and, of course, the Hubble. Once again, data aplenty have left us baffled, yet no one doubts that more data is preferable to less.

Could it be that rings are natural by-products of explosions? In September 1999, Chandra, having just barely been launched, discovered a ring of high-energy particles around the heart of another supernova remnant, the Crab Nebula. The Crab is the child of the great supernova of 1054 (observed and recorded by astrologers in China and Anasazi Indians in North America). Perhaps the X rays come from ejected particles that have fallen back, only to be flung into space again by the rapidly spinning neutron star lurking at the center of the nebula.

In the meantime, Kate Scholberg, a physicist at MIT, has been working to make sure scientists awaiting the next nearby supernova are prepared. She's been instrumental in setting up the Supernova Early Warning System (SNEWS), a network of nine neutrino detectors that stretches from the South Pole to a zinc mine deep in a mountain northwest of Tokyo. As soon as those distant neutrinos arrive on Earth, fresh from the core of a collapsed star, the network will go into high gear. Several hours later, the visible light from the supernova can be expected to arrive.

Will unanticipated, bewildering data emerge from that event? No doubt about it. For every puzzle we solve, we'll get two (or more) new ones. And not until we delve deep into those data—and get an even closer look at that pointillist painting and that gentleman's college ring—and then step back and try to see the patterns, will we know what answers we've unwittingly been sitting on, and what questions we have yet to ask.

[*This is part two of a two-part article.*]

Astrophysicist NEIL DEGRASSE TYSON *is the Frederick P. Rose Director of the Hayden Planetarium in New York City. He is also host of the PBS* NOVA *miniseries "Origins," which premiered in two 2-hour segments, 8–10 P.M. ET, on September 28 and 29* (www.pbs.org/wgbh/nova/origins/).

Climb Every Waterfall!

To reach competitor-free fish nirvana, Hawaiian gobies scale sheer cliffs to reach pools 2,000 feet above the sea.

By Peter T. Sherman and Perri K. Eason

Hawai'i is renowned for its coral reefs teeming with rainbow-hued fishes, but one of the state's most remarkable aquatic species lives in freshwater mountain streams on the five largest islands. On the northern side of the Big Island (Hawai'i), for instance, the waters of Hi'ilawe Falls cascade down a cliff more than a thousand feet high. Some day, if you make your way to the top of the falls, take a look in the pool above the precipice. There you will see only one species of fish, a mottled brown goby that grows, on average, to about two and a half inches long. The Hawaiians call it the *'o'opu alamo'o,* "the local fish with a lizard-like head." If (apart from its Hawaiian name) this fish doesn't seem very impressive at first, think about the following questions: How did a freshwater fish get there, 2,500 miles from the nearest continental landmass? And how did it get to the top of the Big Island's highest waterfall?

The main Hawaiian Islands began to form about 5.5 million years ago, as the Pacific tectonic plate moved over a "hotspot" in the Earth's mantle that spewed enough lava onto the ocean floor to build islands up from the depths. The five largest islands formed in order—Kauai, Oahu, then Molokai and Maui (originally joined), and the Big Island—as the ocean floor slowly inched across the hotspot and toward the northwest. The Big Island still sits over part of the hotspot, growing daily thanks to Kilauea, one of the most active volcanoes on Earth. None of the island's surface lavas are more than 700,000 years old.

Although lush with life today, the islands were all once as barren as the freshly brewed volcanic rock that is still cooling along the southern coast of the Big Island. Plant spores and seeds that drifted on currents of air or ocean were

Hi'ilawe Falls, on Hawai'i's Big Island, drops more than 1,000 feet, a seemingly insurmountable obstacle to any fish traveling upstream. But the fry of the 'o'opu alamo'o (Lentipes concolor), a species of goby native to the main Hawaiian islands, make the ascent after spending a few months at sea.

the first to colonize the newly formed landscape. Animal life followed more slowly. Birds and arthropods were the first to arrive, and with the land to themselves, they evolved into thousands of species that occur only in these islands. No amphibian or terrestrial reptile, and only one terrestrial mammal, the hoary bat, completed the journey on its own. People were the late-comers: not until sometime between 1,000 and 1,500 years ago did they first reach the islands. The original settlers were Polynesians, and with them began the rapid introduction, both intentional and inadvertent, of exotic fauna and flora.

With a fertile imagination, you might think that the ancestors of the goby that now lives at the top of Hi'ilawe Falls had somehow been conveyed there, along with the pool itself. Perhaps, for instance, in the course of geologic time, the 'o'opu alamo'o's ancestors frequented a tidal pool that slowly became isolated from the ocean and then was uplifted by the volcanic forces of island building. But the Hawaiian islands have grown as lava was added to their upper surface; any pool containing fish would be boiled away rather than elevated. The true story of the 'o'opu alamo'o is even more fantastic.

The ancestors of this goby not only had to be athletic enough to make their way to dizzying heights. They also had to overcome what, to most aquatic creatures, is an even more formidable obstacle: the invisible but fundamental barrier between freshwater and saltwater. There are two ways they could have reached their present habitat, and each entails that transition. Either they must have originated as freshwater fish on the mainland or some other island, and then have found a way across open ocean waters. Or, if they were saltwater fish, they had to make a transition from saltwater to freshwater life.

But there's more. It turns out that not only the ancestors, but each new generation of 'o'opu alamo'os has to overcome the same two hurdles. Although the young hatch in the upper streams and pools, they are soon swept downstream and over waterfalls to the sea. There they fend for themselves, growing from hatchling to fry in a marine environment. If they make it through that hurdle, they find their way to an estuary, make the transition to freshwater, and finally undertake the arduous climb to the tops of the waterfalls. They accomplish this journey through some remarkable adaptations as well as single-minded effort.

Adult 'o'opu alamo'o, shown here at about one and three-quarters times actual size, has a sucker on its chest formed by the fusion of its pelvic fins. Gobies that live in intertidal marine environments use this kind of appendage to cling to rocks battered by waves. The 'o'opu alamo'o fry use the sucker to cling to rocks as they make their way up freshwater streams.

But it's all worth the trouble: in contrast to the return of spawning Pacific salmon to the stream of their birth, a goby's arrival brings not death from exhaustion, but a quiet adolescence and adult life.

The 'o'opu alamo'o *(Lentipes concolor)* is one of just five species of freshwater fish native to the Hawaiian Islands. Three of the others are also gobies, and the fifth is a close goby relative called a sleeper, because of its sluggish behavior. That distribution is consistent with the pattern on most of the world's oceanic islands. Gobies are the fishes most often encountered in island streams, and in Pacific island streams, they are typically joined by sleepers. Yet most gobies and many sleepers in the world are marine. The most likely explanation is that the ancestors of the Pacific islands' native freshwater fishes were all saltwater fishes.

Marine gobies are typically bottom-dwelling fish that live in shallow water. Most species have an appendage that acts as a suction cup, formed by the fusion of the two pelvic fins. This "chest sucker" enables the gobies to attach themselves firmly to rocks and stay put despite heavy wave action. Many goby species have become adapted to living in the highest reaches of the intertidal zone, where they are often battered by waves or stranded in tide pools whenever the tide is out. Although sleepers lack a specialized sucker, they, too, often live in tide pools.

Cut off from the ocean for as long as twelve hours a day, tide pools can fluctuate dramatically in salinity, as evaporation concentrates ocean salts or rainwater dilutes them. Most fish species cannot tolerate such fluctuations, but

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some gobies and sleepers have adapted physiologically in ways that have enabled them to thrive. In the outer layers of their gills are cells that pump sodium and chloride ions into or out of the blood, stabilizing the blood concentrations of salts. In the process of compensating for changes in salinity, the fishes also must adjust their intake and excretion of water.

A tolerance for low levels of salinity would enable a goby or sleeper to jump from the harsh, cramped environment of a tide pool to the wide fan of brackish water that forms where a stream enters the ocean. There the fish would have found itself in an environment with fewer marine predators and competitors, simply because few marine species can survive when the salinity is low.

Biologists believe that is part one of the evolutionary story about how Hawai'i's native stream fishes began their journey from saltwater to freshwater. But what about part two: how did some of these species conquer the waterfalls that stand between estuary and upper stream? Lacking the gobies' chest sucker, Hawai'i's freshwater sleeper *(Eleotris sandwicensis)* had to settle for life at sea level. And the goby that has the most weakly muscled sucker, *Stenogobius hawaiiensis*, also settled in the estuaries and lower stream reaches below the first waterfall. But three of the goby species found a new use for the device that had helped their ancestors hang onto rocks as waves crashed over them.

In heavy rain, Hawaiian streams swell as water is channeled into them. If you are brave (and foolish) enough to wade into the raging torrent pouring down a waterfall into the lowest reaches of a stream, you are likely to find fish fry, between half an inch and an inch long, wriggling up the vertical rock surface behind the falls. The thin and clear, or lightly pigmented, fry are the young of Hawai'i's three climbing goby species. Two of them—the 'o'opu alamo'o and *Awaous guamensis*—accomplish their waterfall-climbing feat by attaching their tiny chest suckers to the rock at the base of the falls and then, in bursts of tail-beating, inching upward while remaining attached, like a magnet being slid up a refrigerator door. Although each climbing burst lasts only a fraction of a second, the fry doggedly persevere in fits and starts until they reach an upper pool.

Adult Sicyopterus stimpsoni, *a goby the Hawaiians call 'o'opu nopili, approaches the top of a small cascade. Although Hawai'i's gobies make their most spectacular ascents up waterfalls as juveniles, adults also occasionally climb short distances as they search for food or mates.*

The third goby species *(Sicyopterus stimpsoni)* lingers in the estuary before proceeding upstream: it waits there because before heading inland it first undergoes a physical change that is astonishingly swift for a vertebrate. Within thirty-six hours its mouth, which has spent the past few months facing forward, is permanently remodeled to face downward, and its small upper lip expands to form a large sucker. Thus equipped, *S. stimpsoni* heads upstream, conquering waterfalls by alternately attaching its mouth and chest sucker.

Whereas returning salmon sniff out the specific stream of their birth, the three climbing gobies are not as particular, and appear guided to suitable stream estuaries by the strong outflow of freshwater and, in the case of at least one species, chemicals that signal the presence of adults of their species above the first waterfall. But like the salmon, the long climb is a journey that members of the three species will make only once in their lives. With the exception of *A. guamensis*, which migrates part way downstream to spawn, adult gobies remain in the part of the stream where they settle after their climb.

Of the three climbing species, *A. guamensis* and *S. stimpsoni* only make it to lower or middle reaches of streams. Their fry do not have much

S. stimpsoni has a mouth that can function as a second sucker for climbing rocks. It acquires the feature in the thirty-six hours before it begins its upstream journey: the upper lip rapidly expands and the mouth is remodeled to face down rather than forward.

luck climbing waterfalls more than a hundred feet high. Only the ʻoʻopu alamoʻo can scale the greatest heights; it can claim the upper reaches of the streams all for its own.

So, having spent part of their childhood amid the dangers of the ocean and scaling mountains to reach the heights, what do adult ʻoʻopu alamoʻos do with their time? Well, for most of the year, not much. In the spring and summer of 2001, we conducted full-day observations in several Hawaiian streams. We learned that the fish invested only about 1 percent of their time in feeding—an activity that, for many species living in more crowded conditions, occupies a large part of the day. They feed mostly on algae and small invertebrates, both plentiful in streams and pools. In short, the adults seem to have mastered the good life. A whopping 95 percent of their day is spent sitting, usually in amicable groups of between two and seventeen individuals that include both males and females. Only occasionally did we record any real interactions among the fish, such as courtship, chasing, or biting.

Before we made our observations, another pair of investigators had reported that males of the species establish and defend small, permanent territories. But we observed no permanent territorial defense, and only a few cases in which males briefly defend territories, a behavior most often triggered by the presence of a female ready to lay her eggs. It was at those times that we got to watch the ʻoʻopu alamoʻo's most stunning display. The male instantaneously replaces his usual mantle of mottled brown. He turns his front half and tail fin jet black, his paired dorsal fins pure white, and the rest of his trunk a brilliant orange that seems to give off a red-hot lava glow.

If the female is suitably impressed, she will swim into a channel covered by a convenient rock and lay about 12,000 minute eggs, which the male fertilizes. The male then guards the nest for about four days, until the eggs hatch. The larvae swim to the stream's surface, where they are quickly washed through whitewater rapids and over waterfalls, out into the wide blue expanse of the ocean. After several months, the ones that survive the hazards at sea seek out a new stream and begin the cycle anew.

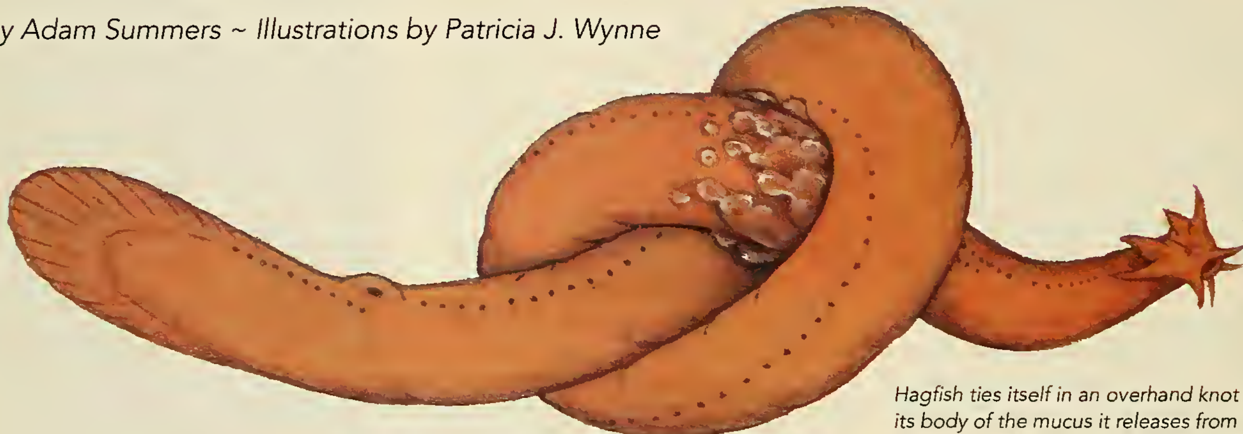
PETER T. SHERMAN and PERRI K. EASON are a husband-and-wife team who met in a graduate seminar on mate choice at the University of California, Davis. They have collaborated on research on and off ever since, most recently studying territoriality in dragonflies and aggression and foraging strategies in ghost crabs. Sherman is an assistant professor at Transylvania University in Lexington, Kentucky, and Eason is an associate professor at the University of Louisville.

Answer to "Cryptic Creatures" puzzle (page 18): a

Slime and the Cytoskeleton

How the defensive ooze of a hagfish sheds light on cellular structure.

By Adam Summers ~ Illustrations by Patricia J. Wynne



Hagfish ties itself in an overhand knot to clean its body of the mucus it releases from its ventral pores. The mucus contains protein structures, known as intermediate filaments, that are also components of cellular skeletons.

The first time I handled a hagfish, I placed it none too gently in a pail two-thirds full of seawater. Within just a few minutes, the creature had become a hazy mirage at the bottom of three gallons of viscous slime. Wonderful biomechanics were going on in that bucket, as the animal released a gel intended to discourage whatever might be harassing it. Watching the ooze, though, I never imagined that it would someday shed light on one of the most intriguing architectural problems in biology—the design and structure of the cytoskeleton, or cellular skeleton.

A hagfish is an unprepossessing creature. A foot or so long, it bears a closer resemblance to a Coney Island frank than it does to a fish. It has a small mouth, surrounded by several short sensory structures called barbels, and it lacks both jaws and teeth. And as I demonstrated when I dropped one into the bucket, a hagfish can exude from its skin a substance so slimy and so plenteous it seems supernatural. After releasing the slime, the hagfish cleans off by tying itself in a knot that it then pulls itself through.

Hagfish slime is made up, in part, of proteoglycans—hydrated protein-and-sugar molecules that give all mucus its characteristic slippery texture. But more important for the question of cellular physics, the hagfish adds long, thin fibers to the mix. Taken together, those ingredients produce a slime reminiscent of what you might find under the noses of a classroom of preschoolers.

To understand what any of this has to do with the cytoskeleton, it's worth sketching what the cellular apparatus is and how it works. The model of the cell most of us learned in school was essentially a ball filled with a fluid (the cytoplasm) within which small bodies (the organelles) drift aimlessly. Cell biologists now know that a skeletal network of filaments permeates the cytoplasm—giving shape to the cell, anchoring its organelles, and choreographing its internal actions.

The mechanics of the cytoskeleton depend in part on how its filaments react when a load is applied. Two kinds of filaments, known as microtubules and filamentous actin, are stiff and strong. Both resist bending, stretching, and compression. Intermediate filaments (IFs), the third kind, seem much more flexible than the other two.

One line of evidence for that conclusion comes from studies done with transmission electron microscopes (TEMs). With a TEM you can make a stop-action image of a single slice of a cell. But how can a still image tell you anything about the flexibility of the filaments? Pasta may offer a useful analogy. Imagine two heaps of linguine, one cooked, the other dry. In any slice through the dry pile, the strands would show up as straight lines. A slice through the cooked pile, though, would show many strands to be curved and curly. When cooked, a strand of pasta becomes more flexible, enabling its ends to move independently—hence the curves.

Filaments of the cytoskeleton are so thin they can be pushed around by the random movements, or so-called Brownian motion, of other, neighboring molecules. Those molecular forces and their effects on the filaments can be modeled mathematically, and the model shows that the more flexible the filaments are, the more they will look like the pile of cooked linguine. Combining such a model with TEM observations, the microtubules seem to be 5,000 times stiffer than the IFs. By itself, that's not entirely surprising: the microtubules are also thicker than the IFs. Yet even the filaments of filamentous actin, which are thinner than the IFs, are about twenty times stiffer.

So what accounts for the flexibility of the IFs? Are their properties similar to those of cooked linguine? Not necessarily. Rope, for instance, only weakly resists bending or compression—yet, unlike linguine, it does a great job of resisting stretch. IFs might be constructed of multiple molecular strands that slide past one another when bending, like the fibers of a rope. That's where hagfish slime comes in: it's an ideal system for testing whether IFs act more like rope or like cooked linguine.

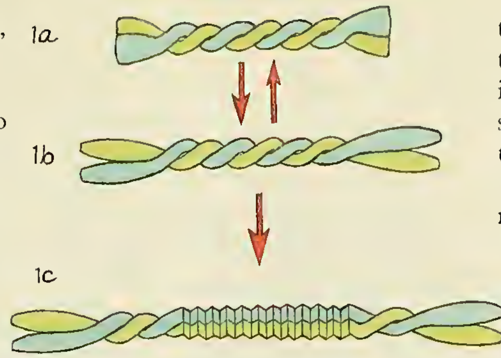
The fibers of hagfish slime are made up almost exclusively of IFs. Moreover, the long axis of each filament is aligned with the long axis of the fiber, making it plausible to think that the entire fiber acts like one filament writ large. On the basis of that assumption, Douglas S. Fudge, a biologist at the University of British Columbia in Vancouver, reasoned that measuring the properties of slime fibers could help clarify the mechanics of IFs.

To test the properties of slime fibers, Fudge and his colleagues constructed a sensitive stretching machine. One end of a fiber was attached to a thin glass rod, just fifty microns in diameter. The other end was attached to a platform that could be slowly pulled away from the glass rod. By measuring the bend in the rod and how much the fiber stretched, Fudge was able to calculate the stiffness of the IFs.

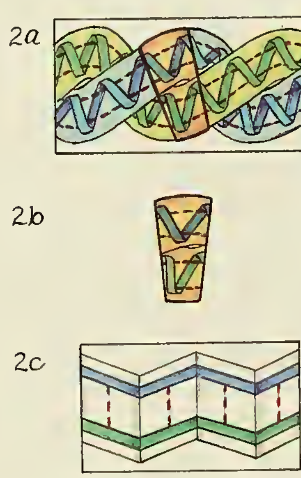
It turns out that the filaments are not very stiff at all, particularly when first stretched. That low initial stiffness, which is attributable to regions of the IFs known as terminal domains [*see illustration at left*], is consistent with their wriggly appearance under the TEM. The low initial stiffness of IFs also suggests they give flexibility and elasticity to the cytoskeleton. Fudge found that an IF could be stretched by more than 30 percent and still rebound to its original length. If stretched much further, though, it would no longer spring back. Only if the filament was stretched by 100 percent would it snap. That makes the structure of an IF unlike either rope or cooked linguine, but rather somewhat like a plastic six-pack holder with a heavy-duty rubber band attached to each end. If you pull gently on the rubber bands, they can stretch and recover their original length. But if you pull hard enough, the plastic holder stretches irreversibly and finally breaks apart.

Those properties could give the IFs two roles inside cells. Stretched to less than their elastic limit (that is, less than 30 percent more than their original length), they could haul a cell back into shape after a deformation. Stretching past that limit could serve as a mechanical signal that some region of the cell has been seriously deformed.

I am not surprised, in a general sense, that hagfish slime holds biomechanical secrets. Most genuine discoveries depend on broad knowledge that spans many levels of organization and design. So why shouldn't the defensive goo of a fish in a bucket reveal the workings of a basic organizational component of all cellular life?



Schematic diagram shows how an intermediate filament (IF), a structural element of cells as well as a component of the defensive slime of hagfish, reacts to mechanical stress. The functional unit of each IF is thought to consist of two proteins coiling around each other, with globular protein structures known as terminal domains at both ends (1a). When an IF first undergoes mechanical stress, the terminal domains stretch easily (1b). That stretching is elastic, or reversible; when the tension is released, the IF reverts to its original length. The central section of the IF, the two coils, noticeably stretches only under large forces. Stretching there deforms the proteins into a sheetlike conformation (1c); that change, absent repair work undertaken by the cell, is inelastic and irreversible.



Closeup views of the diagram at the top of this page show how the proteins rearrange under tension. Each coil (2a) is a helical protein, which is given its shape by internal hydrogen bonds between hydrogen and oxygen atoms (dashed lines). If the ends of a protein are pulled apart hard enough, the hydrogen bonds break. One full period of rotation by the helix (2b) gives way to two periodically pleated sheets (2c); hydrogen bonds re-form between the two unwound proteins, rather than within them.

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

Wherever the Wind May Blow

By Henri Weimerskirch

Among oceangoing avian species, albatrosses and frigatebirds are the quintessential seabirds. Both rely entirely on the ocean for food. Their overall shapes, albeit distinct, free them from any dependence on terra firma except when breeding. Each bird is a magnificent flier in its own environment: an albatross can spend between 90 and 95 percent of its life soaring on cold gales over subantarctic seas; a frigatebird can ride warm thermal updrafts over tropical oceans for more than a week at a time without touching down on land or water. And beyond their oceanic habitat and their superb flying skills, the two birds share some distinctive features of life history: they have the lowest rates of reproduction and the latest onset of maturity among all birds. Frigatebirds live for decades, but albatrosses hold the record for seabirds, reaching ages of sixty to seventy years and continuing to reproduce into their fifties.

Albatrosses and frigatebirds spend most of their long lives soaring over the sea. Miniature electronic trackers and sensors are now showing ornithologists where the birds go.

How did these birds come to have such similar, unusual, life histories? It would be natural to think that the albatrosses (there are between fourteen and twenty species, depending on which ornithologist you agree with) and the frigatebirds (five species) are closely related in evolutionary terms. But they're not. The two groups are members of two well-differentiated evolutionary orders, three major steps up the hierarchy from the species level. But since they're not closely related, what does account for the similarity of life histories? That is a question I've been mulling over for a long time, and one that has been directly guiding my research for several years.

My work on albatrosses, particularly the wandering albatross *(Diomedea exulans)*, began twenty-five years ago, when I was a graduate student studying breeding behavior on small islands in the subantarctic Southern Ocean [*see map on next page*]. At that time, breeding was the only albatross behavior my colleagues and I could observe closely; back then, biologists had no way of learning much more than, say, an observant sailor could discover about the behavior of albatrosses at sea. But in the intervening two and a half decades, technology has come to the rescue. Thanks to generation after generation of ever-smaller electronic tracking devices, biologists have pierced the veil of obscurity and tracked albatrosses on their amazing foraging journeys. Those excursions can cover vast loops more than 9,000 miles long—as if birds nesting in New York City flew to the shores of Italy to forage and then returned to their nests.

As my colleagues and I began to track albatrosses, the question of why their life histories bore such striking resemblances to those of the frigatebirds was never far from my mind. By 2002, when the new tracking technology had revealed many of the secrets of albatrosses, I knew it was time to apply the same methods to frigatebirds. That work is now paying off. The new packages of miniaturized electronic devices are helping biologists understand in detail the many ways frigatebirds are the tropical counterparts of albatrosses. Out of sight of land or ship, the albatrosses and frigatebirds we have fitted with instruments are demonstrating that, despite the birds' genetic distance, the hard facts of soaring and foraging at sea force even the most disparate lives to converge.

My studies of the wandering albatross have repeatedly taken me to two of the most remote islands in the Southern Ocean, Crozet and Kerguelen, where the birds breed and nest. My usual port of departure is Réunion, a French-administered tropical island in the western Indian Ocean. To reach the breeding grounds takes as long as ten days in a supply boat on tossing seas, a

Eleven-foot wing span of the wandering albatross enables the bird to ride the winds in the stormiest latitudes over the Southern Ocean. Gliding at sixty miles an hour, albatrosses can cover thousands of miles with barely the flap of a wing.

Flight paths of three wandering albatrosses (purple), relayed to the author and his colleagues by satellite transmitters attached to the birds, show the birds' locations as they range across vast areas of ocean. The irregular loops, which cover thousands of miles, begin and end at the albatrosses' nesting sites on Crozet Island. The map also shows the location of Europa, a tiny island that serves as a breeding ground for great frigatebirds.

voyage I've now made eighteen times. But the bird, a graceful wanderer whose white body is offset by narrow wings that can span eleven feet, has always been worth the trip.

The breeding behavior of wandering albatrosses is much like that of the frigatebirds I have studied, but it is anomalous among birds in general. Usually neither group mates before reaching age ten or twelve—what in other birds would be a ripe old age. Females of both groups lay only one egg, and then take their time raising the chick to the fledging, or independent, stage. The wandering albatross tends its young for nine months, the frigatebird for a full twelve—the longest of any bird. Such protracted parental responsibilities leave both groups with little choice but to take at least a year's "sabbatical" between reproductive efforts.

Sailors have always known that albatrosses venture far out to sea. Partly because an albatross could appear with strong winds, sailors would respect it as "the bird / That made the breeze to blow," in the words of Samuel Taylor Coleridge, their best-known bard. (According to legend, albatrosses also carry the souls of mariners lost at sea.)

But where do the avian wanderers go when they are out of sight of land or ships, especially when pressed by the needs of their offspring to make return trips to the nest from the feeding grounds at sea? Where, how, and how often do they encounter their prey—squid, fish, and the remains of dead whales, seals, and penguins—that they partially digest and eventually regurgitate for their chick? Back in the 1980s, when an albatross would pass our ship, we had no way of knowing where it had come from, where it was going, or whether it was a breeding adult, an immature bird, or a bird on sabbatical.

In 1989, however, I happened upon a newspaper article about Japanese scientists who had developed a small satellite transmitter for tracking dolphins. The original versions of such transmitters weighed more than two pounds and were used mainly for following the movements of ships. Biologists had adapted them to track large mammals such as bears or reindeer, but they were still too cumbersome for birds. The Japanese version, though, weighed little more than six ounces, which meant it could be carried by a twenty-six-pound wandering albatross. My colleague Pierre Jouventin, then at the Chizé Center for Biological Studies in Villiers en Bois, France, and I modified the tag, or attachment, of the dolphin transmitter to fit an albatross—and thereby became the first investigators to track seabirds on their foraging flights.

The data transmitted and relayed though satellite to our base amazed us. During a single foraging trip, which typically lasted between ten and fifteen days, the birds flew more than 1,800 miles from their nests and covered as much as 9,300 miles. They traced huge irregular loops, and made smaller-scale zigzagging movements within the loops that added substantially to the total length of the trip. To save energy, they soared on tailwinds or side winds. When the winds died, they alighted and drifted on the sea until the winds picked up again. And those dramatic findings were just the first of many waves of fresh data we collected about the specific activities of each bird along its route.

By the early 1990s, transmitter weights had been whittled down to just a bit more than two ounces. That enabled Rory Wilson, a penguin specialist at the Institute for Marine Sciences in Kiel, Germany, and me to attack another question: Do albatrosses find prey at the end of their foraging route or all along the way? Wilson had the superb insight that when a predator catches a fish or squid from the frigid Southern Ocean, the prey will cool the predator's stomach. So he made a recording thermometer that an albatross could swallow—not a problem for a bird that regularly gulps down six-pound fish whole. The thermometer, combined with the location transmitter, showed that, contrary to our expectations, the birds hunt and eat all along their routes. Generally they find schools of prey species at widely spaced intervals every five to six hours, and each time they do, they swallow a couple of fish or squid.

We were beginning to build up a picture of how the wandering albatross feeds. Soaring sixty miles an hour (even faster in optimal winds) across huge expanses of open ocean, it searches for rich but isolated schools of prey. It seemed that such long-distance flights would be physically impossible without a highly energy-efficient form of soaring. To find out just how efficient, I worked with Scott A. Shaffer and Dan P. Costa, ecophysiologists at the University of California, Santa Cruz. This time, we deployed three devices in combination: a satellite transmitter weighing only an ounce; a modified heart-rate monitor like the ones runners wear; and an activity recorder attached to the bird's leg, which let us know when the bird was floating on water.

Those instruments confirmed that the soaring flight of the albatross is among the most energy-efficient forms of avian travel known. The heart-rate monitors showed that albatrosses' heart rates during flight are only 10 to 20 percent higher than they are when the birds are at rest. In contrast, the heart rates of other birds in typical flapping flight can rise to as much as 200 percent higher than the baseline level.

As transmitters have continued to shrink (now down to nearly half an ounce), and as Global Positioning System (GPS) monitors have been miniaturized, we have been able to fill in further details about the long sea voyages of the wandering albatross. Low-pressure systems across the Southern Ocean generate a predictable wind pattern, which the birds exploit to the fullest. Flying northward, they typically move in a large, counterclockwise loop; flying southward, they loop clockwise.

Male (left) and female (right, sitting) wandering albatrosses in the foreground are pictured in a mutual display. Both birds are probably between seven and nine years old, still young for their species. The bird in flight is a mature adult that will probably join the other two. The photograph was made on South Georgia Island, in the South Atlantic, a breeding site favored by wandering albatrosses.

Our growing array of electronics has helped me and my collaborators see how the key elements of the albatross's life cycle are interconnected. The patchy distribution of prey requires long-distance foraging. Long-distance foraging means the chicks are fed at long intervals, and so they develop independence slowly. The nine months between hatching and fledging forces the adults to skip a year between breeding attempts. All in all, the bird's slow-paced life probably contributes to its lengthy life span. And perhaps the decade it takes an albatross to reach reproductive maturity is time spent learning how to find the right winds and ride them while keeping a weather eye out for prey.

As my collaborators and I were penetrating the previously hidden lives of albatrosses, the potential value of comparing them with frigatebirds kept percolating in my mind. My interest was stirred in part by the theoretical work of two other ornithologists. The late David Lack, an evolutionary ornithologist at the University of Oxford, had written extensively on how the specific environment of an avian species contributes to its mode of life. N. Philip Ashmole, a seabird specialist at the University of Edinburgh, has further proposed that tropical seabirds are even more constrained than other seabirds by their environment. The thick layer of

Big red "balloon"—actually, an inflated throat pouch—is flaunted by the male frigatebird at right. Male frigatebirds in breeding mode typically gather in groups to perform the display, which passing females can find irresistible. The three hopeful males in the photograph were strutting their stuff from one of their favorite resting places, the matted foliage on the top branches of a euphorb tree, on the dry, tropical island of Europa.

warm water at the surface of tropical seas restricts the movement of nutrients. And in such nutrient-poor upper layers, prey are even more scattered than they are in colder waters.

As late as 2002, no tracking studies had ever been done on tropical seabirds, and so the time was ripe for testing Ashmole's hypothesis. Olivier Chastel and Christophe Barbraud, ornithological colleagues of mine at the Chizé Center, joined me in April of that year in French Guiana to carry out a pilot study on the foraging ecology of a New World species called the magnificent frigatebird *(Fregata magnificens)*. Having thus gained some experience with frigatebirds, I returned to Réunion in August 2003, but this time, instead of taking the ten-day boat trip to the albatross breeding islands, I took a four-hour flight in a military transport to the islet of Europa in the Mozambique Channel, between Madagascar and the African continent. Europa is just a three-mile-long speck of land, but it serves as a breeding base for a variety of seabirds, including a relative of the magnificent frigatebird, a species known as the great frigatebird *(Fregata minor)*.

All five species of frigatebirds are large black birds with long forked tails and angled wings. As a group they hold the avian record for low "wing loading"—meaning that the ratio of body weight to wing area is lower than that of any other bird. Their physical profile, plus their superb overall flying abilities, makes it possible for them to roam the tropical seas for days on end, coming to land, like the albatrosses, only to breed on such far-flung islands as Europa.

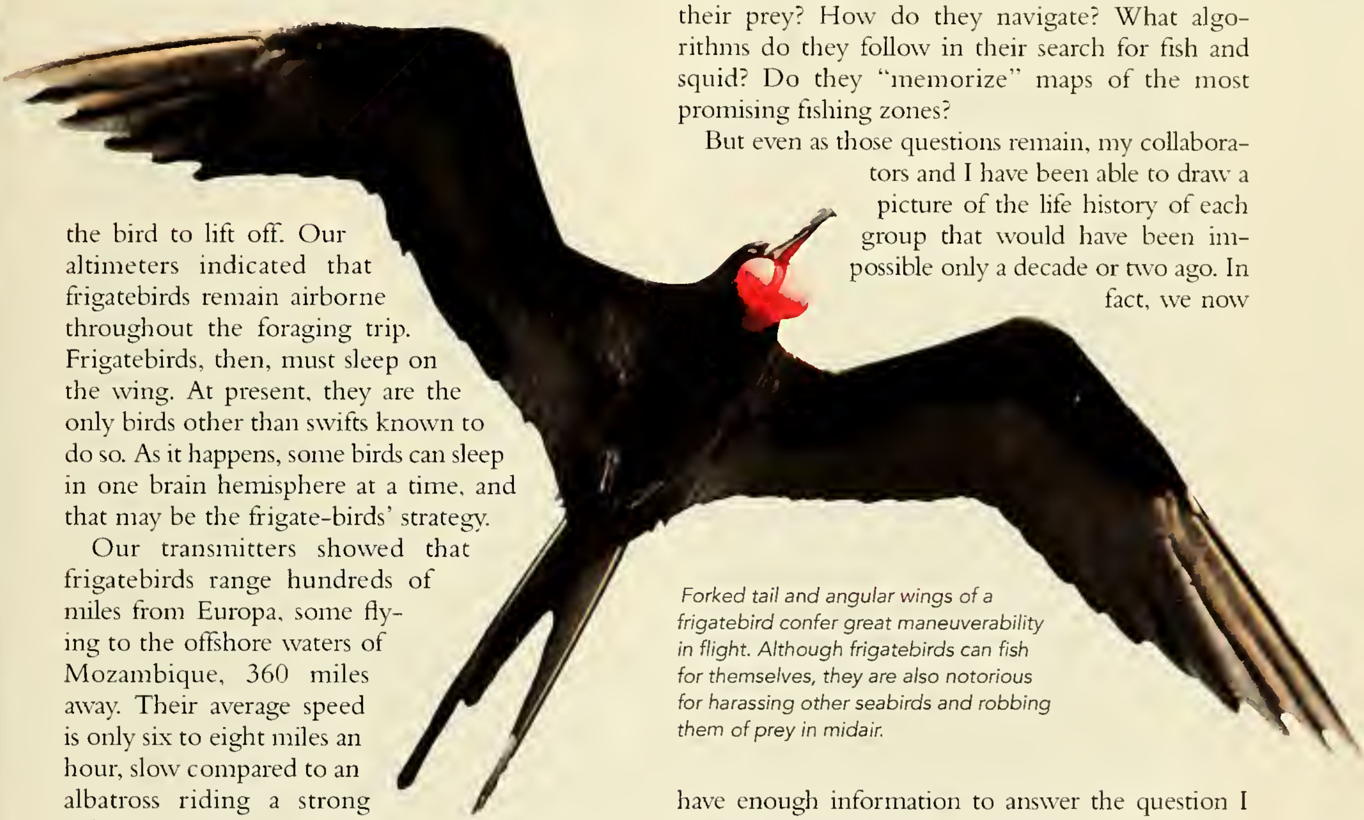
By the time I reached Europa in 2003, I had assembled a formidable tracking arsenal to study frigatebirds. There were location satellite transmitters, GPS data recorders, altimeters, and accelerometers. But my colleague Matthieu Lecorre, an ornithologist at the University of Réunion, and I found working with the frigatebirds to be a challenge nonetheless. We knew that the birds were much more high strung, and thus more difficult to temporarily remove from the nest and "tag," than albatrosses, which are relatively tame. But on Europa, we also had to work at night. By day, clouds of young and nonbreeding frigatebirds soar over the nesting colonies and are quick to steal twigs from nests in the minute it takes to fit a bird with instruments and return it to its egg or chick. When the tagging was done, we kept watch; within a few days, sometimes even within a few hours, the other member of the frigatebird pair would arrive to relieve its electronically enhanced partner. The partner would then head out to sea to fish for its progeny. We would then be ready to track its course.

The magnificent frigatebirds in our pilot study spent two or three days at sea during incubation, but great frigatebirds stayed away between five and ten days. Once we started to analyze the data from the frigatebirds' flight, we began to see how they could sustain their lengthy foraging trips.

Whereas albatrosses have large, webbed feet, which help them "climb" out of the sea and into the air, frigatebirds have minuscule, unwebbed feet and water-permeable plumage. If a frigatebird lands on water, it's in serious trouble because its feet don't provide enough propulsion for the bird to lift off. Our altimeters indicated that frigatebirds remain airborne throughout the foraging trip. Frigatebirds, then, must sleep on the wing. At present, they are the only birds other than swifts known to do so. As it happens, some birds can sleep in one brain hemisphere at a time, and that may be the frigate-birds' strategy.

Our transmitters showed that frigatebirds range hundreds of miles from Europa, some flying to the offshore waters of Mozambique, 360 miles away. Their average speed is only six to eight miles an hour, slow compared to an albatross riding a strong tailwind. But that difference is explained largely by the contrasting styles of flight. Our altimeters showed that during a climb, frigatebirds ride rising warm air masses known as thermals, reaching heights of 9,900 feet, a seabird record. Although the birds sometimes level off, just as a human glider pilot might do, most of their foraging trip is spent climbing and descending.

No doubt because of their inability to take off from the sea surface, frigatebirds rarely get close enough to it to risk a landing. But that raises another, rather obvious question: since they must come down to the sea to feed, how can they do so without getting trapped? The answer is that they often consume flying fish, which leap over the water's surface, and sometimes rob other birds of a meal. But they also feed in conjunction with predators such as tuna and dolphins. During an oceanographic mission that took place while we were on Europa, another colleague studying seabirds, Sébastien Jaquemet of the University of Réunion, observed tuna and dolphins chasing schools of fish and driving them to the surface. As the smaller fish leapt out of the water to avoid their submarine pursuers, low-flying frigatebirds simply snapped them up.



Forked tail and angular wings of a frigatebird confer great maneuverability in flight. Although frigatebirds can fish for themselves, they are also notorious for harassing other seabirds and robbing them of prey in midair.

Our studies of albatrosses and frigatebirds have served to sharpen a series of questions I am keen to pursue. How, precisely, do the birds find their prey? How do they navigate? What algorithms do they follow in their search for fish and squid? Do they "memorize" maps of the most promising fishing zones?

But even as those questions remain, my collaborators and I have been able to draw a picture of the life history of each group that would have been impossible only a decade or two ago. In fact, we now have enough information to answer the question I posed at the beginning of this article: How does it happen that two unrelated groups of birds seem to show such dramatic similarities in life history and in airborne hunting strategies? The black frigatebirds, with their sharply angled wings, ride rising thermals, whereas the white albatrosses, with their long narrow wings, catch a lift on a cold gale. But their foraging strategies converge: soar high, glide long, minimize the expenditure of energy.

Given the pronounced patchiness of their prey, and how albatrosses and frigatebirds have adapted to it, I am convinced that Lack and Ashmole have pointed us in the right direction: the constraints of the environment (in particular, the scarcity of prey in the open oceans) is the primary factor driving the peculiarities and similarities that these remarkable birds display. Evolution has converged, offering a splendid example of how two quite different groups, with two quite different genetic starting materials, can arrive at highly similar life cycles. It is a beautiful evolutionary story, and one that I look forward to documenting in greater detail in the years to come. □

CAMPAIGN 2004

Issues and Answers: Bush *v.* Kerry

When you think about it, it is not surprising that many of the leading issues in this year's—or any year's—presidential campaign are rooted in science and the natural world. Energy, the environment, the state of the nation's natural resources, human health and disease, space science, the place of scientific thinking in government, and science education are continuing concerns for readers of Natural History. *Our editors sharpened and focused those issues into ten questions for the two major-party candidates in this year's presidential election, President George W. Bush and Senator John Kerry.*

When we first submitted our questions, neither campaign seemed likely to answer them directly. The Kerry campaign "was working on" the answers for two weeks before we discovered that the bureaucracy had forwarded our questions to the wrong person. The Bush campaign referred us to their candidate's Web site, and to the public record. Peter Brown's column, "Up Front" (page 8), describes the process in detail.

In the end, the press and policy offices of the Kerry campaign did prepare responses to our questions. They are signaled graphically by Patricia Wynne's charming drawing of a donkey peering out from behind the ornamental letter K. *The Bush campaign decided not to provide specially prepared responses, but instead chose to let stand what we were able to find from President Bush's campaign and presidential Web sites. In those sources, most, though not all, of our questions have been addressed; Wynne's drawing of an elephant and the ornamental letter* B *mark the Bush responses.*

Because of space limitations, we have abbreviated some of the replies; in other respects we have edited them only where necessary for clarity.

—THE EDITORS

ENERGY. ***What actions do you favor taking with respect to the development and conservation of energy resources, both foreign and domestic, including energy from fossil fuels, nuclear power plants, and "alternative" sources?***

B WE'VE GOT TO MAKE SURE THAT WE conserve energy better. But, listen, we can do things in environmentally friendly ways that we couldn't do twenty years ago. We need an energy policy that makes us less dependent on foreign sources of energy. And one way to become less dependent on foreign sources is to promote alternate sources of fuel, like biodiesel and ethanol.

An important part of an energy strategy is clean-coal technology. Our budget for next year provides \$447 million to encourage this vital technology. One other aspect of promising technologies is the hydrogen fuel cell, which captures energy from a chemical reaction between hydrogen and oxygen. I'm confident we can achieve this technological breakthrough to the point where I've asked Congress to spend \$1.2 billion—which they have—in research into developing clean hydrogen-powered cars.

The United States and several major international partners are forming the Methane to Markets Partnership, a new and innovative program to increase energy security, improve environmental quality, and reduce greenhouse-gas emissions throughout the world. The United States will commit up to \$53 million to the partnership over the next five years. Under the partnership, members will work in coordination with the private sector to share and expand the use of technologies to capture methane emissions that are now wasted in the course of industrial processes and use them as a new energy source. The important benefits of this international partnership include improved energy security and air quality from the use of clean-burning methane, improved coal-mine safety, enhanced economic growth, and reduced greenhouse-gas emissions of methane.

I think we have to have safe nuclear energy. We ought to be continuing to research and spend research dollars to make sure that we're able to properly harness nuclear energy without harming the environment.

I HAVE A BALANCED ENERGY PLAN that will reduce our dependence on foreign oil, ensure that American industries and ingenuity will lead the new energy economy, and protect our environment. Its major features include:

• Increasing energy efficiency. I will cut the government's energy bill by 20 percent by 2020—saving the federal government billions of dollars—and will challenge municipalities, corporations, universities, small businesses, and hospitals to do the same. I will also provide tax credits for energy-efficient buildings and homes. I am committed to achieving an increase in the fuel economy of automobiles, and will provide tax incentives for consumers to buy the efficient vehicles of their choice. To ensure that the cars of the future will be built in America, I will provide incentives for manufacturers to convert factories to build more efficient vehicles.

• Producing electricity from renewable sources. America needs a national market for electricity produced from renewable energy, such as wind, solar, biomass, geothermal, and hydrogen energy. I support a national goal of producing 20 percent of our electricity from renewable sources by 2020.

• Expanding the supply of natural gas. I believe that the United States should cultivate a long-term partnership with our neighbors and friends, Canada and Mexico, to develop and expand North America's robust energy supplies.

• Ensuring cleaner coal. A Kerry-Edwards administration will ensure that coal is part of the solution to our energy and environmental challenges and will forge a new way to harness technology to develop and deploy clean electric power from it. At the same time, we need clear benchmarks and a flexible framework by which to measure the emissions performance of existing and new uses of coal. I believe we must invest $10 billion over the next decade—a fivefold increase—to help transition to cleaner and more advanced coal-fired power plants.

FUNDING RESEARCH. ***How will your administration establish priorities for the funding of scientific and medical research? Will you appoint a presidential science advisor in the first six months of your term? What role will that person have in setting funding priorities? In what specific areas of research do you favor increased government funding? In what specific areas do you favor reducing government spending?***

IF WE WANT TO BE COMPETITIVE IN the future, then we've got to encourage research and development so that the next wave of technology is America's wave of technology. I proposed raising federal spending on research and development into $132 billion since I came into office.

When we make decisions, we want to make sure we do so on sound science—not what sounds good, but what is real. And the United States leads the world in providing that kind of research. We'll devote $588 million toward the research and development of energy-conservation technologies. We must and we will conserve more in the United States. And we will spend $408 million toward research and development on renewables, on renewable energy.

We ought to encourage private-sector companies to do the same, to invest in research. And therefore, I believe the tax credits that are critical for encouraging research ought to be a permanent part of the tax code.

AS PRESIDENT, I WILL APPOINT A PRESidential science advisor in the first six months of my term.

It is essential for our government to fund basic research and create an environment that will foster private-sector investment and support the building blocks of a dynamic and innovative economy. I have a plan to invest more at the National Science Foundation, the National Institutes of Health, the Department of Energy, and the National Aeronautics and Space Administration.

In addition, I will eliminate capital gains taxes for long-term investments in small businesses. Small, entrepreneurial firms play a critical role in creating new jobs and commercializing new technologies. As new companies, they are less wedded to incremental improvements to existing products and services, but they often have difficulty attracting capital because of the high degree of risk involved. I will exempt investments held for five or more years in small businesses—a proposal that would cost $6 billion over ten years. I will also extend the research and experimentation tax credit, which

provides a powerful incentive for companies to invest in research and development.

Finally, I will reform or eliminate regulations that impede America's high-tech competitiveness. For example, I will support stem-cell research, which could help find cures for Alzheimer's, diabetes, Parkinson's, and cancer; use market-oriented, performance-based, and other mechanisms that encourage the development of innovative solutions to meet public goals such as environmental protection, rather than forcing prescriptive measures; and ensure that distributed energy resources (such as wind turbines, solar power systems, and fuel cells) can be reliably and affordably connected to the power grid.

BIOTECHNOLOGY. ***Genetic engineering, in which fragments of DNA from one species are reshuffled and recombined with the DNA of another species, is being used to develop new food crops (genetically modified, or GM, foods) and to manufacture new pharmaceuticals. In what ways do you propose to support and/or restrict the development of and trade in such products?***

OUR BIOTECHNOLOGY INDUSTRY IS the strongest in the world, and we need to keep it that way. My administration is committed to working so that the great powers of biotechnology can serve the true interests of our nation and mankind. The biotechnology industry finds itself on the front lines of some of the great challenges of our time. The first challenge is the need to fight terror. All of us know the great possibilities of modern science when it is guided by good and humane purposes. We understand, as well, the terrible harm that science can do in the hands of evil people.

We should encourage the spread of safe, effective biotechnology to win the fight against global hunger. Global hunger is a chronic challenge, and we have a crisis in Africa. The United States is establishing an emergency fund so we can rush help to countries where the first signs of famine appear. The nations of Europe can greatly help in this effort. I hope European governments will reconsider policies that discourage the farmers in developing countries from using safe biotechnology to feed their own people.

I WILL BOOST SUPPORT FOR THE physical sciences and engineering by increasing research investments in agencies such as the National Science Foundation, the National Institutes of Health, the Department of Energy, the National Institute of Standards and Technology, and the National Aeronautics and Space Administration. This funding will help with the broad areas of science and technology that will provide the foundations for economic growth and prosperity in the twenty-first century, including industrial biotechnology. Advances in biotechnology such as "synthetic biology" can lead to biodegradable plastics, fuels, and chemicals based on agricultural waste as opposed to Middle East oil. These advances can also lead to new tools for bioremediation and to cleaner industrial processes that use fewer toxic chemicals. Many of these applications can create jobs and increase incomes in rural America.

STEM-CELL RESEARCH. ***Some believe that stem-cell research holds promise for curing such diseases as Alzheimer's, cancer, and heart disease. In what ways would you support, and in what ways limit, research in this area?***

AMERICA IS ON THE LEADING EDGE of change in medicine. The issue of research involving stem cells derived from human embryos is increasingly the subject of a national debate. Based on preliminary work that has been privately funded, scientists believe further research using stem cells offers great promise for those who suffer from many terrible diseases—from juvenile diabetes to Alzheimer's, from Parkinson's to spinal-cord injuries. And while scientists admit they are not yet certain, they believe stem cells derived from embryos have unique potential.

Stem cells can be derived from sources other than embryos—from adult cells, from umbilical cords that are discarded after babies are born, from human placentas. And many scientists feel research on these types of stem cells is also promising. Many patients suffering from a range of diseases are already being helped with treatments developed from adult stem cells.

However, most scientists today believe that research on embryonic stem cells offers the most promise because these cells have the potential to develop in all of the tissues in the body. Embryonic stem-cell research is at the leading edge of a series of moral hazards. We recoil at the idea of growing human beings for spare body parts, or creating life for our convenience. And while we must devote enormous energy to conquering disease, it is equally important that we pay attention to the moral concerns raised by the new frontier of human embryo stem-cell research.

My position on these issues is shaped by deeply held beliefs. I'm a strong supporter of science and technology, and believe they have the potential for incredible good. I also believe human life is a sacred gift from our Creator.

As a result of private research, more than sixty genetically diverse stem-cell lines already exist. Leading scientists tell me research on these sixty lines has great promise that could lead to breakthrough therapies and cures. I also believe that great scientific progress can be made through aggressive federal funding of research on umbilical cord, placenta, adult, and animal stem cells, which do not involve the same moral dilemma. This year, your government will spend $250 million on this important research. I will also name a president's council to monitor stem-cell research, to recommend appropriate guidelines and regulations, and to consider all of the medical and ethical ramifications of biomedical innovation.

I BELIEVE THAT STEM-CELL RESEARCH holds immense promise for curing or treating diseases and medical conditions. As president, I will lift the ideologically driven restrictions on stem-cell research that are impeding progress toward cures for millions of Americans suffering from debilitating diseases. The August 2001 stem-cell policy allegedly made available more than sixty suitable stem-cell lines to federally funded researchers. However, this has proved to be false. Many of the cells have turned out not to be genuine stem-cell lines or turned out to have no scientific value. As of today, there are only nineteen lines available—less than a third of the number originally promised.

Without federal funding, the nation's top researchers at universities, medical schools, and teaching hospitals cannot be part of the work to find new cures and treatments. Other industrialized nations have allowed extensive research on stem cells with strict ethical oversight. Due to the limited opportunities for federally funded stem-cell research in this country, many scientists—particularly young scientists—who seek to engage in this research do so overseas. As president, I will overturn the present ban on federal funding of research involving stem-cell lines that were created after August 9, 2001, and I will allow doctors and scientists to explore the full potential of these lines with the appropriate ethical oversight, including regulations that reflect our values: strict protections for women's informed consent, for their privacy, and against their being pressured into donations, as well as strict protections to ensure that blastocysts are never created solely for the purpose of research, but are selected from those that would otherwise be discarded or destroyed. Patients and their families should no longer be denied the hope that this new research brings.

SPACE. ***How would your administration balance current and future spending for manned versus unmanned space missions? Will you call for increased spending for NASA manned missions during your administration? For unmanned missions?***

AMERICA IS PROUD OF OUR SPACE program. The exploration of space has led to advances in weather forecasting, communications, computing, search-and-rescue technology, robotics, and electronics.

Yet for all these successes, much remains for us to explore and to learn. In the past thirty years, no human being has set foot on another world, or ventured farther upward into space than 386 miles—roughly the distance from Washington, D.C., to Boston, Massachusetts. Our first goal is to complete the International Space Station by 2010. We will focus our future research aboard the station on the long-term effects of space travel on human biology. To meet this goal, we will return the Space Shuttle to flight as soon as possible.

Our second goal is to develop and test a new spacecraft, the Crew Exploration Vehicle, by 2008, capable of ferrying astronauts and scientists to the Space Station after the shuttle is retired. But the main purpose of this spacecraft will be to carry astronauts beyond our orbit to other worlds.

Our third goal is to return to the Moon by 2020, as the launching point for missions beyond. Beginning no later than 2008, we will send a series of robotic missions to the lunar surface to research and prepare for future human exploration. Using the Crew Exploration Vehicle, we will undertake extended human missions to the Moon as early as 2015, with the goal of living and working there for increasingly extended periods. We will then be ready to take the next steps of space exploration: human missions to Mars and to worlds beyond.

I WILL BE A PRESIDENT WHOSE SCIENCE and technology policies are always guided by sound science, not politics or ideology. I am a firm believer in sound science, and I believe that the shuttle mission has played a crucial role in advancing our knowledge of the universe we live in. Specific decisions about NASA missions will be made after taking many factors into consideration.

As president, I will boost support for the physical sciences and engineering by increasing research investments in agencies such as the National Aeronautics and Space Administration, as well as the National Science Foundation, the National Institutes of Health, the Department of Energy, and the National Institute of Standards and Technology. This funding will help with the broad areas of science and technology that will provide the foundations for economic growth and prosperity in the twenty-first century.

PUBLIC LANDS. ***The national forests, national parks, and national wildlife refuges are scenic, ecological, economic, and recreational resources that are often under pressure from competing interests. What do you consider the proper priorities for the management of the lands that currently fall within each of these jurisdictions? How will you work to improve the maintenance of these valuable treasures for us and for future generations? What steps will you take to modernize laws on mining and extraction on public lands, including the Arctic National Wildlife Refuge? And do you have specific proposals for reclassifying any lands in these jurisdictions, or adding to them?***

B All the parks are owned by the people of this country, and we want the park system to work well and we want there to be a modern infrastructure. We want the 80 million acres of national parkland to be accessible and comfortable for the use of the American people.

The responsibility to maintain our parks has not always been met in America. And so I set out to do something about it. I'm calling on Congress to spend $5 billion over the next five years on maintenance projects and repair projects in the park system all across the country.

K America's national parks are symbols of our heritage, to be preserved and enjoyed by future generations. Despite George Bush's promise to get rid of the maintenance backlog in our parks, they are now facing a budgetary crisis.

I will ensure that our national parks are open, staffed, and managed to allow all Americans to explore and enjoy our national heritage. I will pursue rigorous enforcement of our clean-air and clean-water regulations, and, over the next five years, increase the operating budget of the National Park Service by $600 million to put our parks back on a path toward recovery and restoration. I will fully fund this plan by modernizing the sale of mineral rights and using the revenue generated to increase the operations budget of our national parks.

BIODIVERSITY. ***How will your administration address threats to the loss of biodiversity on public lands such as the national parks, the national forests, and the national wildlife refuges?***

B I want people to understand that if you are concerned about the endangered species, then you need to be concerned about catastrophic fire. Fires destroy the animals that, obviously, live amidst the raging fire. If you're concerned about old-growth, large stands of timber, then you'd better be worried about the conditions that create devastating fires. Thinning underbrush makes sense to save our species, and to save the big stands of trees.

K I am dedicated to the ecological stability of our nation's public lands. My administration will take steps to reinstate protections for roadless areas in our national forests, protect old-growth stands on our public lands from commercial logging, and reverse the Bush administration's secretive, behind-closed-doors deals that have lifted wilderness designations and roadless protections from many public lands. In addition, my administration will take steps to restore open, informed, and balanced decision-making to the management of our public lands.

SCIENCE EDUCATION. ***Science education has been a national priority for the United States, particularly following the launch of* Sputnik I *in 1957. Yet according to* Science and Engineering Indicators 2004, *published by the National Science Foundation (NSF), the U.S. lags behind many other developed nations in secondary science education. Moreover, since the terrorist attacks of 9/11, foreign students who want to study science in the U.S. at graduate or undergraduate levels have found it very difficult to get the visas they need to study here. How will your administration address these two threats to the health of American science and to our influence in science and technology throughout the rest of the world?***

TODAY, CHILDREN ACROSS AMERICA are showing real progress in reading and math. When it comes to improving public schools, we are turning the corner. There's more work to be done. We've got to recognize this world of ours is changing. The jobs of the future will require greater knowledge and higher-level skills. And so we must reform our high schools to make sure a high school diploma means something.

We will expand math and science so our young people can compete in a high-tech world. We will expand the use of the Internet to bring high-level training in the classrooms for four more years. We'll help a rising generation gain the skills and the competence necessary to achieve the American dream.

EDUCATION IN MATH AND SCIENCE IS especially crucial in increasing America's national security and high-tech competitiveness. But today, more than half of America's high school students are being instructed in the physical sciences by teachers who don't have a college major in the subject they're teaching.

As president, I will help America build the math, science, and technology workforce of the future. My plan will offer summer institutes and mentors to 50,000 K–12 math and science teachers and $5,000 bonuses for teachers entering these fields. I will provide $300 million in innovation grants to encourage 1 million girls and minorities to pursue science and math. Among the initiatives I will support will be all-girl math/science schools, after-school programs, and internships with local businesses.

I will also increase the number of undergraduate majors in math and science by fully funding the "Tech Talent" program and increasing support for math/science programs at colleges serving a high share of disadvantaged students, and I will double NSF graduate scholarships for math and science.

In the wake of 9/11, America took important steps to improve security for visa applicants to the United States. However, we can improve our visa system to process visa applications for legitimate scientists and students more quickly, while still screening individuals who pose genuine security risks. We do not need to face a trade-off between scientific exchange and national security. As Robert M. Gates, former director of central intelligence during the first Bush administration, has noted, Osama bin Laden and other terrorists are on the brink of achieving an unanticipated victory, because the unpredictability and delays associated with getting a student visa are causing international students to stop applying to U.S. colleges and universities. This not only damages our economy; it also limits our ability to win the war of ideas by educating the future leaders of developing countries.

SCIENCE MUSEUMS. ***Science museums promote the public understanding of science, and the collections of museums of natural history serve as scientifically indispensable repositories for specimens of plant and animal species. Yet, in order to remain solvent, many museums face cutbacks and, in some instances, the dispersal of part of their collections. What role do you see for the federal government in the funding of these museums, and in what specific areas, if any, should funding be restricted to reflect social values or other policy concerns?***

[*Editor's Note: No answer given; no pertinent recent statements found in the public record.*]

SCIENCE MUSEUMS PROVIDE AN INvaluable service to the American people by serving as a clearinghouse for knowledge and by advancing our understanding of the world around us. As president, I will ensure funding and resources for America's science museums, and ensure that they are able to pursue their mission of promoting knowledge and raising awareness of scientific inquiry.

THEORY OF EVOLUTION IN SCHOOLS. ***Nearly all biologists consider the theory of evolution to be the bedrock of their science. Yet some people feel that evolution should not be taught in the public schools, or that it should be presented as one of several competing theories about the development of life on Earth. Would your administration lend its support to any group or initiative that advocates either of these approaches to the teaching of evolutionary theory?***

[*Editor's Note: No answer given; no pertinent recent statements found in the public record.*]

I BELIEVE IN OBJECTIVE STANDARDS OF scientific inquiry. I support the funding of initiatives, like those of the National Institutes of Health and the National Science Foundation, that advance our understanding of the natural and physical world. Evolution is a part of that understanding. ☐

Dispatches from the Fern Frontier

Plants with an ancient pedigree are yielding their family secrets to molecular approaches.

By Robbin C. Moran

Just as Lewis and Clark are celebrated in the United States, so too, in Australia, are Robert O'Hara Burke and William John Wills, leaders of the first European expedition to cross that island continent. In 1860, Burke and Wills, along with two other expedition members, John King and Charles Gray, made the entire journey from Melbourne in the south to the Gulf of Carpentaria on the north coast. On the way back, however, through a combination of bad planning and bad luck, they ran out of food. Gray died, but the others turned to a wild resource that they had learned about from some Aborigines: the sporocarps—the hard, bean-like reproductive bodies—of a small fern. The fern, *Marsilea drummondii,* called *nardoo* by the Aborigines, is more commonly known elsewhere as water clover because of its four leaflets. In a time of need, here, it seemed, was a fern friend indeed.

Dying of malnutrition in the Australian outback: Robert O'Hara Burke, the leader of an 1860–61 expedition, is mourned by John King. The watercolor by William Strutt depicts, near the pistol handle, some fern "beans" the men used for food. Recent research has revealed why eating the plants actually made the European explorers weaker, even though the Australian Aborigines could consume them with no ill effect.

Burke and Wills prepared the sporocarps the most sensible way they knew how: they ground them into a powder, added a little water, and molded the mixture into small cakes. These they dried and baked in the hot ashes from their campfire. The food satisfied their hunger, but, mysteriously, they still became weaker with each passing day. In the end, Burke and Wills both died of malnutrition; King was rescued, but he suffered permanent nerve damage in both legs.

For many years, it was assumed that the sporocarps simply lacked food value. But about ten years ago, nutritionists provided a new explanation. The sporocarps, they discovered, are loaded with thiaminase, an enzyme that destroys thiamine, or vitamin B_1. When they examined the explorers' journals, they found recorded a classic progression of the symptoms of thiamine deficiency, or the disease known as beriberi.

So much, it would seem, for Aborginal knowledge! But why didn't the Aborigines die from eating the sporocarps of nardoo? The secret lies in the preparation. Unlike Burke and Wills, they mixed the ground-up sporocarps with enough water to make a kind of drink or paste, which they spooned into their mouths with a mussel shell. Diluting the thiaminase, it turns out, decreases its harmful effects to the point that the plant is safe to eat. The mussel shell was also a smart move. If, for example, they had rolled up a eucalyptus leaf to make a spoon (a common Aboriginal technique), the enzyme could have latched onto organic molecules in the leaf that would have increased its potency.

It seems likely that some Aborigines in the distant past, through trial and error coupled with astute observation, had hit upon the right combination of procedures to unlock a resource in their environment.

Perhaps those procedures had become so ingrained that they were taken for granted by the people who met Burke and Wills. Or perhaps the explorers failed to pay enough attention to what they were told.

One moral of the story is, surely, that a little knowledge can prove a dangerous thing. But another lesson is the extraordinary power of modern biology to offer unexpected insights—practical as well as theoretical—about organisms as familiar and commonplace as ferns. Recent investigations can explain far more than the basis for such practices as the Aboriginal preparation of nardoo, or the true cause of death of two national heroes. The study of fern biology is a vast enterprise in itself, encompassing some 12,000 species of ferns, in about forty families, that grow throughout the world. The species range from tropical tree ferns with leaves measured in yards, to small free-floating aquatics with leaves less than a sixteenth of an inch long. The new tools of molecular analysis—along with painstaking field observations—are changing the botanical view of these plants. Among the latest advances is the use of genetic information to help establish the place of ferns in the family tree of plant life. In some cases DNA analysis has overturned some long-accepted conclusions.

As a group the ferns have an ancient pedigree among the species of the Earth. Some living families have fossil records that date back to the Carboniferous Period, between 359 million and 299 million years ago, a time long before the rise of the dinosaurs [*see diagram on next page*]. Later, during the Late Triassic, Jurassic, and Cretaceous periods, when dinosaurs dominated the Earth (between 225 million and 65 million years ago), the bellies of these animals were tickled by the lush growth of fern families such as the forked ferns, the twin-leaf ferns, the tree ferns, and

Annularia, the fossil foliage of a giant calamite tree, is pictured here at about one and one-half times actual size. Calamites, which thrived in swamps of the Carboniferous Period (between 359 million and 299 million years ago), are close relatives of the living horsetails. Considered "fern allies" until recently, horsetails are now classified as true ferns on the basis of DNA analysis.

the ferns of the family Matoniaceae. The very study of ferns is called pteridology, which to some calls to mind the pterosaurs, flying reptiles that were contemporaries of the dinosaurs. The name is not purely coincidental: the root *pterido-*, from the Greek for "fern," is akin to *pteron-*, the Greek for "wing" or "feather" (think featherlike fern).

Before the advent of molecular phylogeny, biologists constructed evolutionary trees largely by studying the morphology and anatomy of living species. They also went to the fossil record, however incomplete, for additional clues that could broaden the contemporary picture. When had various groups of plants first appeared? What kinds of extinct species had once belonged to the groups? The DNA-based evidence developed in the past few years has reinforced some of these traditional classifications and shown where others were mistaken.

The corrections are not limited to just a few matters of detail. Taxonomists can now say that the ferns' closest cousins are the seed plants—angiosperms (flowering plants) and gymnosperms (such as conifers). Both seed plants and ferns are vascular plants, having conducting tissue in their stems. The most obvious difference between them is that ferns do not form seeds; instead they disperse and reproduce by means of single-celled spores. Nevertheless, ferns share a more recent common ancestor with seed plants than they do with the lycophytes, a group of vascular plants that also reproduce via spores. Before DNA studies were made, the lycophytes were considered closely related to ferns and therefore termed "fern allies"—now a misnomer. By the same token, DNA analyses show that the whisk ferns and horsetails, two other groups also considered fern allies, now appear best classified as ferns.

Mosquito fern, the world's smallest living fern, shown at about life size, is a floating aquatic species. Cyanobacteria in its leaves incorporate atmospheric nitrogen in the synthesis of organic molecules. Farmers in southeastern Asia, especially in China and Vietnam, often grow the fern in rice paddies. When the paddies are subsequently drained, the decomposing ferns serve as a nitrogen-rich fertilizer. A living library of hundreds of cultivars is maintained, so that farmers can get the most suitable ones for their particular habitats.

Evolutionary tree of the major living groups of land plants, constructed on fossil evidence (in some cases indirect, based on close but extinct relatives) and DNA analysis. The DNA evidence developed in the past few years suggests that ferns share a more recent common ancestor with seed plants than they do with the lycophytes, a group of plants previously considered close to ferns and consequently termed "fern allies." The whisk ferns, like the horsetails, were once considered fern allies, but they, too, now appear best classified as ferns.

One way the study of DNA can help reconstruct plant family trees is to interpret the genetic code as a kind of molecular clock. As species evolve, they may or may not diverge rapidly in outward appearance or various other major respects. At the molecular level, though, the accumulation of random mutations in DNA is thought to proceed at a fairly uniform pace within a given lineage, largely independently of natural selection. Measuring the accumulated divergence between two homologous, or corresponding, sequences of DNA in two different species can provide an estimate of how long ago the two species diverged. Although the method is controversial, it can be tested and calibrated against the fossil record, wherever independently dated fossils are available.

The molecular-clock technique can be particularly useful as a way to confirm hypotheses and corroborate other lines of evidence about what was happening when some particular group of plants arose. For example, toward the end of the Cretaceous (the period between 146 million and 65 million years ago), flowering plants rose to dominance in Earth's vegetation. Forests apparently became more deeply shaded than they had been earlier. This change may have helped cause the decline of some fern groups and the flourishing of others. For example, ferns in the families Polypodiaceae and Davalliaceae are epiphytes, or plants that grow on trees rather than in soil. The change in vegetation might have worked to their advantage. Consequently, you would expect to see epiphyte species radiating, or diversifying as they filled newly available niches. By working with molecular clocks in those two families, biologists can determine whether these ferns radiated at about the same time that the flowering plants began dominating the landscape.

Molecular biology has also focused attention on another aspect of fern evolution. When the second volume *(Pteridophytes and Gymnosperms)* of the *Flora of North America* was published in 1993, something appeared in its pages that had never been seen before in a book on plant identification: some novel and rather curious-looking, netlike diagrams called reticulograms.

The diagrams look quite different from the more familiar evolutionary family trees, in part because they do not attempt to show how recently two species shared a common ancestor. Instead, reticulograms depict the relationships between species and their hybrids, showing which species have come together to form which hybrids. They also indicate whether the hybrids are sterile (producing "aborted," or nonviable, spores) or fertile (producing viable spores). Nearly all hybrids are sterile when they first form, but if they double their number of chromosomes through "polyploidy," they automatically become fertile.

Reticulograms were included in the reference book because the processes they depict—hybridization and polyploidy—are important evolutionary mechanisms underlying the formation of new species of ferns and lycophytes. Of the 420 species of ferns and lycophytes described in the treatise, about a hundred originated as hybrids and later became fertile through polyploidy. What, then, are those two processes, and how do they work in concert to form new species?

The best way to explain polyploidy may be by ex-

Tree fern, with a trunk twelve feet tall and leaves five feet long, rises above its neighbors, though it is dwarfed by eucalyptus trees in Australia's Ferntree Gully National Park. Once a conspicuous element of the Earth's vegetation, tree ferns faded in importance as the flowering plants rose to dominance.

ample. Related species of ferns often have chromosome numbers that are multiples of a basic set. For example, some species of wood fern (of the genus *Dryopteris*) have 41 pairs of chromosomes in their somatic cells. Other species have 82, and still others 164. All those numbers, of course, are multiples of 41, the lowest-known number of chromosome pairs in the genus. Species with the lowest number in such a series are called "diploids" (two of each chromosome) whereas the ones with higher multiples are called "polyploids" (if you want to be more specific, you can use the terms "tetraploids," "hexaploids," "octaploids," and so on).

Polyploid formation is a process that typically starts with an abnormality in the cell division that produces spores. Normally a spore gets only one chromosome from each pair of chromosomes in the parent fern, but sometimes that fails to happen, and a spore gets a full complement of chromosomes—that is, two of each pair. When the abnormal spore germinates, the eggs and sperm that are ultimately produced also carry the doubled number of chromosomes. That sets the stage for polyploidy. If (for example, by self-fertilization) a "double" sperm then meets a "double" egg, the fern offspring will be tetraploid, and that genetic makeup will be perpetuated in future generations through normal cell divisions.

Polyploidy is often associated with hybridization. Hybrids form when the sperm from one species fertilizes the egg of another. The hybrid zygote grows into a plant with normal roots, stems, and leaves, but the plant turns out to be sterile. Its spores are misshapen, blackened, and nonviable, because during the cell division that produces the spores, the parents' chromosomes pair improperly, if at all, and are then distributed unequally to the daughter cells.

Here's where polyploidy enters the picture. If polyploidy leaves two copies of each chromosome in a hybrid's cells, each chromosome gets a partner that is an exact duplicate of itself. During spore formation in the hybrid, normal pairing of chromosomes can take place, and the chromosomes can be distributed equally to the spores. The new plant is now fertile, able to disperse and reproduce, sometimes beyond the ranges of its parents.

Fiddlehead, or unfurling frond, of an ostrich fern is commonly marketed as a food in the eastern United States. The ostrich-fern fiddleheads are safe to eat, but analysis of bracken fiddleheads, widely consumed elsewhere, shows that they contain harmful substances.

Hybridization and polyploidy have been well studied in Europe, Japan, and North America, but they have received little attention in the tropics, where most fern and lycophyte species occur. Future research will almost certainly show that the two phenomena are just as common there as they are in the temperate zones. They are evolutionary mechanisms that remain in action today, driving the development of new species of ferns and lycophytes for the future.

A practical objective of the research on ferns is to combat what—from a human point of view—are noxious species. For example, one species, molesting salvinia *(Salvinia molesta)*, is one of the world's most widespread and pernicious aquatic weeds. A free-floating aquatic native to southern Brazil, it was accidentally introduced into Sri Lanka in 1939, and has now leaped the continents to become a pest in Africa, Australia, India, and New Zealand. About thirty years ago it was also introduced into the southern United States, where it has spread primarily from Florida to Texas.

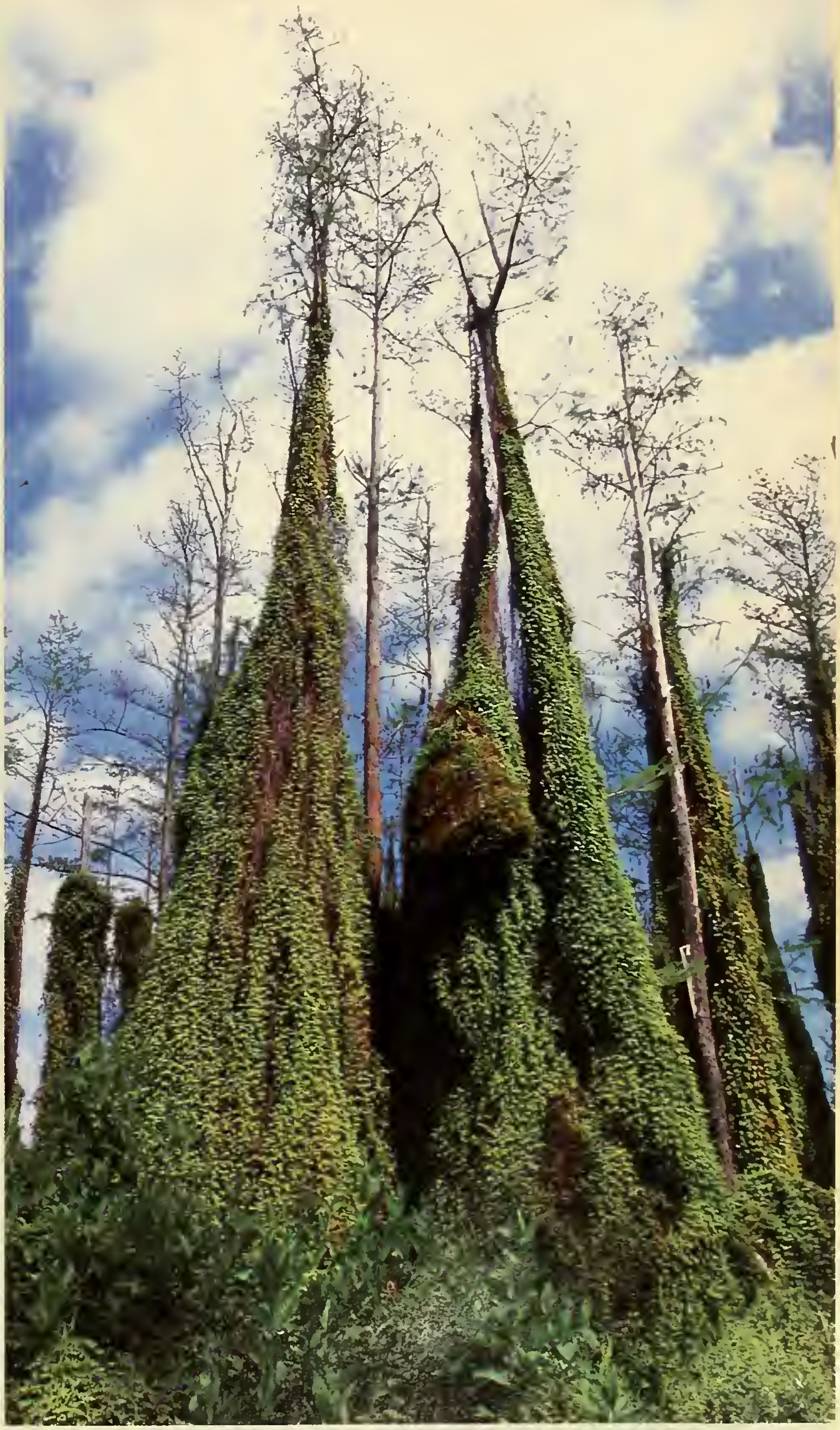
Under optimum conditions a colony of molesting salvinia can double in size in about three days, and given enough time it will carpet the water's surface with a thick, dense mat—a mat so dense that it can support the weight of a cinder block. By the 1970s, teams of entomologists had started searching for a biological control, an insect that would eat molesting salvinia into oblivion. They eventually found a small weevil native to the fern's home range in Brazil. The weevil feeds only on the fern, attacking it in two ways: the adults eat the leaves and the larvae tunnel through the stems and buds. The weevil has been spectacularly successful in controlling infestations in the Old World and is being investigated for use in the U.S.

Ferns are typified by leaves that unfold from coiled buds—the fiddleheads. The coil is, to be exact, a logarithmic spiral, a kind of curve that occurs widely in nature [*see "The Golden Number," by*

Mario Livio, March 2003]. Fiddleheads have long been valued as a food item. Worldwide, the fiddleheads most commonly consumed are those of bracken *(Pteridium)*. In Korea and Japan they are sold commercially and cooked as a spring vegetable. Many Korean American families living in and around Los Angeles gather bracken fiddleheads in the spring, particularly in the nearby San Bernardino National Forest. Harvesting there is so popular that it is regulated by the U.S. Forest Service.

Those traditional dietary uses have also prompted basic research that is illuminating the potential—and risks—of ferns as food. Eating bracken fiddleheads over many years has been correlated with high rates of stomach cancer. Medical scientists in Japan have isolated a compound called ptaquiloside, which they think is the main carcinogen. Bracken fiddleheads also—like the sporocarps eaten by the ill-fated Burke and Wills—turn out to be loaded with thiaminase (though the mature leaves are not). Those high concentrations can be deadly for livestock grazing in early spring, when fiddleheads stand like beacons above the slower-sprouting grasses. The animals become stricken with severe thiamine deficiency. In Britain before the days of the automobile, bracken-induced thiamine deficiency was so apparent in horses that it earned the name "bracken staggers."

But don't be alarmed. The commonly eaten fiddleheads in eastern North America are those of ostrich fern *(Matteuccia struthiopteris)*, a native woodland plant. Unlike bracken, its fiddleheads are safe to eat. And in tropical Asia and many Pacific Islands, the fiddleheads usually served are those of *Diplazium esculentum*, which tastes much like ostrich fern, and is also considered safe. So unless the nutritionists and plant biologists tell you otherwise, by all means enjoy the fiddleheads. They are delicious. Their taste has been likened to that of asparagus, but they have a flavor all their own, a flavor once described by the historic New York restaurateur George Rector as "simple and beautiful, like the soul of spring." □



Lygodium microphyllum, *a climbing fern native to Australia and Southeast Asia, grows over cypress trees in southern Florida. Trees that normally could survive a ground fire are now in danger because the ferns can carry fire a hundred feet up into the crowns. Biologists are studying the fern and its native ecosystem in hopes of finding a method of natural control.*

Two Faces of Texas

Along the Devils River, wetland meets desert, and eastern sycamore thrives in sight of Christmas cactus.

By Robert H. Mohlenbrock


At Dolan Falls, the Devils River drops eight feet.

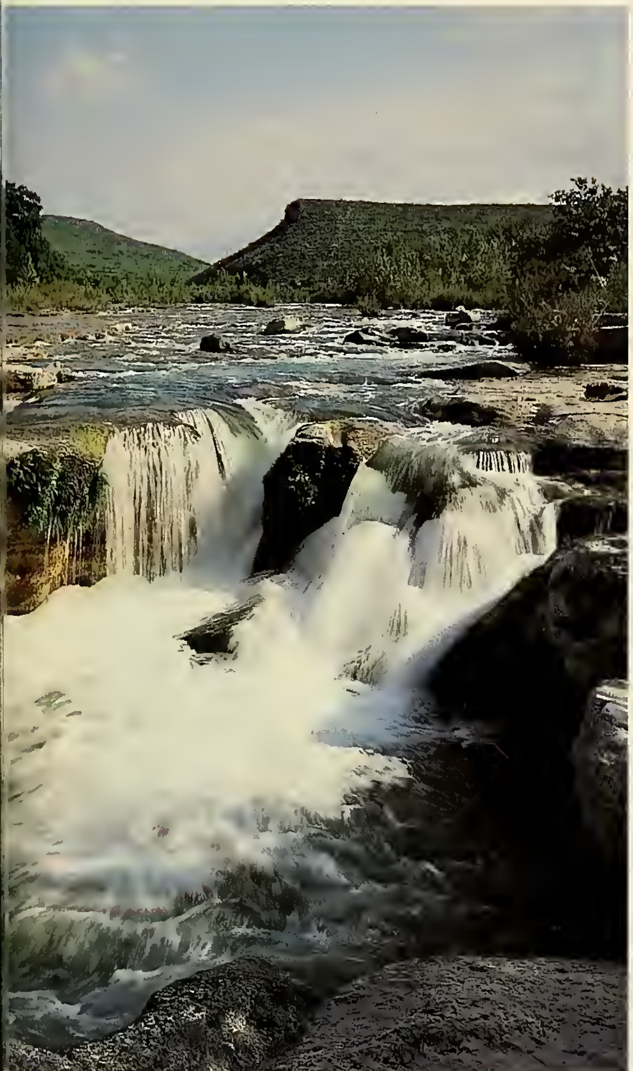
The rocky Edwards Plateau—called the Hill Country by Texans—extends from Austin and San Antonio westward about 230 miles, where it merges with the Chihuahuan Desert. On its western margins, the plateau is semiarid; permanent rivers and streams are scarce. One that does flow year-round is the Devils River. Snaking southward for about a fifty miles, it enters the International Amistad Reservoir, created by the damming of the Rio Grande. Fed by numerous springs, the Devils River disappears underground for some stretches, only to reappear downstream. In several areas along the waterway, springs support a rich wetland flora, yet on dry terraces only fifteen feet above the wetlands grow plants of the desert: lechuguilla, ocotillo, San Angelo yucca, and Turk's head.


Texas plume, also known as the Anacacho orchid tree, blossoms in early April.

Two places to sample both habitats are the Devils River State Natural Area and, adjacent to it, the Nature Conservancy's Dolan Falls Preserve. The state natural area covers thirty-one square miles and is served by a hike-and-bike loop trail. It is open for primitive camping as well as for day use; entrance fees and other regulations apply. Permission from the Nature Conservancy is required to visit Dolan Falls Preserve, which is open periodically for scheduled Conservancy field trips and volunteer workdays [*see contact information on opposite page*].

The centerpiece of the Conservancy's eight-square-mile preserve is Dolan Falls, just downstream on the Devils River from its confluence with Dolan Creek. At the falls, the river drops eight feet over rocky ledges, creating a constant spray of water. Along the western side of Dolan Falls is a scenic, shaded woodland, home to a species of small tree called Texas plume or Anacacho orchid tree. It is a member of the genus *Bauhinia*, which occurs throughout the tropics but rarely this far north. *Bauhinia* leaves are divided from the tip to near the stem, forming two lobes. Texas plume bears large, pink blossoms in early April [*see photograph at left*].

One of the prettiest shrubs that grow along the bed of Dolan Creek and elsewhere in both the state natural area and the preserve is Texas snowbell. On the federal endangered list, the species is known only from a few localities in southwestern Texas. In late April and early May the shrubs are covered with clusters of nearly inch-long white flowers. Each flower has five narrow petals, which



spring above a circular leaf whose underside is covered with silver hairs.

Native Americans frequented this area long before the first settler established a ranch here, in 1883. On the basis of rock-shelters, pictographs, and other finds, the Texas Archeological Society has identified nearly 250 Native American sites in the state natural area and the preserve; the earliest ones date from about 8,600 years ago. Historically recorded groups include Apaches, Comanches, Kickapoos, and Kiowas. At least one battle between the U.S. Cavalry and the Comanches took place on the bluffs overlooking the Devils River.

The Devils River lies along a migration route for birds and butterflies. Among the birds that nest in and around the state natural area and the preserve is the black-capped vireo, which spends the winter on the west coast of Mexico. It, too, is on the federal list of endangered species. Other breeding birds include Bell's vireo, the black-throated sparrow, the elf owl, the hooded oriole, the tropical parula, the red-shouldered hawk, the summer tanager, the white-eyed vireo, the yellow-breasted chat, and the zone-tailed hawk. Other animals of note here are the Texas horned lizard and the Texas tortoise. In addition, several rare fishes live in the springs and the river, including the Devils River minnow, federally listed as threatened.

HABITATS

Wetlands Eastern sycamore often grows as tall as sixty feet, providing dense shade for plants such as American germander, bristly greenbrier, Carolina vetch, common boneset, giant goldenrod, scouring rush, and wild mint, all species common east of the Mississippi River. Mexican ash and the shrubby hoptree often occur with the sycamore. Southern maidenhair often hangs over the mouth of the springs, and watercress is common in the clear spring water.

Other wetland plants that occur along and in the shallow water of the river include American speedwell, American water-willow, California loosestrife, common buttonbush, common monkey-flower, Jamaica swamp saw grass, manyflower marshpennywort, narrowleaf blue-eyed grass, neckweed, switch grass, white star sedge, and several species of spikerush. Submerged in shallow water are entanglements of coon's tail, a common aquatic plant.

Woodlands In addition to Texas plume, mescal bean, or Texas mountain laurel, offers cooling shade, and its deep blue flowers are pretty in bloom. Other woody plants include fragrant sumac, evergreen sumac, little walnut, Mexican buckeye, Texas persimmon, Texas snowbell, and western white honeysuckle.

Dry mesas Gnarly shrubs and cacti are prominent members of the dry mesa flora, which includes allthorn, bear grass, Christmas cactus, desert myrtle croton, guayacan, javelin bush, lechuguilla, ocotillo, San Angelo yucca, Texas barometer bush (ceniza), Texas sotol, and Turk's head.

ROBERT H. MOHLENBROCK is professor emeritus of plant biology at Southern Illinois University in Carbondale.

For visitor information, contact:
Devils River State Natural Area
Dolan Creek Road
HC 01, Box 513
Del Rio, Texas 78840
830-395-2133
www.tpwd.state.tx.us/park/devils

Dolan Falls Preserve
The Nature Conservancy
P.O. Box 420757
Del Rio, Texas 78842
830-775-9292
nature.org/wherewework/northamerica/states/texas/preserves/art6399.html

REVIEW

It or Bit?

Many of the sciences—genetics, for instance—seem preoccupied with information, not matter. That raises a basic question: Is information, not stuff, the essence of the universe?

By Brian Hayes

The computer screen, like Alice's mirror, is a window between two worlds. On our side is the world of atoms, of matter and energy, of everything palpable and ponderable. Looking through to the other side of the screen, we glimpse a world of "bits," a place where intricate structures are built out of nothing more than information—abstract, insubstantial, mathematical. Ours is a world of randomness and evolution and accidents of history; here we have snowflakes, no two alike. Over there, everything happens according to algorithm; if you replay the movie, it comes out the same every time. Our world is all rough edges and never-to-be-repeated moments; the other is relentlessly deterministic.

Any mention of the looking glass, of course, raises a nagging doubt: Which side is reality, and which is reflection? Is it possible that our familiar universe of solid-seeming stuff—the whole hierarchy of atoms, molecules, planets, stars, and galaxies, not to mention ourselves—is at bottom just a pattern of bits manipulated according to some unfathomable algorithm? If we dig deep enough inside the elementary particles of matter, will we find there's nothing there but the Cheshire-cat grin of information? These are the provocative questions that launch Hans Christian von Baeyer on a journey through the science of information, through the "immaterial parallel universe."

The main issues can be framed in terms of two slogans. On one banner are the words of the late physicist Rolf Landauer of IBM: "Information is physical." Although a message might take many different forms—it could be written on paper, encoded in the magnetic domains of a computer disk drive, spoken by the human voice—Landauer insisted that it must always have *some* physical representation. There are no disembodied bits. "Pure" information, divorced from the world of matter and energy, cannot exist, in Landauer's view. It follows that when we want to manipulate information in some way, we are constrained by the laws of physics—including all those irksome thou-shalt-nots about the speed of light and time travel and perpetual motion.

Information: The New Language of Science
by Hans Christian von Baeyer
Harvard University Press, 2004; $22.95

The other slogan comes from John Archibald Wheeler, an eminent, nonagenarian Princeton physicist: "It from bit." What could this pithy koan signify? Wheeler himself (as quoted by von Baeyer) has expanded on his words, though perhaps not quite explained them:

> Every it—every particle, every field of force, even the space-time continuum itself—derives its function, its meaning, its very existence entirely—even if in some contexts indirectly—from the apparatus-elicited answers to yes-or-no questions, binary choices, *bits.*

Whereas Landauer wanted to set bits on a firm foundation of atoms, Wheeler replies that underneath the atoms are just more bits. You begin to feel a little like Wile E. Coyote when he runs off the edge of the cliff: It's only when you look down and realize there's no ground beneath your feet that you begin to fall.

Von Baeyer introduces the disconcerting "It from bit" trope quite early in his story, which may make some readers nervous. If we are already deep in such murky metaphysics on page xii, what kind of spookiness might be waiting in the chapters ahead? But in fact what follows is a sensible and sober-minded tour of the science of information, emphasizing its connections with a surprising variety of other fields, from the engineering of steam engines to the fate of black holes and the understanding of the human genome. At the end of the journey you may not be ready to trade in all your its for bits, but the notion will seem a little less preposterous.

The key ideas in the theory of information—including the all-important idea that it *needs* a theory—were first stated clearly in a 1948 article by Claude Elwood Shannon, a legendary gadgeteer, juggler, and unicyclist as well as a deep thinker. Shannon suggested measuring information in terms of those yes-or-no questions alluded to by Wheeler. If I flip a coin, you can learn the outcome by asking me a single yes-or-no question: "Did it land heads up?" If I roll a six-sided die, you might need three such questions to pin down the result. For example, when you ask "Is it greater than 3?" I answer "Yes." Then you ask "Is it 4?" and I respond "No." After your third question you will surely know whether the number is 5 or 6. Sometimes you might get lucky and guess the outcome sooner, but three is the smallest number of questions guaranteed always to yield the right answer.

Olivia Parker, *Information*, 1989

Shannon defined the information content of a message as the number of yes-or-no questions needed to distinguish the actual message from the set of all possible messages, assuming they are all equally likely. The fundamental unit of measure in this scheme is the bit, which is the amount of information contained in a message that answers a single yes-or-no question. Thus when I tell you how the coin landed, I am conveying one bit of information. When I report on the roll of the die, I am passing along about three bits. If I spin a roulette wheel with thirty-eight slots and tell you which lucky number comes up, I am transmitting about six bits.

The term *bit* began as a contraction of *binary digit*, because a digit in the binary counting system has just two possible values, 0 or 1, which can be made to stand for yes or no. The information content of a message is the number of binary digits it would take to transmit it. In the case of the die, the six possible messages are the numbers from 1 through 6, which in binary notation are written 001, 010, 011, 100, 101, and 110. These are three-digit binary numbers, and so three bits is their approximate information content. Roughly speaking, counting binary digits is all there is to measuring information. (Speaking less roughly and more mathematically, the measure of information is the base-2 logarithm of the number of possible messages, but counting digits is usually close enough.)

A connection between the world of bits and the world of atoms was already apparent in Shannon's 1948 article. His measure of information is closely related—by a sort of mirror reflection—to the concept known elsewhere in the sciences as entropy, the measure of disorder. If you take a hunk of matter—say a billion atoms—the entropy of the substance depends on the number of ways the atoms can arrange themselves. The arrangements are more varied for a gas than for a crystalline solid, because the crystal constrains the atoms to occupy only certain positions, whereas gas atoms can wander willy-nilly. In other words, the gas has the greater entropy. If you write down the number of possible atomic arrangements, the entropy is the number of digits in this number (or, if you want to be a stickler, the logarithm of the number of arrangements). Evidently, the mathematical formulas for information and for entropy are almost identical. Whether that coincidence is trivial or deeply mysterious seems to be a matter of intellectual taste, but it does appear that atoms and bits obey the same laws of nature.

For another look at the tangled relations of atoms and bits, von Baeyer takes us to one of the strangest shores in the universe, the "event horizon" of a black hole. Suppose you throw something into a black hole—say, a book about baseball. As the book disappears across the horizon, its matter becomes inaccessible, but it doesn't really cease to exist. We know that because the mass of the black hole (which you can measure from outside) increases by an amount equal to the mass of the book. But what about the information in the book—all those tables of runs, hits and errors? Where does it go? If the bits are just crushed out of existence, then the total quantity of information in our universe must be steadily declining. Every day, there's less to know.

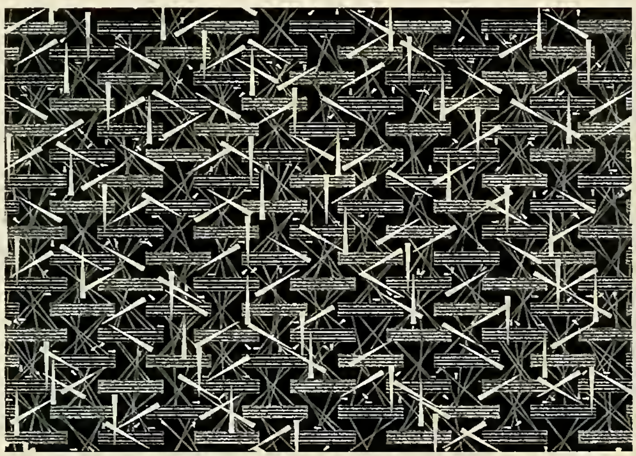
That was the position taken by Stephen Hawking, the Cambridge cosmologist, some thirty years ago—and he backed up his convictions in a wager with another cosmologist, John Preskill of Caltech. This past July, however, Hawking announced that he had changed his mind: he had discovered a way for information to leak out of a black hole, thereby keeping the number of bits in the universe constant. So Hawking paid off the bet, presenting Preskill with a baseball encyclopedia. (The wager was settled too late for von Baeyer's book, but he gives a lucid account of the underlying issues.)

In the life sciences, too, the role of information has its puzzlements. The genetic code, with its alphabet of four letters grouped into words of three letters each, looks uncannily like some kind of computer file format. In recent years this approach to understanding genetic information has burgeoned into an entire academic discipline, and indeed an industry: bioinformatics. Yet there's more to genetic information than just DNA sequences that encode the structure of protein molecules. For one thing, organisms seem to differ more than their genomes do. The question "Are you a man or a mouse?" is not easy to answer from a glance at the DNA; people and mice have 90 percent of their genes in common. Furthermore, most of the DNA in both species has no readily apparent function; life's file format, whatever it is, seems even more grotesquely wasteful of megabytes than the most bloated computer software.

The final informational mystery, and the one that seems most to intrigue von Baeyer, is the elusive seat of meaning. He writes:

> Information . . . resides partly in the mind. A coded message, for example, might represent gibberish to one person, and valuable information to another. Consider the number 14159265. . . . Depending on your prior knowledge, or lack thereof, it is either a meaningless, random sequence of digits, or else the fractional part of pi, an important piece of scientific information. The smell of subjectivity, of dependence on a state of mind, is the source of both the elusiveness and the power of the concept of information.

Once again the comparison of bits and atoms is illuminating. In the case of information, it's no great surprise that meaning is imposed on a message by the sender and receiver. We are all accustomed to thinking of communication as something that happens between people, and so minds are naturally a part of the process. But it's unsettling when a similar kind of subjectivity is invoked to explain the behavior of atoms or electrons. As von Baeyer says, "At the mention of the word subjectivity, physicists cringe"—even though it was physicists who got us into this pickle in the first place, who introduced "the observer" as an essential element of every experiment.



Andrea Way, *Shots*, 1986

We may prefer to think that atoms go their merry way whether we're looking or not, that the material universe maintains a dignified indifference to human whims—but the modern quantum theory won't allow such aloofness. There are experiments on simple, inanimate particles, done with simple instruments, in which the outcome depends on which yes-or-no questions the experimenter chooses to ask. When you decide to peek inside one box rather than another, your action has the power to change what's in *both* boxes. Presumably that is what Wheeler has in mind when he argues that the real ground truth of the universe comes from "the apparatus-elicited answers to yes-or-no questions, binary choices, *bits*." What is still missing is an explicit account of how the bits are to be assembled into atoms and all the other its. Von Baeyer makes a valiant effort to fill in those blanks, focusing in his final chapter on the interesting ideas and experiments of Anton Zeilinger at the University of Vienna. But the vagueness persists. The fault is not von Baeyer's; Wheeler has not clarified the process either, nor has anyone else.

Von Baeyer is a physicist, but he is also an able and accomplished expositor, author of four earlier books and many magazine essays. As one might expect, he is more sure-footed in his own field than in others; his worst stumbles are in the life sciences, as when he describes gene expression as the synthesis of amino acids rather than the assembly of amino acids into proteins. Another minor annoyance: *Information* was published first in Britain, and no one has bothered to convert spellings and currencies and such for American readers.

And I can't resist mentioning a subtle mathematical error. Von Baeyer sets out to show that binary notation is "the least expensive way to handle information," where the "expense" he wants to minimize is defined as the number of digits in the numerical representation of a message multiplied by the number of symbols possible for each digit. In his example, any number from 0 to 127 can be represented by seven binary digits, each of which has two possible values. The expense, therefore, is 14. The trouble is, this supposed optimum isn't.

(Continued on page 66)

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(Continued from page 62)

In almost all cases, binary numerals are less efficient than a ternary (base 3) representation, in which each digit can have a value of 0, 1, or 2. In von Baeyer's example, ternary notation would reduce the cost from 14 to 13. So perhaps information theory ought to be reformulated in terms of yes-no-or-maybe questions.

Setting aside these quibbles, von Baeyer's book brings us the straight dope and the inside info. The presentation is smooth but never slick. History and biography are given due attention but don't overshadow the science. There's some hero worship, but the heroes are mostly deserving of worship. Math-shy readers will not be left behind (von Baeyer devotes an entire chapter to explaining logarithms).

The science of information is hardly an obscure or neglected subject; on the contrary, it's a little too trendy for its own good. Part of von Baeyer's aim is to find out if it merits so much attention. He draws a parallel between the current infatuation with information and the popularity of another big idea, energy, starting early in the nineteenth century. In both cases, the initial impetus was a technological development—the steam engine for energy, the computer for information. But the concept of energy soon spread far beyond the engineering of more efficient power plants. It became a central and irreplaceable part of all the sciences. How could we possibly understand anything about the natural world without the notion of energy?

So far, though, the concept of information has proved itself similarly essential only in the world on the far side of the computer screen. We may have to wait a while to find out exactly what role bits play on our side of the looking glass.

Brian Hayes is a Senior Writer for American Scientist. *His book Infrastructure:* A Field Guide to the Industrial Landscape *will be published next year.*

BOOKSHELF

By Laurence A. Marschall

On the Wing: To the Edge of the Earth with the Peregrine Falcon
by Alan Tennant
Alfred A. Knopf, 2004; $26.95

So here's the story: One early spring day, in the free-flying era long before 9/11, a young bird enthusiast and nature writer has signed on as a falcon trapper's helper with a crew of U.S. Army scientists on Padre Island, off the western Gulf Coast of Texas. Out of the blue, the writer gets the idea that a peregrine, tagged and loaded down with telemetry, could be followed in an airplane as it migrates to its home above the Arctic Circle. No one, to his knowledge, has ever accomplished such a feat.

He enlists the army project's pilot in his plan: a sixty-seven-year-old veteran light-aircraft aviator, former World War II combat flight instructor, and the proud owner of a battered, hailstone-pocked Cessna. After a little planning, and with a good dollop of crazy luck, the two lock on to a falcon fitted with a miniature radio transmitter filched from the army. With scanner-receiver equipment also "borrowed" from the army, they take to the air in pursuit of the errant bird, going wherever it happens to go.

Winging it: Female *Falco peregrinus*

Believe it or not, bird, writer, and barnstormer travel together almost all the way to Alaska, a summer breeding home for the tundra peregrine falcon. Three months later, the gonzo team repeats its performance, latching on to several falcons mid-migration in Texas and tracking them down to their winter homes in Central America. Mostly the two men fly around listening for beeps on their receiver, never catching sight of the birds they're chasing.

Sound like a snooze? Well, having just finished *On the Wing* in one breathless sitting, let me assure you that this book moves with the energy of a four-star action movie. Avian instinct, not wise aviation practice, is what sets the course for the flights, forcing the writer, Alan Tennant, and the pilot, George Vose, to take to the air whatever the weather, terrain, or time of day. Aloft, they often find themselves in the thick of adventure—threading their way in dense fog through a forest of giant oil-refinery towers; catching updrafts that toss them around like feathers; flying dangerously low on fuel while venturing miles from any airstrip.

Down on the ground, it doesn't get much easier. Chasing their falcon across the Canadian border, they enter foreign airspace illegally, and eventually the Mounties bring them in for questioning. Every evening, when the falcons themselves have to stop for food and rest, the two aviators come in to land and fill their tank wherever there's a convenient spot of flat ground.

Once in a while, their impromptu refuelings even require a stop at a rutted dirt strip where drug smugglers, or armed militiamen, hang out. Coming into an urban airport in Belize, they barely escape rear-end collisions with incoming commercial jetliners. Fearless and imperturbable, Vose pilots them out of one near-death experi-

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ence after another, only to have Tennant urge them back into the air.

To Tennant, who has loved raptors since he was a boy, the lure of the migratory bird is too strong to resist. He wants to learn how the peregrine does it, how a bird can fly hundreds of miles a day, feeding sporadically and buffeted by uncooperative winds. Luckily, though, the story also has a human love interest—Tennant's girlfriend Jennifer. Only she has enough sense to know that you can't go on chasing magic forever. And Tennant balances his own passions with plenty of fine nature writing: keen descriptions of bird behavior, well-drawn landscapes, and thoughtful discourses on what it means to be wild. Still, the human action, in the end, is what draws the reader onward.

Tennant and Vose's journey, made in 1985, probably could not be replicated today. GPS radio locators and Internet software have done away with any need to fly around wearing headphones. Nowadays, migrating wildlife can usually be tracked much more easily, and more safely, from the comfort of a university office [*but see "Wherever the Wind May Blow," by Henri Weimerskirch, page 40*]. It's a safe bet, too, that anyone buzzing around in the twenty-first century, violating military airspace and cruising without a flight plan—not to mention crossing international boundaries without the proper paperwork—would probably not live long enough to write about it. The reader is thankful that Tennant did, and the book (rumored soon to be a movie, with Robert Redford as Vose) will keep you rapt to the very end.

The Last Giant of Beringia: The Mystery of the Bering Land Bridge
by Dan O'Neill
Westview Press, 2004; $26.00

The idea that a landmass once joined America and Asia arose not long after the explorer Vasco Núñez de Balboa, in 1513, first waded into the ocean that separates the two continents. In 1590 José de Acosta, a member of the Jesuit brotherhood, published a natural history of the New World that drew on biblical "facts" to prove the existence of such a bridge. Native Americans, he wrote, being descendants of Adam and Eve, must have migrated on foot from the environs of the Garden of Eden eastward to the mountains of Mexico and Peru. Fray de Acosta reasoned that they must have come across a land connection somewhere in northwestern North America. That coastline, however, would remain uncharted for more than a century, until its exploration by the Scandinavian navigator Vitus Bering.


David M. Hopkins on the Russian coast of the Bering Strait

By the middle of the twentieth century, the conjectured existence of a Bering land bridge had been bolstered by a wide range of circumstantial evidence. New World animal species that live along the shores of the Arctic Ocean appeared to be similar to the Old World species that inhabit Siberia. And the farther south you went, the greater were the differences between the species on the opposite shores. The evidence suggested that a wave of animal migrations radiated southward from the Arctic long ago; as time passed and the distance from their common origin increased, the Asian species diverged from their North American counterparts.

Oceanographic data provided another line of evidence. A continuous continental shelf fringing Asia and North America was discovered offshore. Geologic records suggested that sea levels during the last ice age were low enough to expose the shelf beneath what is now the Bering Strait, between Alaska and Siberia. But "land bridge" seems an inexact term for a connection that, unlike the narrow isthmus that joins North and South America, was probably, at its widest, as broad as the north-south distance across present-day Alaska. For that reason, specialists prefer to call the connection Beringia, reflecting its former character as a shared territory, a cosmopolitan province where the mammoths and steppe grasses of the Old World mingled with those of the New.

In the past fifty years, investigators have managed to reconstruct the vanished landscape of Beringia—from its varying size and coastline as the eons passed, to the natural history of its plant, animal, and human populations. A central figure of that research, until his death in 2001, was David M. Hopkins, a geologist with the U.S. Geological Survey, and the "Beringian giant" of historian Dan O'Neill's book.

Hopkins pioneered a multidisciplinary approach to paleogeography, but he also inspired several generations of Arctic scientists with his love for the Alaskan wilderness. As a government employee during the cold war years, his official task, at least early on, was to find suitable sites for air bases and related facilities, and to assess what natural resources might be exploited in the barren sub-Arctic outback. But his superiors, recognizing his genius for seeing the big picture, apparently had enough sense to give him lots of slack.

Hopkins's research was liable to take an unplanned turn at any time. As O'Neill tells it, the man had uncanny luck, augmented by a knack for quickly distinguishing what was im-

portant from what was not. A chance remark by a bush pilot who had seen some arrowheads led Hopkins to Trail Creek, in the remote Seward Peninsula. Cave excavations there subsequently unearthed artifacts of some of the earliest people on the continent. A conversation about shells with an Inupiat native from Nome named William Oquilluk led Hopkins to rich deposits of fossil shells, which proved key to tracing the changing shape of the Beringian coastline over the past 60 million years.

Hopkins was also energetic about recruiting pioneers in other disciplines for his field trips, and enlisting their expertise in such disciplines as dendrochronology (tree-ring dating), palynology (the study of fossil pollen), and radiocarbon dating. In his later years Hopkins was influential in establishing the Bering Land Bridge National Preserve in Alaska, a part of the U.S. National Park Service. Like many modern scientists whose work involves close collaboration, he was never a celebrity outside his field. O'Neill's *Giant of Beringia*, appropriately, is a modest tale, but a satisfying one, an instructive record of an inquiring mind and a life well lived.

The Forest for the Trees: How Humans Shaped the North Woods
by Jeff Forester
Minnesota Historical Society Press, 2004; $32.95

On topographic maps of Minnesota's Arrowhead region—a long, flat triangle sandwiched between the northwestern shore of Lake Superior and the Canadian border—the Boundary Waters Canoe Area Wilderness looks like a tattered pennant fluttering against a clear blue sky. Its million-plus acres of forestland are so thoroughly perforated with lakes, creeks, and rivers that it's hard to tell whether it is a land sprinkled with lakes or a sea dotted with islands. After Congress passed the Wilderness Act of 1964, Boundary Waters became one of the most popular and treasured backcountry preserves in the lower forty-eight states. On many of its waterways a visitor can paddle a canoe for days without hearing the din of an outboard engine, or even the whisper of another human voice.

Yet Boundary Waters is no virgin territory. After the vast forests of New England, Pennsylvania, and Ohio had been logged, lumbermen set their sights on Minnesota, home of some of the last large stands of unexploited forest east of the Rockies. A century ago, the rhythmic chunking of loggers' axes and the scream of sawmills were as common among the trees and lakes of Minnesota as the call of the loon. On large lakes near major access roads and rail lines, rafts of floating logs often made canoe travel impossible. In summer, logging roads were bulldozed over the rocky terrain, and steamships carried men and supplies to remote forest camps. In winter, teams of horses dragged sledges loaded with cut logs across frozen lakes.

Canoer's paradise: Minnesota's Boundary Waters

The mill yard of the Knox Lumber Company, in Winton, stretched for nearly a mile along the shores of Fall Lake. In Ely, now the canoeing capital of the world and a mecca for outdoor adventurers, the steam whistles of lumber mills regulated the daily routine of townspeople well into the twentieth century. Between 1880 and 1920 alone, more than 2 billion board feet of white pine were shipped out of northern Minnesota to build the towns and cities of the growing nation.

Jeff Forester, a freelance writer and frequent visitor to Boundary Waters, has written a thoughtful history of how the Minnesota backwoods became, for a time, an industrial hub, and was then returned to wilderness. *The Forest for the Trees* is enriched with the lore of the enterprising woodsmen and lumber barons who developed the rugged area, bringing in roads, rails, and electricity. And its author tells some good yarns about working the timber mills and living in the timber camps, about the rough-and-tumble life of the mill towns, where dozens of whorehouses and saloons offered the main entertainment after hours.

But Forester also outlines the history of social and economic development in this resource-rich region. The pioneering lumbermen, he notes, were independent operators, family men who just wanted to make a comfortable life for themselves and their neighbors. As the pace of cutting increased, however, the northern forest came under the control of such commanding industrialists as Frederick E. Weyerhaeuser, who thought big and who hauled great stands of trees to the lumber yards with giant steam-driven tractors and mile-long trains of flatbed railcars.

By the time of Teddy Roosevelt, industrial laissez-faire policies were being challenged by a growing conservation movement. Properly managed forests, the movement taught, could provide both exploitable harvests and recreational getaways. Yet it was only in the

1960s that wilderness advocates began to widely promote the idea that some land should remain "forever wild," leading to the creation of the Boundary Waters reserve. The concept of untouched wilderness there, however, is being reevaluated. A freak straight-line windstorm caused a massive blowdown of trees in the area in 1999, and the profusion of fallen timber raised fears of a catastrophic firestorm. Eventually the U.S. Forest Service was forced to schedule controlled burns.

Whatever the forest policy these days at Boundary Waters, Forester's book should be required reading for anyone planning an adventure in the Minnesota north woods—or, for that matter, for anyone who wants a better appreciation for the past, present, and future of America's forests.

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

nature.net

Mother Tongue

By Robert Anderson

Visiting a neighbor recently, I found her chatting in Armenian with a workman. I listened intently; I'd never heard Armenian spoken before. Noting my interest, the two speakers proudly informed me that their language was not related to any other. When I checked their claim on the Internet, I discovered, for one thing, that Armenian contains so many Farsi words, acquired during centuries of Persian influence, that early linguists mistakenly believed it was a Persian dialect. But I also found out that, though Armenian is a branch of the Indo-European family, the language evolved for thousands of years in the relative isolation of the Caucasus Mountains; it is, in fact, unlike any other.

My curiosity piqued, I poked around for other language-specific sites and found an instructive Web page created by C. George Boeree, a professor of psychology at Shippensburg University in Pennsylvania (www.ship.edu/~cgboeree/languages.html). I began by clicking on "Language Families of the World (maps)," and discovered a series of informative geographic charts, each one accompanied by brief but illuminating comments and statistics.

The "Archaeolink" Web site provides a page with numerous links to sites that specialize in linguistic anthropology (www.archaeolink.com/linguistic_anthropology_index.htm). Click on the very first link to find a transcript of the PBS *NOVA* television program "In Search of the First Language." The material focuses on the quest for the linguists' holy grail—Nostratic—a hypothetical tongue that some maintain was once the universal spoken language.

To show how parts of our modern alphabets evolved from pictographs and symbols, Robert Fradkin, a classicist at the University of Maryland in College Park, has developed a Web page of animated course material (www.wam.umd.edu/~rfradkin/alphapage.html). Click on the last item in his list, "The evolution of the Latin character set," and watch as Phoenician symbols from the tenth century B.C. slowly morph into our own ABCs.

For the latest on living languages, go to the Web version of *Ethnologue: Languages of the World* (www.ethnologue.com/web.asp), a compendium of information about the world's spoken languages, now in its fourteenth edition. Published by SIL International (an organization best known for Bible translating), the "Ethnologue" site is on a language-preservation mission; it lists, for the year 2000, a total of 6,809 languages spoken (but not necessarily written) worldwide.

A cogent introduction to the major language families of the world can be found at one section of a site operated by Kryss Katsiavriades and Talaat Qureshi, a well-traveled couple who work as computer-science professionals in London (go to www.krysstal.com/language.html#langfams and click on "Language Families").

Although it isn't as easy to listen to languages on the Web as it is to read about them, you can still find an eclectic range of audio experiences. An issue of the online magazine *Exploratorium* (www.exploratorium.edu/exploring/language/index.html) has five pages on the evolution of language that include several links to audio files. Listeners who go to Haukur Thorgeirsson's online course in "Old Norse for Beginners" (www.hi.is/~haukurth/norse/) can hear epic poetry recorded in Old Norse, as well as in Icelandic and in English (click on "Recordings" on the main page, and then on "Vellekla").

For something more contemporary, Transparent Language, Inc., which sells learning software, offers some language and culture pages at its online site (www.transparent.com/languagepages/languages.htm). You can listen to the pronunciation of useful, common words and phrases in thirty different tongues. And www.everytongue.com, which is affiliated with SIL, offers a relatively long audio sample of nearly a hundred different spoken languages, from Armenian to Zulu. Not surprisingly, most of the passages are readings from the Bible.

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

Double-lobed cloud of hot gas surrounds Eta Carinae (bright white spot at the center of the image), one of the most massive stars known. Variations of light and shadow in recently obtained images suggest the star may have a hidden companion.

Shadowy Partner

Astronomers may have detected what lurks in the shadow of the giant star Eta Carinae.

By Charles Liu

In the southern constellation Carina, literally the "keel" of a larger group of stars called Argo Navis—the celestial ship of Jason and the Argonauts—a giant star lies shrouded in mystery. Eta Carinae is a titanic object—at least fifty and perhaps as much as 120 times the mass of the Sun—enveloped in a thick cocoon of glowing, dusty gas. The star is pumping out energy millions of times faster than the Sun is—probably faster, in fact, than just about any other star in the Milky Way. For that reason alone, understanding the workings of Eta Carinae would go a long way toward unlocking the details of the birth, growth, and death of stars.

But there's more: Eta Carinae also "hiccups." Actually, that's putting it mildly—the star unabashedly belches energy, varying so wildly in brightness over the years that its behavior has fascinated and baffled astronomers since the early nineteenth century. From 1837 until 1858, the star's mood swings were so visually amazing that the period was labeled the Great Eruption. In April 1843, Eta Carinae, despite its distance (nearly 8,000 light-years from Earth) briefly became the second-brightest star in the night sky. Throughout most of the three succeeding decades, though, its energy output plunged to less than a thousandth of that value. Since then, its luminosity has steadily risen again, though on average it is still less than 1 percent of what it was in the glory days of the Great Eruption.

Although the cause of the huge brightness variations remains unclear, astronomers have noted since 1984 that some of the variations are periodic. In 1996 the Brazilian astronomer Augusto Damineli confirmed that, since the 1940s, Eta Carinae's output has pulsed briefly but substantially every five and a half years. To an astronomer, periodic behavior in a star usually signals one of two things. First, the pulses could be caused by interior processes—the best-known examples are Cepheid variables, whose periodicity helps astronomers measure distances to nearby galaxies. Second, the pulses could be the consequence of a rotational effect: the star could be spinning at a regular rate, or a second, companion star could be orbiting it with a regular period.

For several years most Eta Carinae experts have supported the companion-star hypothesis. There's just one big problem: despite years of searching, no such star has ever been found. But recently a group of astronomers led by Nathan Smith of the University of Colorado in Boulder announced they detected ultraviolet shadows that were moving in accord with the 5.5-year cycle of Eta Carinae, suggesting the star may have a hidden partner.

The Great Eruption left a souvenir for us to see today: two globular blobs of hot, glowing gas, the equivalent of roughly one and a half million Earth-masses, bulging outward from the star in opposite directions.

Dubbed the Homunculus—I guess it looked like a little man to the astronomer who named it in 1950—the two blobs are each expanding at more than a million miles an hour. The Homunculus is a fascinating observational target in its own right—it's the star-stuff of Eta Carinae, violently ejected by the Great Eruption. But our stunning view of materials blasted off the star has its downside: the Homunculus obscures the star itself, making it impossible to separate Eta Carinae from its surrounding gas with any Earthbound observatory.

Enter the Hubble Space Telescope. Because Hubble orbits some 400 miles above the Earth's surface, it is immune to the obscuring effects of our atmosphere. The telescope can thereby resolve Eta Carinae itself, distinguishing the star from its surrounding nebulosity. As an added bonus, Hubble's instruments can detect astronomical emissions of ultraviolet radiation that would otherwise be absorbed by Earth's atmosphere. Thus Hubble opens a major window in the electromagnetic spectrum for the study of the universe.

That is particularly important for the study of Eta Carinae. The star itself emits copious quantities of UV radiation, whereas the gas and dust surrounding it scatter and absorb UV. So patterns of light and shadow—not just the light and shadow of visible light, but of UV as well—provide important clues about the shape and clumpiness of the Homunculus and the other dusty clouds surrounding the star.

Smith and his collaborators take full advantage of those facts in their search for Eta Carinae's partner. Imagine, they suggest, that a companion star about thirty times the mass of the Sun is orbiting Eta Carinae. The companion would be an impressive star in its own right, but still dwarfed by Eta Carinae. Next, imagine that the companion's 5.5-year orbit is highly elliptical, shaped more like a kayak than a circle, with Eta Carinae near one end.

The companion star would emit plenty of its own UV radiation, but this radiation would be blocked in the direction of Eta Carinae by the thick nebulosity of the giant star's surrounding gas, dust, and stellar wind. For more than five years of its orbit, while it is far from Eta Carinae, the companion would shine its UV light toward us largely unobscured. But during the several-month period when the companion star is next to or behind Eta Carinae, the companion's emission would be dramatically altered. The ultraviolet shadow cast by Eta Carinae, coupled with our alignment with the two stars, would illuminate different parts of the nebula around Eta Carinae.

Examining Hubble images of Eta Carinae made between October 2002 and November 2003 in both ultraviolet and visible light, Smith and his colleagues studied subtle variations of light and shadow from parts of the Homunculus within several billion miles of Eta Carinae. Their analysis showed that the changes in the UV shadows were consistent with the companion-star hypothesis—and that the companion star's closest approach to Eta Carinae took place in mid-2003, exactly when the energy output of Eta Carinae hiccuped once again.

As attractive as the binary-star model seems, the cause of Eta Carinae's 5.5-year periodicity is still not definitively settled. Further analysis of more data may well point to a different explanation for the observed phenomena. The question won't really be put to rest until a companion star is detected more directly.

Happily, the data we need may already be in hand. Smith and his team analyzed only a small part of a huge database the Hubble has collected on the superstar and its environment. As astronomers continue to mine the Hubble data, more information will surely emerge about what, for now, still lurks in the shadows of Eta Carinae.

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

By Joe Rao

Mercury reaches superior conjunction—on the opposite side of the Sun from Earth's vantage point—on the 5th, and thereafter moves into the evening sky. But the planet remains hidden in the glow of sunset throughout the rest of October.

Venus, at magnitude –4.1, dominates the eastern sky for more than three hours before sunrise. It is the brightest morning "star" this month, and remains so throughout autumn. Although Venus appears less luminous and slightly lower in the sky than it did in September, the planet still dazzles. Seen through a telescope on successive nights, however, the planet is shrinking. Before dawn on the 3rd, Venus appears only 0.3 degree (about half the apparent diameter of the full Moon) from the star Regulus, as seen the East Coast of the United States, and 0.2 degree as seen from the West.

Dim, red Mars, shining at magnitude 1.7, emerges from the morning Sun's glare toward the end of October. On the 31st the planet rises in the east-southeast less than an hour and a half before sunrise. During the next twelve months, as Mars slowly approaches opposition, it will rise progressively earlier and become nearly forty times brighter than it is now.

Jupiter leaps out of the glow of sunrise this month. At the beginning of October the giant planet shines low, in the murk above the horizon, as day brightens. But by month's end it beams brightly in the east at dawn, drawing to within five degrees of Venus by month's end. Jupiter is now in the constellation Virgo, the virgin: the planet shines from that constellation for the next year. Because Jupiter takes twelve years to orbit the Sun, it advances though the zodiac by one constellation each year. A slender crescent Moon, just thirty-six hours from new, appears to hover above Jupiter on the morning of the 12th.

Saturn rises in the east-northeast about six hours after sunset on the 1st. By the end of the month the ringed planet rises two hours earlier than it did at the beginning of the month, which, with shortening days and the return to standard time, works out to five hours after sunset. At any rate, Saturn has climbed high in the south-southeastern sky by dawn all month. At magnitude 0.2, Saturn is the brightest "star" in the constellation Gemini, the twins. In the early morning hours of the 7th, sky watchers can see Saturn and a fat crescent Moon hovering near the twin stars Castor and Pollux.

The Moon wanes to last quarter on the 6th at 6:12 A.M. and becomes new on the 13th at 10:48 P.M. It waxes to first quarter on the 20th at 5:59 P.M. and to full on the 27th at 11:07 P.M. That full Moon, the first after the harvest Moon, is sometimes called the hunter's Moon.

On the night of October 27–28 the Moon is totally eclipsed over North America, less than a year after the last such event over the continent. Almost everyone in the Americas and Western Europe has a beautiful view of the eclipse. Over most of the United States and Canada the eclipse begins well after dark, and the Moon is well up in the evening sky; only along the far West Coast does it begin in twilight, just minutes after the Sun has set and the Moon has risen. But by late twilight even westerners will have a fine view of the totally eclipsed Moon, probably glowing dimly like a reddish ember low in the eastern sky. Across much of Alaska the eclipse is already underway when the Moon comes up; over southwestern Alaska, the Moon rises totally eclipsed, appearing like a weird, mottled, dim ball among the twilight stars. Over Hawai'i, moonrise comes just after the end of totality; the Moon gradually emerges from Earth's shadow as the satellite rises.

Totality lasts eighty-two minutes, which is somewhat longer than average, because the Moon tracks through the northern portion of the Earth's shadow. Unless airborne volcanic aerosols or other atmospheric effects influence its appearance, the Moon's disk should appear relatively bright, particularly during the beginning and end of totality. The upper part of the Moon is likely to appear brightest and to glow with a ruddy or coppery hue, whereas the lower half of the Moon should look more gray or chocolate.

The Moon enters the Earth's shadow at 9:14 P.M. on the 27th. Totality begins at 10:23 P.M.; mid-eclipse comes at 11:04 P.M. and totality ends at 11:45 P.M. The Moon exits the shadow at 12:54 A.M. on the 28th.

The Sun is partially eclipsed by the Moon late on the afternoon of the 13th. Sky watchers living in the western half of Alaska can see the eclipse reaching a spectacular peak just as the Sun is setting below the west-southwestern horizon. Look for an eerie counterfeit twilight to fall over the landscape just prior to sunset.

Never look at even the smallest sliver of the Sun's disc unless you are using a proper filtering device, such as #13 welder's glass or aluminized Mylar plastic, to protect your eyes. You'll get all the safety tips from the local media—be sure to observe them!

Daylight saving time ends on the 31st, the last Sunday in October. Clocks in Canada and most of the U.S. (with the exceptions of Arizona, Hawai'i, and Indiana) are set back one hour, and the clock hour from 1:00 A.M. until 1:59 A.M. is repeated. The mnemonic is "spring ahead; fall back."

All precise times are given in eastern daylight time.

EXPLORER GUIDE

At the Museum

Totems to Turquoise

Opening October 30, 2004, at the American Museum of Natural History, *Totems to Turquoise: Native North American Jewelry Arts of the Northwest and Southwest* celebrates the beauty, power, and symbolism of modern Native jewelry arts with more than 500 pieces of dazzling contemporary and historic Native American jewelry and artifacts. The exhibition also presents recent totem sculptures, traditional and modern masks, and photographs and videos of Northwest Coast and Southwest rituals that are strongly connected with the sociological beliefs of the tribes represented.

PHOTOS BY KIYOSHI TOGASHI

Left: Woman in the Moon pendant. Jim Hart (Haida). 2003. Private collection. Right: Universe Within the Bear pendant. Jesse Monongya (Navajo). 1991. Private collection.

Artwork presented in the exhibition comes from the Northwest Haida, Kwakwaka'wakw, Tsimshian, Gitxsan, Nisga'a, Tlingit, Nuu-chah-nulth, Nuxalk, Heiltsuk, Haisla, and Coast Salish tribes, and the Southwest Navajo, Zuni, Hopi, Santo Domingo, Apache, Taos and other Pueblos, and other tribes. These magnificent pieces show how techniques, materials, and styles have evolved as Native American jewelers have adapted to technical, societal, and commercial changes, transforming traditional craft into a full-fledged mode of artistic expression.

Groups of spectacular jewelry and objects introduce visitors to the key themes in the exhibition, such as cultural continuity over time and distinct regional styles. Motifs transferred to jewelry from other art forms are represented in masks and blankets.

Cosmological and societal context is generated within the exhibition space by a section divided into an inner and an outer circle. The inner circle displays jewelry together with masks, headdresses, pottery, and other historic objects to explore the roles of seasonality, cosmology, shamanism, and mythology in the Northwest and Southwest cultures.

The outer circle displays objects and stories relating to community forms: clans, moieties, and house groups. This section contrasts the two geographic regions but also presents similar community rituals that pervade both territories. The roles of men and women as they relate to jewelry-making are also explored in this area.

The final section of the exhibition explores further commonalities between the two geographic regions, displaying artifacts from the Northwest Coast and the Southwest that suggest intriguing parallels in the past and illustrate mutual influence in the present. Similarities in historical pieces whose creators were separated by hundreds of miles of rugged terrain are little understood, but contemporary objects show how recent meetings of artists from these regions have enriched and inspired new directions for each other's work.

A video display shows dramatic images of the land and communities while artists whose work is represented in the exhibition discuss art—jewelry-making in particular—as a way of passing on tradition, sharing ideas between the geographic areas, and teaching those outside their communities about their living cultures.

Totems to Turquoise honors a rich, complex, and diverse art form, the foundations of which lie in thousands of years of culture and experience. "Both the Northwest Coast and the Southwest feature an uninterrupted tradition of extraordinary indigenous artwork and iconography: transformed into jewelry, this tradition achieves a powerful cultural continuation," said Peter Whiteley, Curator of North American Ethnology in the Museum's Division of Anthropology and co-curator of *Totems to Turquoise.*

"This is above all an exhibition about connections," noted Lois Dubin, lecturer, author of several authoritative books on Native American jewelry, and co-curator of *Totems to Turquoise.* "These connections range from sacred to pragmatic, ancient to contemporary, macro to micro, and Native to non-Native."

Advising artists are Jim Hart, a Hereditary Chief of the Haida Nation and an accomplished carver and jeweler, and Jesse Monongya, a highly regarded Navajo and Hopi jeweler whose inlay work is considered to be among the finest today.

Totems to Turquoise

Native North American Jewelry Arts of the Northwest and Southwest

October 30, 2004–July 10, 2005

Gallery 3, third floor

"Seeing" Earthquakes

It's reassuring for some to think that only California and Japan are at risk for earthquakes—but incorrect. A colorful, real-time, three-drum earthquake station unveiled this summer in the David S. and Ruth L. Gottesman Hall of Planet Earth at the American Museum of Natural History clears up this misconception. By constantly recording worldwide ground shaking as it occurs and reaches stations in Fairbanks, Alaska; Tucson, Arizona; and Matsushiro, Japan, the seismograph shows that earthquakes occur daily and continually worldwide.

D. FINNIN/AMNH

Although some earthquakes are deadly and destructive events, the seismograph also conveys the message that earthquakes of various magnitudes are signals of the ongoing geological processes that shape the planet's surface. Through exhibits like these, visitors can learn that Earth is a dynamic planet with a crust covered by constantly moving plates that create ocean basins, continents, islands, and mountain ranges.

Using stationary pens fixed on rotating mechanical drums of white paper, the seismograph records the squiggly-line signals of current earthquakes in different parts of the world broadcast to the Museum in real time via the Internet. Above the seismograph, a monitor lists the times, magnitudes, and geographic locations of earthquakes that have occurred within the past few days. These data are updated every ten minutes. A wide-screen color monitor displays the locations and magnitudes of recent earthquakes as color-coded dots on global maps based on satellite data.

The real-time seismograph exhibit was donated to the Museum by the Incorporated Research Institutions for Seismology (IRIS) and the U.S. Geological Survey, with support from the National Science Foundation.

New Study Finds Teenage *Tyrannosaurus rex* Gained Nearly Five Pounds Daily

How did *Tyrannosaurus rex*, one of the most enormous terrestrial carnivorous animals ever, grow to be so large? Fast growth does it for some beasts. Long-lasting growth does it for others. For *T. rex*, it was the former, in particular a four-year, teenage growth spurt during which it gained as much as 4.6 pounds (2 kilograms) daily, according to a recent study by a scientist with the American Museum of Natural History and his colleagues.

The study involved estimating the longevity, or ages, of *T. rex* and other related North American tyrannosaur specimens by counting growth lines in their fossilized bones, just as one might count tree rings to estimate arboreal age. The *T. rex* relatives studied for comparison were *Albertosaurus sarcophagus, Gorgosaurus libratus*, and *Daspletosaurus torosus*. The circumferences of the specimens' leg bones were used to estimate the dinosaurs' body masses. All these data were used to generate and compare growth curves for the four tyrannosaur species. Gaining only 0.68 to 1.06 pounds (0.31 to 0.48 kilograms) daily during a growth spurt of equal length, the other tyrannosaurs could not keep up with *T. rex*'s astounding daily weight gains.

The growth spurt finding is described in the journal *Nature* by Mark A. Norell, Curator and Chairman of the Division of Paleontology at the American Museum of Natural History; Gregory M. Erickson of Florida State University; Peter J. Makovicky of The Field Museum; Philip J. Currie of the Royal Tyrrell Museum of Paleontology; Scott A. Yerby of Stanford University; and Christopher A. Brochu of the University of Iowa.


C. CHESEK/AMNH

Behind-the-scenes work on the groundbreaking new exhibition, *Dinosaurs Alive: Ancient Fossils, New Ideas,* which will open at the Museum on May 14, 2005, curated by Mark Norell. On view through January 8, 2006, the exhibition will highlight ongoing cutting-edge research by Museum scientists and other leading paleontologists around the world.

Museum Events

American Museum of Natural History

M. CARLOUGH/AMNH

EXHIBITIONS

The Butterfly Conservatory: Tropical Butterflies Alive in Winter

Opens October 9, 2004

A return engagement of this popular exhibition includes more than 500 live, free-flying tropical butterflies in an enclosed habitat that approximates their natural environment.

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

Frogs: A Chorus of Colors

Through January 9, 2005

This delightful exhibition introduces visitors to the colorful and richly diverse world of frogs, with over 200 live specimens thriving in re-created habitats.

Frogs: A Chorus of Colors is presented with appreciation to Clyde Peeling's Reptiland.

Art in Nature: The Photographs of John Daido Loori

Through January 9, 2005

These striking abstract photographs reveal hidden treasures and explore notions of scale in the dramatic land- and seascape of Point Lobos State Reserve in California. The photographer is the abbot and founder of Zen Mountain Monastery, in Mt. Tremper, New York.

Vital Variety: A Visual Celebration of Invertebrate Biodiversity

Through Spring 2005

Invertebrates, which play a critical role in the survival of humankind, are the subject of these extraordinarily beautiful close-up photographs.

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

Fall Colors across North America

Through March 13, 2005

The fiery colors of autumn come to life in these images by Anthony E. Cook, taken as he journeyed from northern tundras to deep southern bayous.

LECTURES

The Museum at the End of the World

Saturday, 10/2, 2:00 p.m.

Laurel Kendall, Curator in the Museum's Division of Anthropology, and Alexia Bloch, University of British Columbia, discuss the AMNH's late 19th-century Jesup North Pacific expedition to Siberia.

Quinine: Malaria and the Quest for a Cure That Changed the World

Tuesday, 10/5, 7:00 p.m.

Fiammetta Rocco weaves a historical tale depicting the ravages of malaria and the discovery of quinine in the 17th century.

One with Nineveh

Thursday, 10/7, 7:00–8:30 p.m.

Paul and Anne Ehrlich collaborate to expose how overpopulation, overconsumption, and political and economic inequity are shaping today's politics and humankind's future.

Becoming a Tiger

Tuesday, 10/19, 7:00–8:30 p.m.

Susan McCarthy presents fascinating examples of animal behavior in the laboratory, in controlled "natural" settings, and in the wild.

The Prism and the Pendulum: The Ten Most Beautiful Experiments in Science

Thursday, 10/21, 7:00 p.m.

Robert P. Crease, philosopher and historian of science, explores dazzling breakthroughs from the ancient world to modern physics.

SPECIAL PROGRAMS

Living with Nature: Healthy Eating for You and the Planet

Tuesday, 10/12, 7:30 p.m.

The Center for Biodiversity and Conservation presents a panel on sustainable cooking, eating, and food production. A resource fair precedes the program, beginning at 6:00 p.m.

FAMILY AND CHILDREN'S PROGRAMS

Giants of the Outer Solar System

Saturday, 10/2, 11:00 a.m.–12:30 p.m. (Ages 6–7) or 1:30–3:00 p.m. (Ages 8–10)

Learn about the Cassini mission, which is beginning a four-year tour of the Saturn system.

ORGANIZATION FOR BAT CONSERVATION

Wild, Wild World: Bats

Saturday, 10/9, 12:00 noon–1:00 p.m.

Find out amazing facts about bats in this interactive live-animal program with the Organization for Bat Conservation.

Space Explorers: The Planets of Our Solar System (and Meteorites Too!)

Tuesday, 10/12, 4:30–5:45 p.m. (Ages 10 and up)

On the second Tuesday of each month, kids (and their parents) can learn under the stars of the Hayden Planetarium.

Visit the Space Station!

Saturday, 10/23, 11:00 a.m.–12:30 p.m. (Ages 4–5) or 1:30–3:00 p.m. (Ages 6–7)

Come see what a day might be like aboard the International Space Station.

Artist's rendition of *Cassini* approaching Saturn

Astrofavorites for 4- to 6-Year-Olds: NASA Missions
Three Thursdays, 10/7–10/21
4:00–5:30 p.m. (Ages 4–6, each child with one adult)
Three programs on three consecutive Thursdays.

Robots in Space
Three Wednesdays, 10/13–10/27, 4:00–5:30 p.m. (Ages 8–10)
Learn how robotic rovers can explore where humans cannot survive and build your own robots.

Halloween
Sunday, 10/31, 1:00–4:00 p.m.
Enjoy a safe and fun Halloween in the Museum with trick-or-treating, arts and crafts, fun with roaming characters, a film, and live performances.

HAYDEN PLANETARIUM PROGRAMS

TUESDAYS IN THE DOME
Virtual Universe
The Galaxies Next Door
Tuesday, 10/5, 6:30–7:30 p.m.

This Just In...
October's Hot Topics
Tuesday, 10/19, 6:30–7:30 p.m.

Celestial Highlights
Night of the Red Moon
Tuesday, 10/26, 6:30–7:30 p.m.

COURSES
Stars, Constellations, and Legends
Four Wednesdays, 10/27–11/17
6:30–8:30 p.m.
Learn to locate the stars of the season and enjoy sky lore from different cultures.

Introduction to Astronomy: The Solar System
Six Mondays, 10/18–11/22
6:30–8:30 p.m.
Topics include the Moon, the Sun, our solar system, and common celestial phenomena. No astronomy background necessary.

PLANETARIUM SHOWS

SonicVision
Fridays and Saturdays, 7:30, 8:30, and 9:30 p.m.
Hypnotic visuals and rhythms take viewers on an unforgettable ride through fantastical dreamspace.

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

The Search for Life: Are We Alone?
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ENDPAPER

Fishing for a Living

By Deborah Stone

I'd been observing the birds in a heron rookery on a beaver pond near my home for more than two decades, before I finally saw a great blue heron catch a fish—three fishes and a frog, to be precise.

True. I hadn't tried terribly hard to witness the heron's fabled hunting prowess. My patience, I'd assumed, would be no match for its reputed ability to stand motionless for long periods, waiting for the right moment to strike. I was wrong: my heron, at least, was no statue.

The heron that changed my mind was standing in full view in the middle of the pond one day, the water just clearing the tops of its legs. The feathers on its underbelly lightly brushed the lily pads on the surface. I decided to wait and watch. I settled in on the shoreline, my back against a boulder, and positioned my binoculars.

Far from motionless, this heron was positively fidgety. It moved its head backward, forward, and side to side. It stretched its neck high and then abruptly lowered it; at times it rested its neck in a loose S curve. Occasionally the heron swallowed, as if exercising its throat muscles in anticipation. Every so often it opened its beak and shook its head vigorously, as if trying to dislodge a bad-tasting morsel.

While I ruminated on the significance of these gestures, the heron abruptly turned its head to look over its left shoulder. Then, without turning its body, it plunged its long sharp beak into the water so swiftly that the eye could barely follow—and plucked out a frog. It raised its head high, tossed back the frog, and swallowed.

After an interlude of more restless fussing, the heron drew its neck into a tight S, then thrust it forward, shot its beak into the water, and withdrew a shiny black fish. This catch proved a lot trickier to handle than the frog. The heron solved the problem by pitching its head back three or four times and quickly opening its beak each time, just enough to keep hold of the fish while positioning it more accurately for swallowing. Soon enough, the black fish followed the frog down the bird's gullet.

For its next catch, the heron switched strategies. Suddenly its head and neck shot straight out, cantilevering over the water. A few seconds later the bird jutted its neck out still farther, then plunged its head into the pond. This time the heron barely had its catch by the tail fin. After several vigorous head tosses, though, the bird cleverly manipulated that fish, too, down the hatch.

The last fishing feat I saw that day was the most spectacular. All at once the heron turned its head sharply to the right and, without moving its legs, thrust its beak down past its right shoulder and into the water. It spread its wings a little and then went under, up to its shoulders. The fish it came up with was seven or eight inches long—longer than the heron's bill—and it was putting up a mighty struggle. I counted nearly a dozen head tosses, the heron opening its beak and then clamping down hard each time, the fish flopping furiously. The tussle lasted for more than a minute.

Most of us are used to seeing life in nature through a Darwinian lens. We expect the pressures of natural selection to lead to the kind of simple, rigid behavior we associate with "hardwired" instincts, and that's just what I had expected from the heron. But after watching the bird, I came to think that there's ultimately not much difference between the ways my heron and I go about our lives: we both keep our eyes wide open, we improvise, and occasionally we stick our necks out.

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