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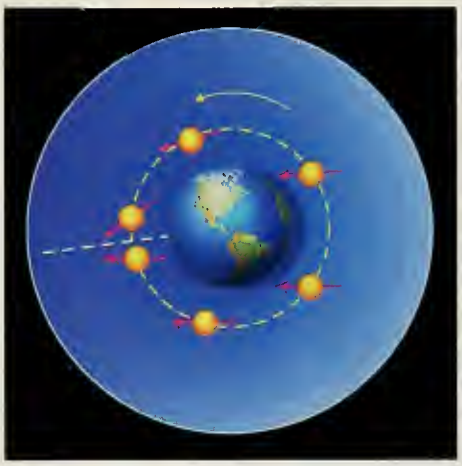
NATURAL HISTORY

MARCH 2005 VOLUME 114 NUMBER 2

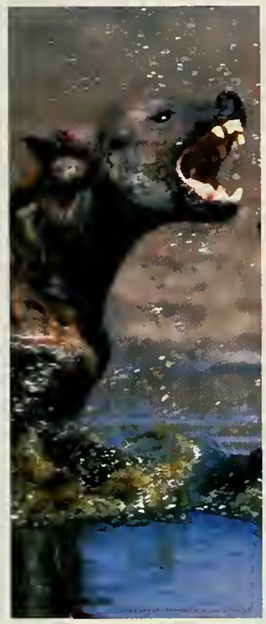
FEATURES



ON THE COVER:
Tangle-veined fly bearing orchid pollen sac

6

DEPARTMENTS



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PICTURE CREDITS: Page 10

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IS THE HUMAN BODY EVOLVING TO
SURVIVE WITHOUT OXYGEN?

Spiking the Lunch

Photograph by Carlos Sanz

THE NATURAL MOMENT

◄ *See preceding two pages*

Take a spring walk in the woods, and you'll see twittering birds, rustling underbrush—and a tree spiked with corpses? The songbird family of shrikes that is responsible for such carnage is well represented by the woodchat shrike *(Lanius senator)*, pictured here grappling with a lizard. Shrikes are keen carnivores, but they have relatively weak claws and twiggy little legs that make hawk-style hunting impossible. Instead, the birds strike with their beaks and hook their fresh meat on thorns or barbed wire. They earn their nickname: "butcher birds."

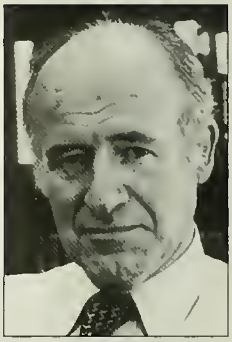
Insects, rodents, and even other robin-size birds are impaled in shrike territory. Research shows that some shrikes will go so far as to lure their fellow songbirds into a trap by mimicking parts of various distress calls. However they secure their hefty and numerous catches, shrikes seem wasteful: they often leave food uneaten. Yet the extra effort of the males, at least, is not in vain. Females are attracted to prospective mates that keep their larders stocked.

Photographer Carlos Sanz came across a pair of woodchat shrikes last spring near the small village of Almiruete, in central Spain. Sanz watched their nest closely, while a scorpion, a mouse, and the lizard pictured here were systematically skewered. Then the delicate, red-headed birds turned quickly away from slaughter and back to singing. —*Erin Espelie*

UP FRONT

Milestones

Dennis Flanagan, the founding editor of the modern *Scientific American*, who died this past January on the day the *Huygens* space probe landed on Titan, never liked anniversaries. They were lame excuses, in his estimation, for the common practice of filling magazines with articles that wouldn't stand up without the crutch of the calendar. Yet I think Flanagan would have enjoyed the coincidence between the imminent results from Gravity Probe B (see Arthur Fisher's article "Testing Einstein (Again)," page 52) and this year's centennial of Einstein's *annus mirabilis* (see Robert Anderson's column "Einsteiniana," page 72).



To the physicists who designed Gravity Probe B, the coincidence must seem an absurdist joke. The project is a space-based test of Einstein's general theory of relativity, but it was his special theory, not the general theory, that was published in 1905. More to the point, the project was begun in 1959 and, by all original estimates, should have concluded decades ago. Maybe Flanagan's impatience with the counterfeit currency of anniversaries was well founded.

His impatience with cranks certainly was. A crank, according to Flanagan, is anyone who "believes something that on the face of it is unbelievable." Apart from the curved space-time of Einstein's universe, no other scientific principle acts more like flypaper for cranks than does evolutionary biology. The reason, no doubt, is that it makes seemingly remarkable claims about familiar things: flowers, trees, snakes, human beings.

But the evolutionary biology of Darwin and the late Ernst Mayr continues to explain the natural world with such clarity that to deny its insights has become "something that on the face of it is unbelievable." Laura A. Sessions and Steven D. Johnson offer a striking example of the power of evolutionary thinking in their article "The Flower and the Fly" (page 58).

For a *Natural History* forum in which proponents present their case for intelligent design and leading evolutionists respond, see the page www.naturalhistorymag.com/darwinanddesign on our Web site.

• • •

Flanagan's version of *Scientific American* became the very model of the modern science magazine. He created, through his tutelage and example, a generation of science journalists and editors—I'm proud to be one of them—who have carried his legacy to *American Scientist, Discover, Muse, National Geographic, Natural History, Science, Technology Review, The Sciences,* and many other magazines. When he retired, he remarked—characteristically—that he hoped he had given his colleagues a chance to do intriguing and valuable work. Indeed he had.

• • •

Speaking of milestones, with his tour of the island of Saint Lucia ("Peak Experience," page 64), our contributing editor and columnist Robert H. Mohlenbrock has published his 201st "This Land" column. To my knowledge, only Stephen Jay Gould, with his 300 columns, holds a longer record at *Natural History*. —PETER BROWN

CONTRIBUTORS

Sanz

Biologist **CARLOS SANZ** ("The Natural Moment," page 6), a native of Spain, specializes in the study of Iberian wolves *(Canis lupus signatus)*. He recently co-authored a book on the wolves, published under the title *Amigo Lobo* (Friend Wolf). Sanz has worked extensively as a nature writer and photographer, and has also helped produce nature documentaries. His photograph of a shrike with prey was taken in Spain's central Guadalajara province.

Clark

Cancalosi

Rattlesnakes have enthralled **RULON W. CLARK** ("Social Lives of Rattlesnakes," page 36) since childhood. He recalls being particularly drawn to wild animals that didn't try to fly or run away, because then he could hold them. For the past seven years Clark has been studying timber rattlers in the northeastern United States. He recently completed his Ph.D. at Cornell University in Ithaca, New York, with a dissertation on the group interactions of snakes. He continues to stalk the forests near Ithaca, where he is now a postdoctoral associate at Cornell. Photographer **JOHN CANCALOSI** also lives in Ithaca. He became a teacher after earning a master's degree in zoology, but left the position more than a decade ago to pursue his passion for nature photography full-time.

Fisher

Back in 1983 **ARTHUR FISHER** ("Testing Einstein (Again)," page 52) wrote an article for *Popular Science* about Gravity Probe B, a major experimental test of Einstein's general theory of relativity. Physicists and engineers had already been working on the project for more than twenty years, when Fisher's article came to the attention of Stanford University physicist C.W. Francis Everitt, the project's principal investigator. Everitt invited Fisher to help write the project's brochure. With the satellite finally aloft and collecting data, both men look forward to seeing the final results. Fisher, who was the science editor at *Popular Science* for many years, has been a frequent contributor to many other science publications, and has received numerous awards for his science writing.

Sessions

Johnson

With degrees in both ecology and science communication, **LAURA A. SESSIONS** ("The Flower and the Fly," page 58) is well prepared to write about her interest in plant-animal interactions. A native of Virginia, Sessions has lived in New Zealand for the past eight years. This article is her fourth contribution to *Natural History*. Botanist **STEVEN D. JOHNSON** is an associate professor at the University of KwaZulu-Natal in Pietermaritzburg, South Africa. Working in one of the world's major centers of biodiversity, Johnson says, has heightened his interest in the role of pollinators in the evolution and ecology of plant species. He has co-authored a book about Cape Town's famous scenic landmark *(Table Mountain: A Natural History)*, and is also a regular contributor to natural history magazines in South Africa.

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Fruit Cocktail

In "The Drunken Monkey Hypothesis" (12/04–1/05) Dustin Stephens and Robert Dudley suggest that human alcoholism is rooted in the evolutionary history of primates. They reason that frugivorous primates evolved mechanisms for tolerating dietary ethanol because low levels of alcohol are characteristic of ripe fruits.

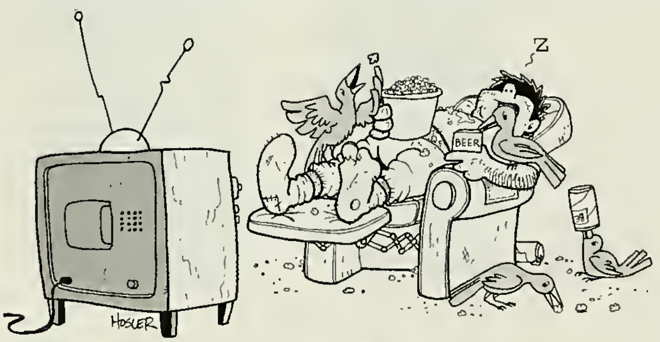
It is compelling supporting evidence for the hypothesis that approximately 10 percent of the total soluble protein in the human liver is alcohol dehydrogenase, one of the enzymes that metabolizes alcohol. But it is also important to consider how primates recognize ethanol, if it is a major foraging cue. Matthais Laska of the University of Munich and others report that macaques possess an exquisite olfactory sensitivity to alcohol. Vicktoria Danilova and Göran Hellekant of the University of Wisconsin–Madison have shown that nerves that convey taste and somatic sensations from the mouth respond to ethanol. The responses are far greater in primates than in other mammals. A tendency towards tipsiness, then, could well be an evolutionary hangover.

Nathaniel J. Dominy
University of California
Santa Cruz, California

The key assumption of the argument by Dustin Stephens and Robert Dudley is that contact between prehistoric primates and ethanol is necessary for alcoholism. On closer examination, however, that seems unlikely.

Alcoholism is an addiction; it is characterized by dependence, the development of tolerance, and a loss of control over intake. People become addicted to many different substances that our primate cousins never came in contact with, such as methamphetamines, heroin, and crack cocaine. What appears necessary for addiction is that a substance interacts in specific ways with neural pathways involved in motivation, reward, and reinforcement. Those pathways, of course, also have an evolutionary history, but one that long predates frugivorous primates. A thoughtful critique of the drunken monkey hypothesis was recently published by Katharine Milton ("Ferment in the Family Tree," *Integrative and Comparative Biology*, **44:** 304–314, 2004).

Justin S. Rhodes
and John C. Crabbe
Portland Alcohol Research Center
Portland, Oregon



Now, this *is what I call a niche.*

On our property in the Hudson Valley, my wife and I have several old mulberry trees with berries that ripen in July. As the sun warms the berries, many fruit-eating birds that rarely visit our seed feeders come and feast. It seems as though the berries begin to ferment in the sun. The young robins are particularly affected. They eat their fill and then try to fly, usually flapping and landing close to the tree, seemingly quite drunk. We have not noticed the same phenomenon in more mature birds.

David Ginsberg
New York, New York

ROBERT DUDLEY REPLIES: Alcohol is unique among the addictive substances in that all fruit-eating animals, including human ancestors, regularly consume low-levels of alcohol while feeding on ripe and overripe fruit. Justin S. Rhodes and John C. Crabbe are correct in suggesting that the neural pathways associating alcohol ingestion with reward precede the origin of primates. As Dustin Stephens and I stated in our article, fruit flies track ethanol plumes to find fruit, and the flies' fecundity and longevity are enhanced at low levels of alcohol exposure.

Recent work by Ulrike Heberlein, an anatomist at the University of California, San Francisco, has demonstrated that fruit flies also have molecular pathways of inebriation similar to those of humans. Her finding shows that fruit flies are good models for studying drug abuse in people. Identifying the evolutionary origins of such physiological and behavioral responses to alcohol is an important goal for basic research in the biology of addiction.

Good Cause

I was deeply touched by James A. Zingeser's article, "Sight for Sore Eyes" (12/04–1/05). Mr. Zingeser's straightforward description of the disease touched my heart, as I imagined how constant the misery of trachoma would be.

I have become sickeningly accustomed to hearing about "solutions" to problems in developing countries that are really political decisions serving the interests of ruling classes and militaries. The epidemiological work and the implementation strategies involved in the trachoma-control effort seemed to me profoundly thoughtful and well grounded in the principle of meeting people where they are.

Keith Thurlow
Truro, Massachusetts

JAMES A. ZINGESER REPLIES: I thank Mr. Thurlow for his kind and perceptive remarks about the global efforts to control trachoma. He is absolutely correct, we live in a world in which we can either share our enor-

mous wealth to end extreme poverty, hunger, and disease, or watch resources waylaid and squandered for war and greed.

Our strategy has always been to "meet people where they are" by listening to them and responding to their needs. In the same way, the Carter Center, the Centers for Disease Control and Prevention, and the World Health Organization, along with dedicated development and health-care workers worldwide, are on the verge of eradicating guinea worm disease and poliomyelitis.

President Jimmy Carter has played another crucial role by using his direct access to heads of state and leaders of industry to speak out for forgotten persons worldwide. A year ago I presented President Carter with compelling data suggesting that providing latrines would reduce trachoma and have a huge impact on other hygiene-related illnesses for extremely impoverished families. He stopped me and asked, "How many latrines are we talking about?" "Hundreds of thousands, perhaps millions," I replied. He didn't flinch, "All right then, who do I need to speak with to get this going? Let's not waste time."

Come Together

As one of the originators of the mission, it was a special pleasure for me to read John C. Zarnecki's account of the Cassini-Huygens mission to Saturn's largest moon, Titan ("Destination: Titan," 12/04-1/05). One of the most satisfying aspects of this project has been its international character. The Cassini-Huygens mission illustrates what can be accomplished when Europe and the United States work closely together as equal partners on a project that is at the cutting edge of technology.

Mr. Zarnecki and I and all the other members of our intrepid crew will still be happily puzzling over the secrets of Titan on the 25th of this month, the 350th anniversary of Christiaan Huygens's discovery of the enigmatic satellite. Huygens would surely be pleased. [*For a picture of Titan's surface, see page 15.*]

Tobias C. Owen
University of Hawai'i at Manoa
Honolulu, Hawai'i

Naming Rights

In Peter M. Whiteley's article "Ties That Bind" (11/04), the credit given for the portrait of the Hopi Chief Kewanimptewa on page 26 was incomplete. The painting is by Eben Cummins; it is part of the collection of the Michael and Margaret B. Harrison Western Research Center at the University of California, Davis.

Natural History *welcomes correspondence from readers* (nhmag@naturalhistorymag.com). *All letters should include a daytime telephone number, and all letters may be edited for length and clarity.*

Narwhals get a break (in the ice).

Room to Breathe?

Sea ice in the Arctic is decreasing, right? That's certainly true overall: 9 percent of the "perennial" ice and 3 percent of the annually formed ice have been disappearing each decade for the past quarter century. But in some areas the ice has been *increasing*. One such area is Baffin Bay, between Canada and Greenland. The bay is home to the world's greatest concentration of narwhals, and for them an increase in ice is a big problem.

Narwhals—small whales that live in the High Arctic—are noted for the males' long, lone tusk. Sensibly, they migrate south in winter. "South," however, is no farther than the middle of Baffin Bay, which is mostly covered in dense pack ice from December through March. At present the ice still has enough leads and cracks so that the narwhals can breathe. But Kristin L. Laidre and Mads Peter Heide-Jørgensen of the Greenland Institute of Natural Resources have found that the winter ice cover in the narwhals' northernmost wintering grounds in Baffin Bay increased by 0.04 percent a year between 1978 and 2001.

That may not sound like much, but from mid-January until mid-April less than 3 percent of the narwhals' wintering grounds are open water. The icing trend could become disastrous for the narwhals. Not only will they run the risk of getting trapped in the ice, but there will also be fewer places from which they can dive for one of their main winter foods: the halibut that live at depths of more than 3,000 feet. ("Arctic sea ice trends and narwhal vulnerability," *Biological Conservation* **121**:509–17, 2005)

—*Stéphan Reebs*

Telling Teeth

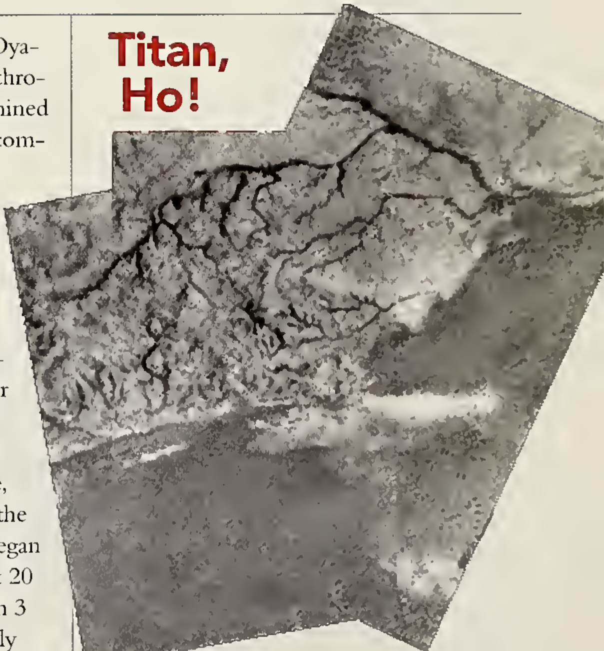
That the rich are healthier than the poor is no surprise. But a recent study puts a new face on that dismal truism: centuries ago in Japan, the samurai had healthier teeth than their less affluent neighbors.

Best known as warriors, the samurai became part of Japan's ruling class during the Edo period (1603–1867). Joichi Oyamada and his colleagues, all dental anthropologists at Nagasaki University, examined the teeth of 357 samurai and 1,211 "commoners" (merchants, farmers, and their families) buried in the city of Kokura between the sixteenth and nineteenth centuries. It turns out that the adult samurai had half as many teeth with decayed roots as adult commoners did. Younger samurai had only an eighth as many as their poorer counterparts.

The reasons? Oral hygiene was key. Tooth powder had long been available, but brushing with an early relative of the toothbrush—the tufted toothpick—began in the Edo period. The teeth of about 20 percent of the samurai, compared with 3 percent of the commoners, were highly polished in precisely those spots that the new device could reach. ("Dental pathology in the samurai and commoners of early modern Japan," *Anthropological Science* 112:235–46, 2004) —*Caitlin E. Cox*

Mask representing a samurai, 14th century

Titan, Ho!



On January 14 the European Space Agency's Huygens *probe landed on Saturn's largest moon. From a height of five miles,* Huygens *photographed what appears to be a ridge with drainage channels that lead to a flat plain.*

Fighting hyenas make their clan's social structure clear to human observers.

Battlefield Protocol

Social complexity is often cited as the driving force behind the evolution of intelligence. Until recently, animal behaviorists thought only primates displayed the intellectual abilities necessary for complex cooperation or for selfish manipulation of comrades—abilities such as individually recognizing other members of their own group and taking into account both the members' rank in the group hierarchy and their blood ties. Now a team of behavioral ecologists at Michigan State University in East Lansing has determined that spotted hyenas exhibit that same level of sophistication in their group interactions.

Anne L. Engh and other students of Kay E. Holekamp's observed a clan of spotted hyenas for eleven years in the Masai Mara National Reserve in Kenya. The investigators paid particular attention to fighting behavior—an excellent way, they found, to figure out both pecking order and kinship relations. When two hyenas were fighting, a third would sometimes join in. But no matter which animal started the fight or which one was winning at the time, the meddler almost always sided with the combatant having the higher social ranking. Moreover, in the secondary skirmishes that often followed the original fight, the hyena that started the earlier fight was more likely to pick on its opponent's relatives.

Thus, primates are not the only group-dwelling animals that may have evolved intelligence because of the need to handle social complexity. And in a contest of social acumen between hyenas and monkeys, who knows who would get the last laugh? ("Patterns of alliance formation and postconflict aggression indicate spotted hyaenas recognize third-party relationships," *Animal Behaviour* **69**:209–17, 2005) —*S.R.*

Birds of a Feather Sink Together

Divers keep warm in cold water by wearing a dry suit, which traps a layer of air between suit and skin. Unfortunately, the foam insulation inside the suit also makes divers more buoyant and even less able to swim downward. To compensate, they carry weights. Pity the poor diving birds, then: they have a dry suit of their own—air-trapping plumage—but no weights. The birds have to kick or swim their way down.

Cormorants, however, seem to be an exception. The birds' habit of spreading their wings open to dry after a dive suggests that their plumage can get at least partly wet—a compromise between buoyancy and insulation that's unique among diving birds. Some ornithologists, in fact, have thought that great cormorants get completely drenched, leaving no air pockets to impede the birds' diving efficiency. But David Grémillet, an ecophysiologist at the National Center for Scientific Research in Strasbourg, France, and his colleagues have shown that's not so.

The investigators discovered that the submerged carcasses of great cormorants displaced more water than did the combined volumes of the plucked body and the feathers, measured separately. In other words, the whole bird sank less readily than the sum of its parts. The difference, Grémillet's team contends, results from a thin layer of trapped air—only one-tenth of an inch thick, but still able to provide some insulation.

What keeps the plumage from getting totally wet is the unusual structure of the birds' feathers: loose peripheral barbs around a water-resistant central area. ("Unusual feather structure allows partial plumage wettability in diving great cormorants *Phalacrocorax carbo*," *Journal of Avian Biology* **36**: 57–63, 2005) —*S.R.*

Dazzler

What's the brightest thing a telescope has ever detected? Answer: a burst of radiation from a small, dense star 12,000 light-years from Earth—a pulsar known as B1937+21.

Pulsars spin much like the searchlight in a lighthouse, except they do it hundreds of times a second. If Earth happens to lie in the path of the pulsar's beam, we see bright blasts, or pulses, of radiation lasting a few nanoseconds. Sometimes a pulsar puts out an astoundingly powerful "giant pulse" that's as much as a thousand times more intense than a run-of-the-mill pulse. Vladimir A. Soglasnov of Lebedev Physical Institute in Moscow and a team of astrophysicists caught B1937+21's fleeting giant outburst through a radio telescope near Canberra, Australia, back in May 1999. It was invisible to the naked eye, but if you'd been talking on your cell phone at the time (and if interstellar space were devoid of matter), you'd have heard a loud click.

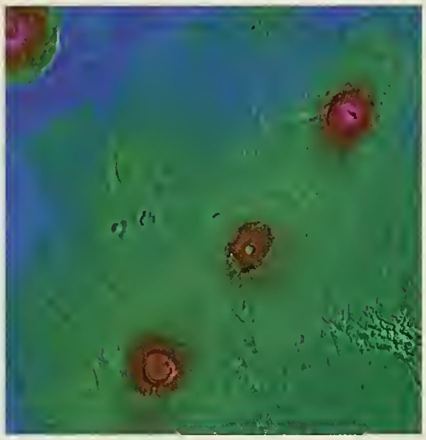
At peak intensity, the giant pulse's brightness indicated a temperature of 10^{40} degrees Fahrenheit (the brightness of the hottest areas of the Sun correspond to "only" about 3×10^7 F). ("Giant pulses from PSR B1937+21 with widths ≤ 15 nanoseconds and $T_b \geq 5 \times 10^{39}$ K, the highest brightness temperature observed in the universe," *The Astrophysical Journal* 616:439–51, 2004)

—*Dave Forest*


Stauer

Is Mars Alive?

Geologically speaking, most planetary scientists have given up Mars for dead. Although the Red Planet bears the scars of faulting, volcanic eruption, and even glaciation, investigators have generally concluded that any such activity took place long ago. Álvaro Márquez, a geologist at Rey Juan Carlos University in Spain, and his colleagues disagree.



Trio of massive Martian volcanoes

Satellite images of three Martian volcanoes, all situated on the vast dome known as the Tharsis region, show knobby, ridged piles of rock on the volcanoes' flanks. According to Márquez and his colleagues, the rock piles look much like the moraines left behind by retreating glaciers on Earth. Not only were the rocks probably left by Martian ice, the investigators say, but they were also deposited less than 10 million years ago—recent by geological standards. The basis for that date is crater counting: Tharsis has far fewer fresh craters caused by asteroid impacts than do regions of the Moon whose rocks are known to be older.

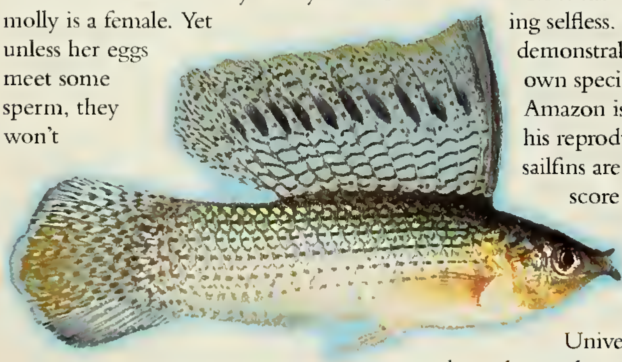
Another sign of geologic activity at Tharsis is a series of ridges and plateaus separated by large fractures. There are conspicuous layers of rock, not obscured by accumulated dust, at the edges of the fractures. Several fissures appear to have spewed lava. All of those features point to active Martian tectonics. Similar patterns occur on Earth where continental plates are being torn apart, such as in East Africa's Great Rift Valley.

The most intriguing implication of the observations is that, at its heart, Mars may be neither dead nor cold. Internal heat energy could be driving the dynamic processes visible on its surface. Such energy, say Márquez and his colleagues, may mean increased chances of finding life on the Red Planet. ("New evidence for a volcanically, tectonically, and climatically active Mars," *Icarus* 172:573–81, 2004)

—*D.F.*

Marriage of Convenience

In the rivers and lagoons of northern Mexico and southern Texas lives a fish called the Amazon molly. Every Amazon molly is a female. Yet unless her eggs meet some sperm, they won't grow into embryos. Who, then, supplies the sperm? Obviously not an Amazon molly: they're all females, remember? The sperm comes instead from the males of a closely related species, such as the sailfin molly.



But why should a male waste his sperm on eggs that ignore his DNA? After all, making sperm takes energy.

As it turns out, the male isn't being selfless. Although a male sailfin demonstrably prefers females of his own species, mating with an Amazon is a fine item to add to his reproductive résumé: female sailfins are drawn to males that score with a female molly of any species. Andrea S. Aspbury and Caitlin R. Gabor, both biologists at Texas State University in San Marcos, have shown that charity has its limits, however. Male sailfins are not profligate sperm donors: when cooped up with an Amazon molly, they save energy by producing less sperm. ("Discriminating males alter sperm production between species," *Proceedings of the National Academy of Sciences* 101:15970–73, 2004

—*S.R.*

Housing Shortage

For many creatures, there's no cozier shelter from the storm than a hollow in a tree. In Australia, more than 300 species of vertebrates hide or make their nests there, often in one of the continent's multitudinous species of eucalyptus, and the patches of forest scattered across suburbia offer many species the best chance of finding refuge in urbanized areas. Within those patches, however, trees offering hollows are getting scarce, say Michael J. Harper and two other ecologists from the Australian Research Centre for Urban Ecology in Melbourne.

Hollow tree branch houses a lorikeet.

Aussie vertebrates don't have the equipment to excavate hollows on their own. So they depend on fire, wind-induced branch breakage, or boring insects to breach the external sapwood; the breach then permits fungi to reach the heartwood and decay it. According to Harper and his colleagues, the entire process usually takes at least 150 years, though it goes faster in dead trees.

In a study of forty-four forest remnants in the suburbs of Melbourne, the investigators found that hollows are most common in eucalypts that are large, more exposed to the wind, or dead. Decades of logging have made large trees a rarity, though, and within city limits, dead trees are often removed. Fire, of course, is suppressed. That leaves only insects and wind as effective initiators of tree hollows. Harper's team found fewer than two tree hollows, on average, per suburban acre (natural woods have two to four times as many). More than a quarter of the forest remnants had none. ("The abundance of hollow-bearing trees in urban dry sclerophyll forest and the effect of wind on hollow development," *Biological Conservation* 122:181–92, 2005)

—*S.R.*

Seacow Head Cliffs, Prince Edward Island

The Great Outdoors

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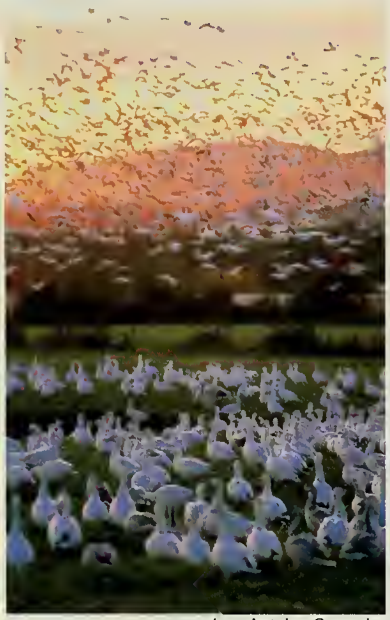
Get close to the wildlife in
Québec City.



Luc-Antoine Couturier

Yves Tessier

Brigitte Ostiguy

Top left: Snow geese at Cap Tourmente; top right: Summer nightlife on Grande Allée; above: Old Port, Old Québec

Québec City

QUÉBEC CITY IS A CITY WITH A European flair, nestled on the shores of the St. Lawrence River since 1608. Cradle of French civilization in America, Québec City with its historic district is recognized by UNESCO as a World Heritage Site. Narrow winding streets, old stone homes and churches, ramparts and cannons, copper roofs and graceful architectural curves all bring to mind the old continent. It is a lively and dynamic city, with one foot set in the 21st century and the other in history, with its numerous patrimonial sites.

You can stay in a hotel or inn in Old Québec, enjoy a myriad of restaurants, bistros, sidewalk cafés, and yet you are only 40 minutes away from the great outdoors. The best example is Cap Tourmente National Wildlife Area, home to many species of birds and other animals.

Cap Tourmente

Cap Tourmente National Wildlife Area is located on the north shore of the St. Lawrence River about 50 miles downstream from Québec City.

The 5,500-acre wildlife area has been the scene of remarkable natural phenomena. A major fault runs across the site from east to west and separates the Laurentian Shield from the St. Lawrence Lowlands. The break is clearly visible in the form of an escarpment rising more than 500 feet above the coastal plain.

The Laurentian Plateau that dominates the site is characterized by well-rounded, forest-covered summits with many streams. A sheer cliff separates it from the lowlands and gives rise to numerous waterfalls.

The convergence of river, plain and mountains makes the Cap Tourmente National Wildlife Area a place of outstanding beauty, rich in opportunities for observing nature. The area is famous for the breathtaking spectacle afforded by the tens of thousands of snow geese that stop over here in spring and fall. The site's biodiversity is extensive: nearly 305 bird species and many mammal species can be seen here. An interpretation centre, a network of hiking trails and qualified naturalists make Cap Tourmente an ideal natural setting for getting close to wildlife, all this less than an hour's drive from Québec City.

One astonishing feature of Cap Tourmente is the great variety of vegetation in a relatively limited area: more than 22 forest associations and nearly 700 plant species. Over thirty mammal species visit or live in the wildlife area. Cap Tourmente also provides shelter for a multitude of birds. To date, more than 300 bird species from over 45 families have been identified at the site.

High quality facilities have been built to improve access to the site. The 12 miles of nature trails have encouraged the public to discover the site's attractions while at the same time reducing impact on the natural environment. Visitor information and documentation are provided to more fully appreciate and support the conservation and protection of the wildlife area's unique habitats.

Consult www.quebecregion.com for more information.

SCF

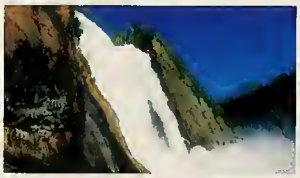
Migration Time around Québec City

At the heart of the Atlantic Flyway you will find the "Cap Tourmente National Wildlife Area" - one of the best sites for bird watching in North America. This location is one of Québec's oldest farms established in 1626 by Samuel de Champlain. Located on the north shore of the St. Lawrence River, where great coastal marshes, plains and mountains meet, it is the point of convergence for the St. Lawrence Lowlands and the Canadian Shield.

The region offers over 200 km of hiking trails, 20 of which are located directly on the Cap Tourmente protected area where over 300 species of birds have been observed. After your visit, you will understand why Cap Tourmente is the perfect resting station for migratory birds. From here, they continue to travel East, West and North. Twice a year, bird lovers and enthusiasts can watch thousands of geese on their migration North in Spring or their return South in Autumn. So this spring, follow the geese *in one of the most beautiful areas of their migratory route near Québec city. This city offers an immersion in one of North America's most fascinating colonisation history. It is a region that must be seen, so plan your next migration time around Québec City.*

Cap Tourmente, heart of the Atlantic Flyway

Luc-Antoine Couturier



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Bonjour! Québec

Photos: Tourism PEI/John Sylvester

Above: Orwell Cove - Charming views are found on Prince Edward Island's scenic drives; Paddlers take an excursion to beautiful Hog Island off the coast of Lennox Island, Prince Edward Island

Prince Edward Island

Small and green are often among the first words people use to describe Canada's island province, Prince Edward Island.

THE ISLAND'S NATIVE PEOPLES, THE Mi'kmaq, are credited with the expression "cradled on the waves" which perfectly portrays the way this crescent-shaped slip of red soil and sandy beaches settles into the Gulf of St. Lawrence, on Canada's east coast.

Thousands of years ago, those same Mi'kmaq considered the Island a favorite summering place, rich in fish and wild fruit and gentle of climate. Now, modern-day visitors find much the same attractions. If earlier visitors paddled their way to Prince Edward Island shores, today's visitors can enjoy sea kayking along the same sandy beaches and red sandstone cliffs, stopping for a snack in a secluded cove.

Probably the delicious shellfish sampled by the Aboriginal visitors has changed little; delicious fresh lobster, mussels and oysters are part of the everyday fare in Prince Edward Island. In fact the Prince Edward Island blue mussel has developed such a reputation that it is seen on all the best menus across North America.

At Greenwich, **Prince Edward Island National Park** has opened a site that interprets 10,000 years of the Island's history as well as explaining the ecology of a dramatic migrating dune system. Other interpretive centres around the province present intriguing information about potatoes, seaweed, mussels, railways, windmills, shipbuilding or Acadian, Celtic or Mi'kmaq culture!

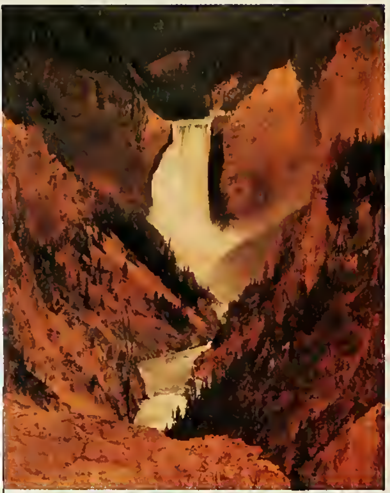
An important part of the Prince Edward Island identity is entwined with a story about a red-haired orphan called Anne of Green Gables. The novel, published in 1908, is set in Prince Edward Island and readers from around the world visit the storybook island to enjoy the landscapes so lovingly described by local author L. M. Montgomery. That pastoral landscape, a rich quilt of reds and greens, farm fields and woodlots, is greatly admired by all who visit.

Rustico Fishermen

Four Parks

Glacier National Park

Spanning three states, millions of acres and a billion years, each of the **Four Parks** is a must-see American icon.



Yellowstone National Park

Mount Rushmore

GLACIER NATIONAL PARK'S MILLION acres of untouched wonder serve as a home to countless wildlife including elk, deer, antelope, eagles, hawks, great blue herons, mountain goats, bighorn sheep and grizzly bears. Drive the 50-mile long Going-to-the-Sun Road along the shores of the park's two largest lakes and the cliffs below the Continental Divide, hike over 700 miles of trails or discover secluded areas of the park.

Mount Rushmore lets you look history—and nature—in the eye. Mount Rushmore's 60-foot granite faces gaze out over South Dakota's Black Hills which offer outdoor nature lovers a chance to hike, bike, fish and rock climb.

Hike the Presidential Trail and attend the patriotic Lighting Ceremony, which takes place nightly throughout the summer. Tour Badlands National Park, Crazy Horse Memorial, Wind Cave National Park, Jewel Cave National Monument, and Custer State Park—with its herd of 1,500 bison. See wildlife such as bison, elk, mountain goats and bighorn sheep.

The youngest of the Rocky Mountain system, the Teton Range is the centerpiece of **Grand Teton National Park**. Rising 13,000 feet above sea level Grand Teton offers magnificent wildlife watching, fishing and birding opportunities. On the Snake River scenic float trips spy bald eagles, beavers and osprey. If you're angling for fishing then try world-class fly fishing on the Snake River or fish for the infamous native cut throat trout on Jackson Lake.

Yellowstone, the world's first national park, offers endless opportunities to experience unique natural phenomena. Guided tours, ranger-led hikes and naturalist-led mini-expeditions will take you to Old Faithful, Mammoth Hot Springs, the famous Lower Falls in the Grand Canyon area, and Yellowstone Lake, as well as into the secret side of Yellowstone. Wildlife species abound, including North America's largest wild bison herd as well as elk, deer, moose, wolves, bears, trumpeter swans, and cut throat trout.

Grand Teton National Park

Marco Polo Oceanliner (Antarctica)

The Deck Chair Traveler

The Greek isles, Scandinavian fjords and the Amazon River—some of the world's most spectacular places are best experienced by boat. On a luxury cruise you can sit back, relax and enjoy the passing splendor of the great outdoors—as well as the on-board fun.

Explore the spectacular icescapes of the Antarctic Peninsula in the company of distinguished naturalists, come face-to-face with local wildlife, venture through Chile's fjords or into the rainforests of the Amazon. An **Orient Lines** Marco Polo cruise offers an ideal vantage point for admiring the natural wonders of the world, plus it's a world-class destination of its own.

Enjoy the cultural diversity and natural splendor of South America, including Chile's fjords and Patagonia's spectacular wilderness. Visit the lands of castles, kings and Viking chiefs including Stockholm, Dublin, Berlin and St. Petersburg. Get to know the Highlands and islands of Scotland. Or cruise through the Mediterranean, stopping at Santorini, the great crusader's fortress on Malta, Sicily and the exquisite Amalfi Coast.

When you're finished enjoying the great outdoors, Marco Polo's on-board treats include delicious cuisine, a nightclub, disco, health club, swimming pool, library, casino, card room and lounges.

Randall Perry Photography

Beach Picnic on Little St. Simons Island

The Shore Thing

If your ideal great outdoors vacation involves beach combing, bird watching and boating, then head to the shores of Alabama and Georgia.

Hike through wildlife refuge areas, gaze at gators, or add to your bird watching life list. Cast your line for deep-sea adventure on a charter-fishing trip, travel back in history with a visit to Fort Morgan, or putter around on a championship golf course. An **Alabama Gulf Shore** vacation offers lots of options for both nature and history buffs.

The Gulf Islands National Seashore offers miles of untouched beaches, sparkling emerald green waters, fertile coastal marshes and dense maritime forests. For plant lovers, visit The Biophilla Nature Center. This 20-acre ecological restoration project features carnivorous plants, wildflowers, forest, an 11-foot long alligator, butterfly nursery and native wildlife. If sea life is your interest, stop by the Bon Secour National Wildlife Refuge and the Estuarium Sea Lab marine education and research center.

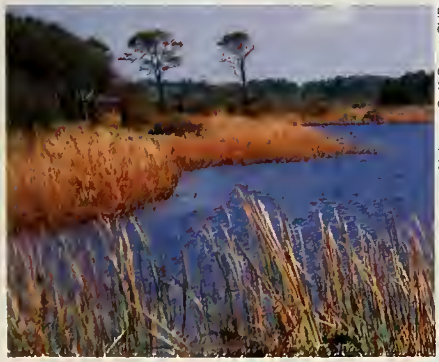
For a dose of history, don't miss Fort Morgan, situated on a beautiful beach and the site of the Civil War Battle of Mobile Bay. Then tour Bellingrath Gardens and Home, 65 lushly landscaped acres in semi-tropical rain forest that resonates with Old World charm.

Located off the coast of Georgia, **Little St. Simons Island** is a privately owned 10,000-acre barrier island accessible only by boat and shared with no more than 30 overnight guests.

Recognized as one of the premier birding areas on the east coast, Little St. Simons Island is located in the path of the Atlantic Migratory Flyway. Each spring, waves of warblers, sparrows and a variety of shorebirds settle on the barrier island's seven miles of deserted beach and vast maritime forests. Over 280 species of birds, some of which are threatened or endangered, have been recorded on Little St. Simons Island.

Besides birding, activities include strolling secluded, shell-strewn beaches, boating, kayaking, canoeing horseback riding, bicycling, hiking and naturalist programs. Delicious regional cuisine, gracious accommodations and a knowledgeable staff make a trip to St. Simons Island even more enjoyable.

Bayou, Alabama Gulf Coast



Alabama Gulf Coast CVB

Lomaki Ruin, Wupatki National Monument

Sunset Crater lava flow

Flagstaff CVB

Mountain High

At an elevation of 7,000 feet, **Flagstaff** offers exceptional opportunities to not only experience the spectacular natural beauty of the high country, but also to enjoy historic downtown area shops, galleries and world-class restaurants. Plus, Flagstaff is just a short drive to Sunset Crater, Walnut Canyon, Oak Creek Canyon and Sedona, many Native American Reservations and of course, the Grand Canyon.

When in Flagstaff, don't miss the Arboretum, presenting the nation's primary collection of Southwestern high country wildflowers and a mile-long nature trail through Coconino National Forest, the world's largest contiguous Ponderosa Pine Forest. Step back in time at the Riordan Mansion State Historic Park, a turn-of-the-century mansion highlighting arts and crafts style architecture filled with original Stickley furniture.

Living Space

The universe is filled with the chemical ingredients of life—and there are plenty of places to get the chemistry going.

By Neil deGrasse Tyson

If you ask people where they're from, they will typically say the name of the city where they were born, or perhaps the place on Earth's surface where they spent their formative years. Nothing wrong with that. But an astrochemically richer answer might be, "I hail from the explosive jetsam of a multitude of high-mass stars that died more than 5 billion years ago."

Outer space is the ultimate chemical factory. The big bang started it all, endowing the universe with hydrogen, helium, and a smattering of lithium: the three lightest elements. Stars forged all the rest of the ninety-two naturally occurring elements, including every bit of carbon, calcium, and phosphorus in every living thing on Earth, human or otherwise. How useless this rich assortment of raw materials would be had it stayed locked up in the stars. But when stars die, they return much of their mass to the cosmos, sprinkling nearby gas clouds with a portfolio of atoms that enrich the next generation of stars.

Under the right conditions of temperature and pressure, many of the atoms join up to form simple molecules. Then, through routes both intricate and inventive, many molecules grow larger and more complex. Eventually, in what must surely be countless billions of places in the universe, complex molecules assemble themselves into some kind of life. In at least one cosmic corner, the molecules have become so complex that they have achieved consciousness and attained the ability to formulate and communicate the ideas conveyed by the marks on this page.

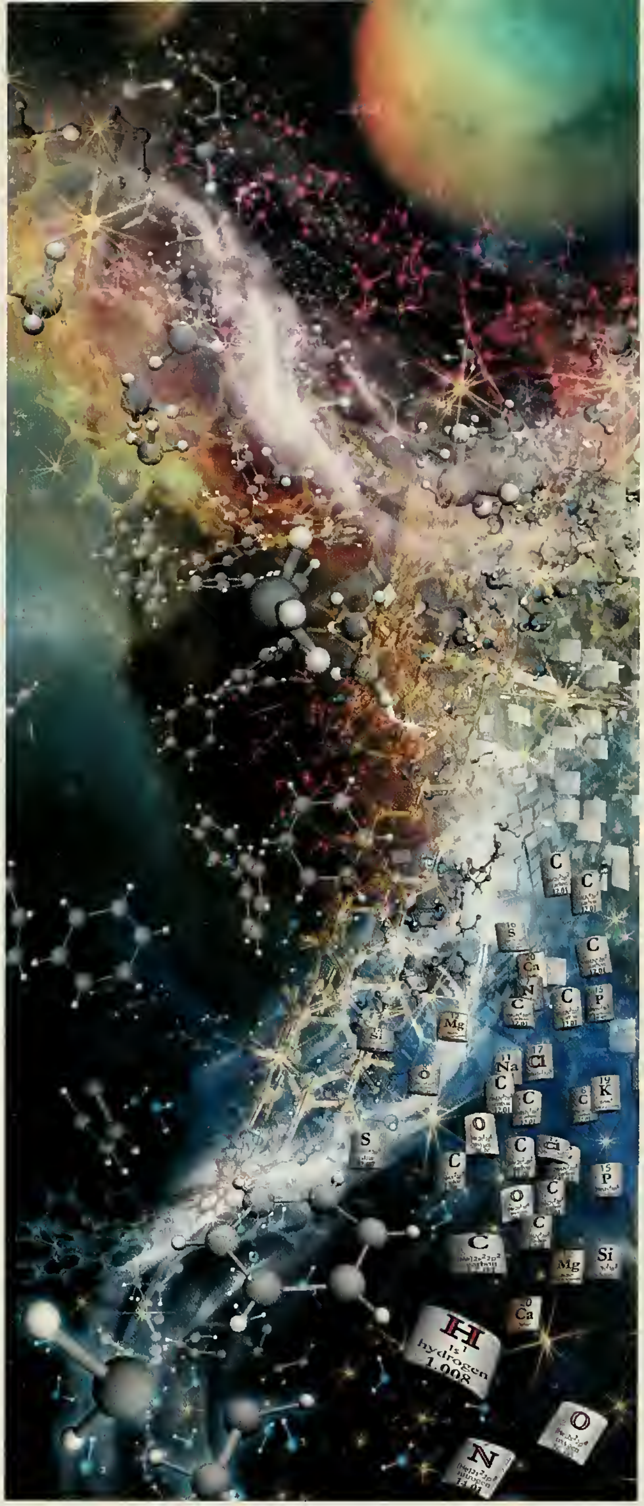
Yes, not only humans but also every other organism in the cosmos, as well as the planets or moons on which they thrive, would not exist but for the wreckage of spent stars. So you're made of detritus. Get over it. Or better yet, celebrate it. After all, what nobler thought can one cherish than that the universe lives within us all?

Every organism in the cosmos is made from the wreckage of spent stars.

To cook up some life, you don't need rare ingredients. Consider the top five constituents of the cosmos, in order of their abundance: hydrogen, helium, oxygen, carbon, and nitrogen. Take away chemically inert helium—which is not fond of making molecules with anybody—and you've got the top four constituents of life on Earth. Awaiting their cue within the massive clouds that lurk among a galaxy's stars, these elements begin making molecules as soon as the temperature drops below a couple thousand degrees Kelvin [*see Neil deGrasse Tyson, "Send In the Clouds," December 2004/January 2005*].

Molecules made of just two atoms form early: carbon monoxide and the hydrogen molecule (hydrogen atoms bound together in pairs). Drop the temperature some more, and you get stable three- or four-atom molecules such as water (H_2O), carbon dioxide (CO_2), and ammonia (NH_3)—simple but top-shelf ingredients in the kitchen of life. Drop the temperature even more, and hordes of five- and six-atom molecules form. And because carbon is both abundant and chemically enterprising, most of the molecules include it; indeed, three-quarters of the nearly 130 molecular "species" sighted in interstellar space have at least one carbon atom.

Sounds promising. But space can be a dangerous place for molecules. If the energy from stellar explosions doesn't destroy them, ultraviolet light from nearby ultraluminous stars will. The bigger the molecule, the less stable it is against assault. Molecules lucky enough to inhabit uneventful or shielded neighborhoods may endure long enough to be incorporated into grains of cosmic dust, and ultimately into asteroids, comets, planets, and people. Yet even if none of the original molecules survive the stellar violence, plenty of atoms and time remain available to make complex molecules—not only during the formation of a particular planet, but also on and within the planet's nubile surface. Notables on the short list of complex molecules include adenine (one of the nucleotides, or "bases," that make up DNA), glycine (a protein precursor), and glycoaldehyde (a carbohydrate). Such ingredients, and others of their caliber, are essential for life as we know it—and are decidedly not unique to Earth.



But orgies of organic molecules are not life, just as flour, water, yeast, and salt are not bread. Although the leap from raw ingredients to living individual remains mysterious, several prerequisites are clear. The environment must encourage molecules to experiment with one another, and must shelter them from excessive harm as they do so. Liquids offer a particularly encouraging environment, because they enable both close contact and great mobility. The more chemical opportunities an environment affords, the more imaginative its resident experiments can be. Another essential factor, brought to you by the laws of physics, is a generous supply of energy to drive chemical reactions.

Given the wide range of temperatures, pressures, acidity, and radiation flux at which life thrives on Earth, and knowing that one microbe's cozy nook can be another's house of torture, scientists cannot at present stipulate additional requirements for life elsewhere. Demonstrating the limits of this exercise is the charming little book *Cosmotheros,* by the seventeenth-century Dutch astronomer Christiaan Huygens, wherein the author speculates that life-forms on other planets must grow hemp, for how else would they weave ropes to steer their ships and sail the open seas?

Three centuries later, we're content with just a pile of molecules. Shake 'em and bake 'em, and within a few hundred million years you might have thriving colonies of organisms.

Life on Earth is astonishingly fertile, that's for sure. But what about the rest of the universe? If somewhere there's another celestial body that bears any resemblance to our own planet, it may have run similar experiments with its similar chemical ingredients, and those experiments would have been choreographed by the physical laws that hold sway throughout the universe.

Consider carbon. Its capacity to bind in multiple ways, both to itself and to other elements, gives it a chemical exuberance unequalled in the periodic table. Carbon makes more kinds of molecules (how does 10 million grab you?) than all other elements combined. A common way for atoms to make molecules is to share one or more of their outermost electrons, creating a mutual grip analogous to the fist-shaped coupler between freight cars. Each carbon atom can bind with one, two, three, or four other atoms in this way, whereas a hydrogen atom binds with only one, oxygen with one or two, and nitrogen with three.

By binding to itself, carbon can generate myriad combinations of long-chain, highly branched, or closed-ring molecules. Such complex organic molecules are ripe for doing things that small molecules can only dream about. They can, for example, perform one kind of task at one end and another kind at the other; they can coil and curl and intertwine with other molecules, creating no end of features and properties. Perhaps the ultimate carbon-based molecule is DNA: a double-stranded chain that encodes the identity of all life as we know it.

What about water? When it comes to fostering life, water has the highly useful property of staying liquid across what most biologists regard as a fairly wide range of temperatures. Trouble is, most biologists look to Earth, where water stays liquid across 100 degrees of the Celsius scale. But on some parts of Mars, atmospheric pressure is so low that water is never liquid: a freshly poured cup of H_2O boils and freezes at the same time! Yet in spite of Mars's current sorry state, its atmosphere once supported liquid water in abundance. If ever the Red Planet harbored life on its surface, it would have been then.

Water has another useful, though eccentric, property: when it freezes, it expands, becoming slightly less dense than when it's liquid. That's why pipes break when the water in them freezes. It's also why, when a pond freezes, the ice floats and the pond's inhabitants can endure the winter in liquid safety.

Liquid water can occur far beneath a surface, too. Vast quantities can be locked up inside the rocky interior of a planet, or sloshing away under the permanently icebound exterior of a world orbiting far from an external source of heat. Evidence suggests the latter condition may prevail on Jupiter's moon Europa.

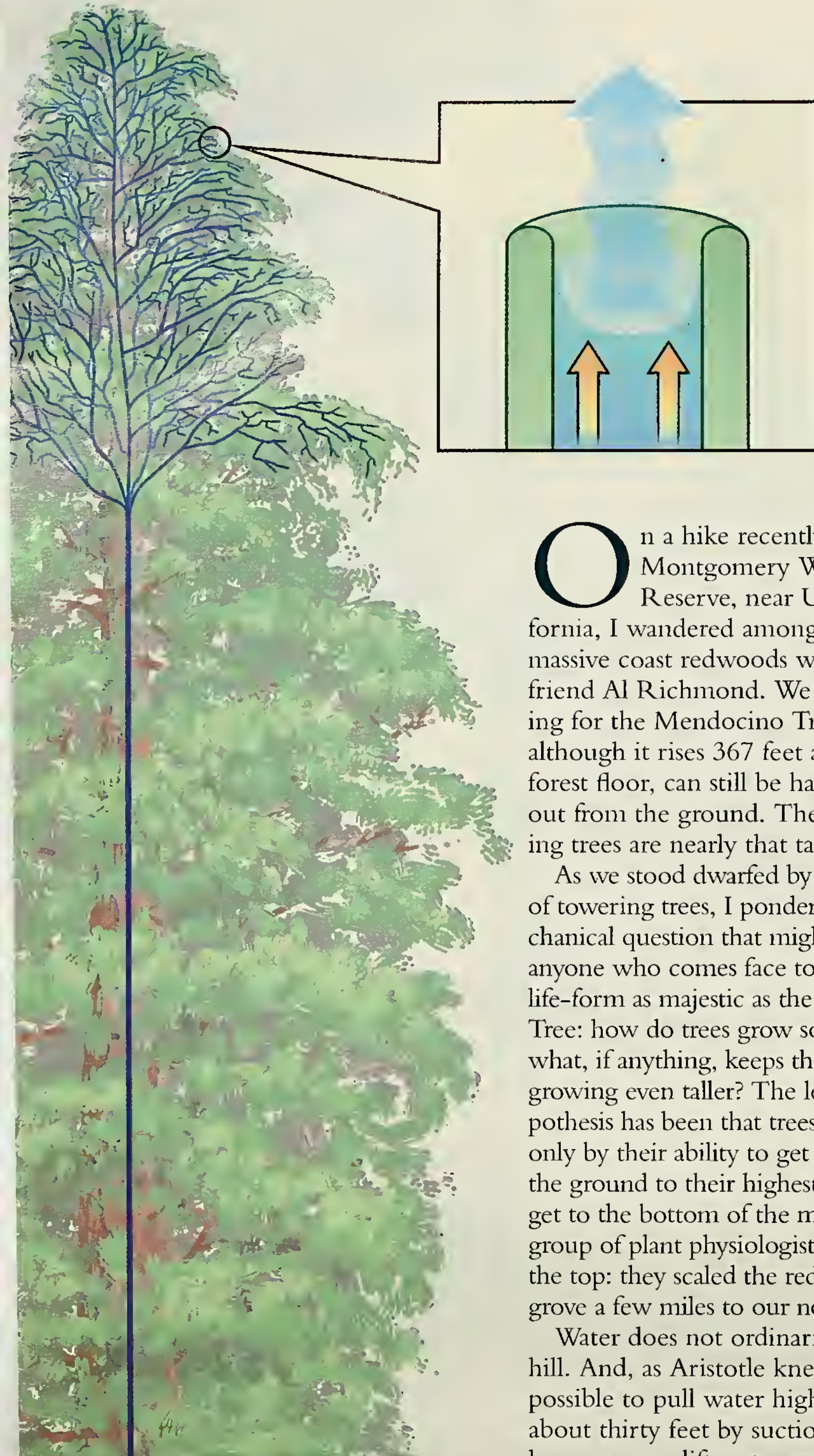
Earth, of course, happens to have a goodly—and occasionally deadly—amount of water on its surface. Where did it come from? Comets are a logical source: they're chock full of (frozen) water, the solar system holds countless billions of them, some are quite large, and they would regularly have been slamming into the early Earth back when the solar system was forming. Another source of water could have been volcanic outgassing—a frequent phenomenon on the young Earth. Volcanoes erupt not simply because magma is hot, but because hot, rising magma turns underground water to steam, which then expands explosively. The steam no longer fits in its subterranean chamber, and so the volcano blows its lid, bringing H_2O to Earth's surface from below. All things considered, then, the presence of water on our planet's surface is hardly surprising.

Although Earth-life takes multifarious forms, all of it shares common stretches of DNA. The biologist who has Earth on the brain may revel in life's diversity, but the astrobiologist dreams of diversity on a grander scale: life based on alien DNA, or on something else entirely. Sadly, our planet is a biological sample of one. Nevertheless, the astrobiologist may glean insights about life-forms that dwell elsewhere in the cosmos by studying organisms that thrive in "extreme" environments here on Earth.

Once you look for them, you find these "extremophiles" practically everywhere: nuclear dump sites, acid-laden geysers, iron-saturated acidic rivers, chemical-belching vents on the ocean floor, submarine volcanoes, permafrost, slag heaps, commercial salt-evaporation ponds, and a host of other places you would not elect to spend your honeymoon but that may be more typical of the rest of the planets and moons out there. Biologists once presumed that life began in "some warm little pond," to quote Darwin; in recent years, though, the weight of evidence has tilted in favor of the view that extremophiles were the earliest earthly life-forms.

For its first half-billion years, the in-

(Continued on page 73)



How Trees Get High

And the limit on their height is set by the force that holds water together.

By Adam Summers ~ Illustrations by Tom Moore

On a hike recently in the Montgomery Woods State Reserve, near Ukiah, California, I wandered among the area's massive coast redwoods with my friend Al Richmond. We were looking for the Mendocino Tree, which, although it rises 367 feet above the forest floor, can still be hard to pick out from the ground. The surrounding trees are nearly that tall.

As we stood dwarfed by the grove of towering trees, I pondered a biomechanical question that might occur to anyone who comes face to face with a life-form as majestic as the Mendocino Tree: how do trees grow so tall, and what, if anything, keeps them from growing even taller? The leading hypothesis has been that trees are limited only by their ability to get water from the ground to their highest leaves. To get to the bottom of the mystery, a group of plant physiologists went to the top: they scaled the redwoods in a grove a few miles to our north.

Water does not ordinarily run uphill. And, as Aristotle knew, it's impossible to pull water higher than about thirty feet by suction. Trees, however, can lift water well past vertical water column to draw more water from below the ground up to the top of the tallest redwood.

The weight of the water column itself puts a good deal of tension on the internal cohesive forces at its top. Imagine a narrow tube filled with water and running to the ground from a treetop 360 feet in the air. Water is free to move in the xylem, and the walls of the xylem tube provide no direct support to the water inside. The support comes instead from the water itself. Its internal cohesiveness makes the column of water act like a long suspended string, and the tension on the molecules at any point in the column must support the weight of all the water below them. Expressed as a pressure, or force per unit area, the tension on the water in the xylem is surprisingly high: for every thirty feet of tree height, the tension increases by roughly fifteen pounds per square inch. For a xylem tube 360 feet high, the tension at the enough to break the water column, though, to cause problems for a tree. Photosynthesis, which takes place in leaf cells, converts carbon dioxide and water to carbohydrates and oxygen. To get the water into the cells, plants rely on osmosis, the movement of water from dilute to concentrated solutions. Such a flow can be reduced and even halted by applying a countervailing pressure. That's precisely what the tension in the water column does. With the osmotic flow reduced by the great tension in tree's lofty heights, leaf cells take up less water, which limits the amount of water available for photosynthesis.

Indeed, photosynthesis in the topmost leaves, at about 360 feet, scarcely occurs at all. By extrapolation, the investigators determined that photosynthesis would cease just above 420 feet. The finding dovetails nicely with the height of the tallest tree ever measured—a Douglas fir that towered 415 feet

The cohesiveness of water makes it act like a string.

thirty feet, so what gives? Well, for one thing, they don't suck. Thanks to a phenomenon known as capillary action, water, even if it can't climb hills, can climb walls. Look at the surface of water in a clear vessel, and you will see at the edges that water does indeed move up the sides of the vessel. That property of water is crucial to the life of the tree.

The wooden core of a tree trunk is largely a dense array of narrow tubes, called xylem, that carry water from the roots up to the leaves. The water moves up the xylem via an entirely passive process known as transpiration, which is driven by a combination of capillary rise and evaporation through the leaves. At the tops of the open xylem tubes, the water evaporates into spaces within the tree's leaves, then exits to the atmosphere through pores in the leaves. As the water evaporates, capillary action—the electrostatic attraction between the water and the leaf cells and the inner surface of the xylem tubes—moves more water up the xylem and into the leaves. At the same time, the electrostatic attraction of the water molecules for one another provides enough cohesive force on the entire top is 180 pounds per square inch.

Coast redwood tree relies on evaporation to raise an unbroken column of water from the soil up to its leaves, where some of it is used in photosynthesis. The water diffuses from the soil through root hairs and into xylem tubes running upward within the sapwood. The electrostatic attraction of water molecules for one another can sustain enough tension to support a continuous, cohesive column of water as high as 420 feet. Much of the water at the top of the column evaporates into empty space within a leaf, then diffuses into the air through pores on the underside of each leaf. The evaporation opens up space near the top of the column for more water to move upward through capillary action. That motion, transmitted through the unbroken column of water, ultimately draws more water from the ground into the root hairs.

But water is only so cohesive; if the tension is great enough, the column will break. An air bubble at the break would obstruct the xylem. Theoretical calculations led plant physiologists in the 1990s to surmise that water transport, rather than the strength of wood or some other constraint, limits the height of a tree.

George Koch, a plant physiologist at Northern Arizona University in Flagstaff, and his colleagues tested the theory in the most direct way possible: they dragged measuring equipment to the tops of five of the tallest trees on Earth. Gauging pressure in the xylem as well as the rate of photosynthesis as they climbed, Koch and his colleagues established how those two measures vary with height. And sure enough, tension in the water column is highest, and the rate of photosynthesis lowest, nearest the top.

Tension in the water column does not vary only with height, though. The environment at large affects it, too. At dawn, when the air is foggy and moist, little water evaporates from the leaves, and tension in the xylem is just what is predicted by gravity: about 180 pounds per square inch. But at noon, dry air and sunlight conspire to increase evaporation from the leaves, and the tension in the water column increases to some 260 pounds per square inch. Koch performed laboratory tests on the same plant tissue he had measured in the field, and the tests showed that the measured tension on the water column in the dry, sunlit air at noon is right at the limit of its cohesive strength.

The tension doesn't have to be great It was still possible that the anemic oxygen production was the result of low light levels or some other characteristic of leaves that grow at such lofty heights. But two other lines of evidence made a strong case for water pressure. First, when leafy twigs from the tops of trees were placed in water, the leaves acted just like less lofty leaves. The finding suggested that nothing about the leaves themselves was restricting photosynthesis. Second, the tree climbers discovered an important "natural experiment": they found a seedling that had germinated in a crotch near the top of one of the trees and had grown as tall as a person. Its leaves were carrying out photosynthesis as fast as if they were only six feet off the ground.

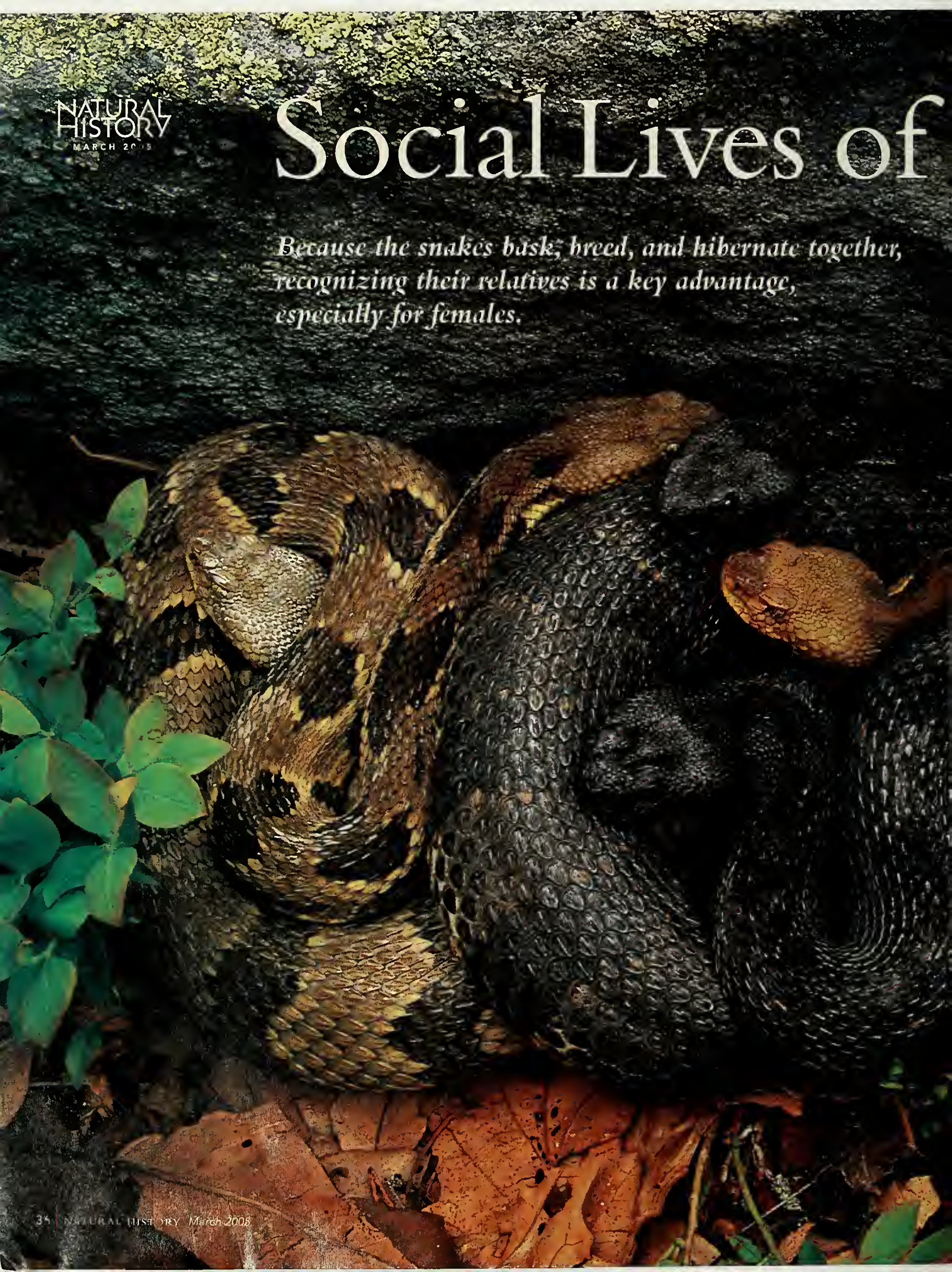
There is one final bit of evidence suggesting that the giant redwoods are as tall as water will let them be: the tops of the tallest trees have died back a number of times. In the trees' 2,000-year life span, there must have been many times of drought, when a strong capillary force would have pulled water both out of the leaves, as well as out of the roots and into the dry soil. The tension in the column would have become high enough to break the column at lower heights, killing the topmost branches. Then, when water became plentiful again, and xylem tensions were lower, new shoots would have reached skyward. Only a few places on Earth, though, enable the giant redwoods to reach their full potential.

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

NATURAL HISTORY
MARCH 2005

Social Lives of

Because the snakes bask, breed, and hibernate together, recognizing their relatives is a key advantage, especially for females.



Rattlesnakes

By Rulon W. Clark
Photographs by John Cancalosi

Timber rattlesnakes (Crotalus horridus) cluster near a communal den in the Pennsylvania woods. Group congregation sites such as this one are becoming rare, as are the snakes themselves, in part because they are often prime targets for hunters.

So, what good are they anyway?"

I sigh as I hear this question, yet again, about the animals I study: rattlesnakes. I suppose anyone who spends taxpayer dollars studying animal behavior has to deal with that kind of skepticism at some point along the way. Answering such a question gets even trickier if what you study is small and seemingly insignificant, like a cricket. And getting a sympathetic ear for such a feared, hated, misunderstood, and potentially dangerous species as a rattlesnake is nearly impossible.

On this occasion, a retired truck driver has queried me over breakfast at the counter of a rural Pennsylvania diner. As it happens—though he doesn't know it—we are just a few miles from one of the largest concentrations of timber rattlesnake dens in the country. Rattlers, usually thought of as solitary tailshakers, actually breed in groups, making them an easy, albeit elusive, target for hunters—not to mention the people who take part in the dreadful "rattlesnake roundups," in the mistaken belief that killing snakes improves the woods. The group behavior of rattlesnakes is the focus of my research. Yet it is becoming increasingly difficult to study large groups of the snakes, because their numbers are dwindling. Pennsylvania continues to be one of the few places in the United States where timber rattlesnakes *(Crotalus horridus)* are still common.

Immediately I'm on the defensive—cautious about revealing too much about where I'm going to study the snakes, yet eager to respond. Being flip, I nearly say, "Well, what good are *you*?" Instead, I settle on an easy, utilitarian answer: they help control rodents.

But the timber rattlesnake is more than a simple rodent-eater. As top-level predators, rattlesnakes are an integral part of the ecosystem, contributing to the overall health of the forests. The snakes influence prey populations and perform vital ecosystem functions through their natural effect on the dynamics of the food web, helping to maintain balances between herbivore populations, plants, and predators. The loss of any one species from a community may not be catastrophic, but the ongoing decline of many populations in an ecosystem erodes the balances that make natural systems persist.

I was in Pennsylvania to observe the spring emergence of the timber rattlesnakes. Several years ago an expert on local rattler populations, Curt E. Brennan, who works for the Pennsylvania Department of Conservation and Natural Resources, first showed the populous rattler den to me. My return trek in the spring took me to the secluded site up along a steep, forested bluff. At the summit of the bluff is a small clearing with exposed slate bedrock, fractured by cracks and crevices. Such exposed openings are few and far between in northeastern forests; whenever possible, the snakes use them as dens. Timber rattlesnakes are ectothermic, or cold-blooded, animals; come winter, they take refuge in the cracks beneath the frost line. By early May, though, temperatures become warm enough for the rattlers to move safely out into the woods. They don't return to their dens for hibernation until mid-October, just before the nighttime frosts begin.

I had arrived in the middle of May, the peak of the spring emergence period. The day was cool and slightly overcast—perfect for viewing snakes. They would be out in the open, trying to soak up what little warmth penetrated the haze. It took a moment of scanning to see them. A dozen or so large, thick-bodied, velvety timber rattlesnakes lay loosely piled and wrapped around each other just under the edge of a large stone slab. They basked contentedly in the sun, gently shifting their muscular coils every so often. If they were aware of my presence, they seemed unconcerned about it. I felt I was looking through a small window onto an alien world.

Everyone I have ever taken into the field—my mother, a businessman, a local redneck, a college student, a six-year-old child—has been equally moved by the sight of timber rattlesnakes in the wild. After such an experience, no one seems to have any further doubts about the value of these animals. Perhaps the overhyped fear and loathing whipped up about animals such as rattlesnakes arises from surprise encounters that people have with snakes, in which the snakes are perceived as intruders. Yet a visit to the same animal in its natural environment can have the opposite effect, fostering a sense of value and appreciation.

Timber rattlers are striking in such large aggregations. They come in two colors: some are almost solid black, whereas others are bright yellow, marked with splotches of brown. These two "color morphs" can even occur in the same litter. As I watched the jumble of snakes in May, I noticed one large, yellowish-brown male start to make his way slowly but steadily up the slope and into the woods. He was probably beginning his yearly migration through the forests in search of food. Males, juveniles, and non-

Timber rattlesnakes are unfazed by the stray garter snake (left foreground in the photograph at right) that is sharing their basking area amidst rocky crevices and boulders. Within a few weeks of emerging from winter hibernation, male snakes, like the one pictured at the top of this page, and non-pregnant females slip into the woods in search of prey.

pregnant females all leave the denning areas over the course of a few weeks. After a winter without food, the animals need to seek out the small mammals that constitute their diet.

Rattlesnakes are not fast animals, and they certainly lack endurance. Instead, they rely on patience, camouflage, keen senses, and a lightning-quick strike to capture their prey by ambush. After several months of such hunting and feeding, males become restless and start dispersing more widely through the woods—fifteen to twenty times farther than normal—to pick up the scent of receptive females.

Adult females become receptive to male advances only in years when they have stored enough body fat to bear a litter. The storage process usually takes no less than three years following a season of pregnancy and sometimes as long as six, depending on hunting conditions—leaving only a fraction of the female population available for breeding each year. Mating season is in late summer. Females hold sperm in their reproductive tract during winter hibernation and fertilize their eggs at the beginning of the following spring. During pregnancy, females forgo foraging. Incredibly, even after a winter without food, the expectant mothers spend almost the entire summer without hunting. Instead, they stay at exposed, south-facing basking areas near their winter den, allowing their hard-earned fat reserves alone to support the growth and development of their embryos [*see photograph on pages 36 and 37*].

In a good year, the females give birth to live young in late August. But the mothers, typically emaciated

by this point, still aren't quite ready to abandon their newborns. Even though a baby rattlesnake is venomous from birth, it is a somewhat helpless creature, susceptible to attack from a wide range of predators that have no problem dispatching tiny reptiles. The babies need to spend the first week of life basking in the open until they shed their natal skin and can disperse into the relative safety of the woods. During that natal basking period, the mothers stay near their young, defending them from potential predators.

Biologists have long taken it almost for granted that snakes lead simplistic lives of solitude; in fact, they are highly social animals.

Male timber rattlesnakes search the forest for food in the summer months, but they travel even greater distances in early autumn when looking for mates.

Although this form of parental care is common among rattlesnakes and other vipers, herpetologists have been slow to appreciate the sacrifices it entails. Imagine what it would be like to carry eggs around in your body all year and forgo your own chance to eat until your young have fed off your fat and can survive on their own! Small wonder that female timber rattlesnakes in northern climates can afford such an ordeal only once every three to six years. Such a slow reproductive rate, combined with a maturation period as long as ten years for the young snakes, leads to a slow rate of population growth and—if a population endures a crash—to a slow recovery.

Perhaps the most impressive aspect of the reproductive cycle, however, is its communal nature. Like the denning areas, a good basking area is a prize find. In spring and summer, piles of gravid females can be found lounging in the sun together, black and yellow coils piled up in intricate mounds. These females give birth together at sites that biologists have termed "birthing rookeries." The rudimentary protective crèche they form with their entwined bodies probably makes a basking area the safest place for newborn snakes.

Are such groupings merely chance meetings at an ideal locale, or do they constitute gatherings of more subtle and sophisticated social groups? Vertebrate biologists have long taken it almost for granted that snakes in general are asocial animals, leading simplistic lives of solitude filled only with basic instinctual drives toward food and sex. My research, in which, among other techniques, I radio-tag individual snakes and follow them around in the field, has led me to think otherwise.

Timber rattlesnakes live as long as thirty years in the wild, and they seem to live as stable, cooperative community members. They appear to form lasting relationships with other individuals, follow similar paths through the woods, bask together before shedding their skins under the same fallen log, and sometimes follow each other from one den to another. Young timber snakes have demonstrated a tendency to trail older ones. A recent genetic study has demonstrated that snakes sharing a den are closely related. Other research on a similar species, the prairie rattlesnake *(Crotalus viridis)*, has shown that the species can mobilize a

Baby rattlesnake finds safety in its mother's coils (next page). Females stick together during their pregnancies and in the first few weeks after giving birth. The communal gathering provides a safe environment for newborn rattlers.

group defense, mediated, in part, by alarm pheromones. Add to those findings the clear concern of mother snakes for their young [*see photograph on preceding page*], and you have to wonder whether the social lives of rattlesnakes are really so simplistic after all.

Those and similar observations sent me to the laboratory, to see whether snakes raised in captivity could recognize their relatives. Kin recognition serves as the foundation of advanced social systems in a wide variety of other animal societies. No one, though, had ever demonstrated that ability among snakes. Yet if snakes did work collectively, they could enjoy several important benefits in the wild. A group of snakes could retain their combined heat longer than an individual could, making thermoregulation more efficient. And a group of snakes could make a far more convincing display against predators, and mount a much fiercer defense, than could a lone snake on its own.

As we approach the boulder-strewn clearing, dozens of females and their babies are lying in huge piles at the base of a large rock.

Because relatives share genetic material, the benefits of group membership would be enhanced if the group were made up of kin—from an evolutionary perspective, raising offspring is just one way of passing your genes on to the next generation. The same genes could be passed on if they helped nondescendant kin, such as siblings, survive and reproduce. Working in the laboratory, I raised litters of timber rattlesnake siblings in isolation from one another, and then placed the snakes one by one at random in an enclosure with a nonsibling snake. The snakes—at least the females—associated more closely with littermates than with unrelated females. In other words, the female snakes seemed to recognize their sisters.

That intriguing result has led me to investigations that are still ongoing: with genetic techniques I am testing the kin relationships among females in the wild that spend time basking together at communal rookeries. Perhaps it will turn out that timber rattlesnakes organize themselves matrilineally—in other words, that social groups form along the maternal line, with extensive contact among related individuals across generations. Such a finding could go a long way toward changing people's negative perceptions about snakes. The stereotype—that they are emotionless predators leading solitary and uninteresting lives devoid of social contact—is certainly untrue.

To collect tissue samples for the genetic project, I return to the Pennsylvania woods in late summer with John Cancalosi, a nature photographer who has decided that snakes are, photogenically, "the new birds." As we approach the boulder-strewn clearing, dozens of females and their babies are lying in huge piles at the base of a large rock. As many as thirty females have given birth here. Each litter includes, on average, seven or eight young, putting the number of babies in the hundreds. The sight is awesome. How many people realize that one can view hundreds of venomous snakes in their natural habitat without seeming to create much of a disturbance? Even the busy whirring of Cancalosi's camera makes no notable impression on the snakes.

In the middle of a pile, we notice a garter snake [*see photograph on page 39*]. The garter has apparently decided that even in the presence of its venomous, mammal-eating cousins, the slab isn't such a bad place to get a little sun of its own. Since natural breaks in the woods are so important for ectotherms, it is not uncommon to find several different snake species sharing basking and denning sites.

The annual aggregation of rattlesnakes is a natural spectacle that remains underappreciated by naturalists and the public alike, and it underscores the importance of these vital habitat sites to the local reptile population. The once-abundant timber rattlesnake is quickly succumbing to the twin pressures of habitat loss and overhunting. Its plight is worsened by its public-relations problem: lots of people don't care if the species is actively protected or not. The problem is not insurmountable, though. In my experience, people in general have an innate fascination with snakes. That fascination can be the hook that fosters an appreciation for unusual and interesting wildlife of all kinds.

The next time you see a snake in the woods, you will be startled and probably a little frightened. But think of the myths and fables that once portrayed the woods as a magic, mysterious place—a place where the senses quickened to catch any whiff of danger that might be lurking beyond the next tree. Would a domesticated forest, without that spice of risk, the unpredictable wild, really be a better place? The loss of the rattlesnake—a very real possibility—would change our forests irrevocably, making them a kind of stage set, rather than a portal to nature. □

MARYLAND

THIS SPRING, EXPLORE THE STATE THAT HAS IT ALL

Maryland has it all: mountains and forests, Atlantic and Chesapeake Bay shorelines, the Potomac and Patuxent rivers and more. With such a diversity of ecosystems, it's no wonder that this state draws nature lovers from near and far. And best of all, every single one of these attractions is easy to get to—within three hours from Maryland's major city, Baltimore, close to the state capital, Annapolis, or near Washington, D.C.

Maryland has so many different geographical regions you'll feel you've visited several states in one.

Photos: Tim Tadder

The battlefield at Antietam; biking along the C&O Canal

The state has so many different geographical regions that it was once nicknamed "America in Miniature." Visit Maryland, and you'll feel you've visited many states, but all are within easy driving distance of one another.

Outdoors fans prize **Western Maryland** for its hiking and picturesque mountains. This is where you'll find the best white-water rafting in the state, with all levels of technical difficulty. Here, Deep Creek Lake, which is man made, is a haven for boaters and fishermen.

In **Central Maryland**, you'll find Annapolis, Maryland's capital—as well as America's sailing capital. This beautiful center of naval history has rows of pristine eighteenth-century houses, more than any other city in the country. In Baltimore, don't miss the attractions of the famed Inner Harbor, a model urban preservation and renewal project that been imitated throughout the country. After a day at the harbor's world-known National Aquarium in Baltimore or exploring the shops, enjoy a harbor-side meal of oysters, fish, or Maryland's beloved blue crabs.

Annapolis, America's sailing capital

Patrick Soran

The **Capital Region**, just outside of Washington, D.C., is where you'll find Bethesda and Glen Echo. The region combines all the sophisticated attractions of an urban environment with abundant recreational and rural opportunities. Spend the day fishing for bass, then head to the Olney Theatre for a well-staged play.

Southern Maryland is on the western side of the Chesapeake Bay and also distinguished by two powerful rivers, the Potomac and the Patuxent. The state was first settled here, and you'll find many quaint and historic waterfront towns, all offering some of the best seafood you're likely to ever have. Visit ponds, swamps, fragile marshes, and pretty beaches along the Chesapeake, or fish the area's many streams and rivers.

The state's beautiful **Eastern Shore**, part of the Delmarva Peninsula, is surrounded by the Chesapeake Bay, and its southern tip fronts the Atlantic Ocean. Explore the Eastern Shore by biking its country roads, boating along meandering inlets and Chesapeake kayaking trails, or lazing on the beach at Ocean City.

With so many places to choose from, plan your trip to Maryland ahead of time. Read ahead for a guide to some of the state's most rewarding counties.


MARYLAND'S
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MARYLAND
WELCOME

A Guide to Maryland's Counties

Fish for largemouth bass, tiger musky, crappie, catfish, sunfish, and more.

CAPITAL REGION

An hour away from Baltimore, and just outside of Washington, D.C., you'll find Maryland's **Capital Region.** Sophisticated **Montgomery County**, just outside D.C., offers several museums, public galleries, theaters, and historic sites. But it is also a place to explore the outdoors. Hike along the historic C&O Canal, or rent a canoe and spend a day on Seneca Lake at Black Hills Regional Park. Located in Boyds, Black Hills has excellent fishing, especially for largemouth bass. Purchase a Maryland state fishing license at the park's Visitor Center. Black Hills also boasts miles of forest trails, horseback riding, mountain biking, and camping. Reserve a naturalist-led trip on the pontoon boat *Kingfisher*, which carries up to thirty people, by calling ahead at 301-916-0220.

Prince George's County, adjacent to Montgomery and Washington, D.C., is a magnet for aerospace fans. College Park Airport, founded by the Wright Brothers in 1909, is the world's oldest airport in continuous operation. It's also home to the College Park Aviation Museum, which houses historic flying machines, including a 1911 Wright B and a 1918

Charles County buck

Fishing for largemouth bass

Curtis Jenny. Nearby, in Suitland, the Airmen Memorial Museum profiles pioneering aviators. NASA's Goddard Space Flight Center, in Greenbelt, is responsible for the development of unmanned sounding rockets and research in space and earth sciences. Visitors can explore interactive educational exhibits, which focus on the center's contributions from 1958 to present. Current exhibits include "Hubble Space Telescope: New Views of the Universe," which presents spectacular backlit color images, taken from the Hubble, of planets, galaxies, and black holes.

Once at the crossroads of the Civil War, **Frederick County** attracts history buffs with its many battlefield sites and monuments. Frederick also is home to the Catoctin Mountains and the Potomac River, and has ninety parks offering swimming, boating, camping, skating, horseback riding, and nature programs. You might hike part of the Appalachian Trail along the county's western border, or try your hand at fly fishing in Catoctin Mountain Park, located in Thurmont. Full of wildlife and wildflowers, the park offers hiking trails and historic buildings. West of Thurmont, in Cunningham Falls State Park, hike a trail to a cascading waterfall almost eighty feet tall.

SOUTHERN MARYLAND

South of the Capital Region, explore Charles, St. Mary's, and Calvert counties in **Southern Maryland**. These three counties are located in the Atlantic Coastal Plain peninsula and are easy to reach by water, whether the Chesapeake Bay or the Potomac and Patuxent rivers. Because they lie along the Atlantic Flyway, the counties are great places to spot waterfowl in the winter and a host of migrants in the spring and fall.

Just 30 miles from Washington, D.C., on the western border of **Charles County**, you'll find one of the most unusual nature areas in Maryland: Mallows Bay. Near Sandy Point, and just ten minutes from Sweden Point Marina, Mallows is a

Historic St. Mary's City

Located along the Atlantic Flyway, Southern Maryland is a great place to spot migrating birds.

one-mile-long natural embayment of the Potomac River. It also is one of the largest graveyards of ships in North America, with vessels dating from as far back as the Revolutionary War. Among the ships are a fleet of wooden steamships, built to serve in World War I but then abandoned and brought here to be salvaged. The task was never completed, and many of these hulks have become islands filled with trees and bushes. The mini-ecosystems have converted the bay into a refuge for wildlife. Mallows Bay now harbors herons, snowy egrets, and American bald eagles. Incidentally, the bay also has some of the best inland largemouth bass fishing on the eastern seaboard.

St. Mary's County is the birthplace of Maryland, and not surprisingly, there is a lot of history in this county. It is home to the first permanent settlement in Maryland, St. Mary's City, which was the state's first capital. Historic St. Mary's City, an 800-acre living history museum with interpreters in authentic 17th-century dress, has replicas of the first statehouse, a tobacco farm, and an inn. Combine history with the outdoors at Point Lookout State Park. Once the site of a Civil War prison housing more than 50,000 Confederate soldiers, the park now has a museum that recounts this part of its history. It's also a good place to swim, fish, and boat in a beautiful bay setting.

Would-be archeologists can hunt for fossils of prehistoric shark teeth and more along the shores of Calvert Cliffs in **Calvert County**. Don't miss the county courthouse in Prince Frederick, the seat of the county, or the waterside town of Solomons, an island community known for boating and fishing. Battle Creek Cypress Swamp, a nature center that is home to the northernmost naturally occurring stand of bald cypress trees in America, has a self-guided boardwalk trail. These towering subtropical trees, once widespread in the region, fell victim to logging and are now only found in scattered sites. In early spring, the park is blanketed with wildflowers, including violets, may apples, spring beauties, and lady's slipper orchids. While you're in Battle Creek, keep an eye out for warblers: Kentucky, worm-eating, prothonotary, parula, and hooded warblers migrate to the swamp each spring to breed.

EASTERN SHORE

Don't leave Maryland without exploring its beautiful **Eastern Shore**, the peninsula directly opposite of Southern Maryland. Spend a day sailing the

Above: Calvert County view; right: Assateague Lighthouse on the tip of Worcester County

Chesapeake Bay Maritime Museum, Talbot County

On the Eastern Shore, watch watermen reap a hard day's harvest and sample some of the best crabs, oysters, and fish in the state.

Chesapeake Bay or drive from one waterfront village to the next.

Start in **Dorchester County**, perhaps with a stay in a quiet inn in historic Cambridge. The town boasts many stately eighteenth- and nineteenth-century homes, especially along brick-paved, tree-lined High Street. Sign up for a historic tour or a ghost walk to learn about the prosperous era in which these homes were built. Outside Cambridge, visit the Blackwater National Wildlife Refuge, home to many endangered species and a haven for waterfowl. More than 85 species of birds, including the American bald eagle and more than 20 species of ducks, make their home in Blackwater. After a day of birdwatching, catch one of Dorchester County's spectacular sunsets along its 1,700 miles of shoreline.

From Dorchester, you might head to **Worcester County**. Worcester is known for the sandy beaches of

Ocean City and the exotic ponies at Assateague. But its many different habitats—barrier islands, coastal bays, tidal wetlands, cypress swamps, upland fields, and primeval forests—have made it the county in Maryland with the most recorded bird sightings. Plan to attend the Delmarva Birding Weekend, from April 22–24, and witness the migration of hundreds of warblers, shorebirds, and waterfowl as well as many nesting birds and raptors. The weekend will include boat and canoe trips as well as walking expeditions.

In charming **Talbot County**, explore the lovely small towns of St. Michaels, Easton, Oxford, Wye Mills, and Tilghman Island. All are full of history, heritage, culture, and architecture, as well as natural beauty and serenity. Their historic downtowns are now filled with fine art galleries, antiques stores, museums, theaters, and boutiques, as well as fine restaurants. In St. Michaels, don't miss the Chesapeake Bay Maritime Museum, located on the waterfront. The museum brings together the most complete collection in the nation of Chesapeake Bay artifacts, visual arts, and indigenous water craft.

Kent County, a scenic peninsula on the Chesapeake Bay, claims a portion of the only National Scenic Byway in Maryland. It is a destination of historic waterfront towns dating back to the 1600s; stretches of low, rolling farmlands; dramatic sunsets; scenic beauty; and rich heritage, with some of the United States' most quaint and beautiful towns. Stroll tree-lined, red brick sidewalks lined with art galleries and specialty and antique shops. Enjoy the county's five museums, terrific restaurants, farmer's markets, and beaches. Catch a performance at the Prince Theatre in Chestertown or the Mainstay in Rock Hall, which feature local and internationally acclaimed performers.

Maryland is a great place to explore—naturally.

The schooner *Sultana 1768* may be found in her home port of Chestertown when she's not sailing the Chesapeake

Testing Einstein (Again)

In 1959, just two years after the launch of Sputnik I, *investigators began work on a space-based experiment to verify the general theory of relativity. Their efforts are about to come to fruition.*

By Arthur Fisher

Ptolemy made a universe, which lasted fourteen hundred years. Newton also made a universe, which has lasted three hundred years. Einstein has made a universe, and I can't tell you how long that will last.

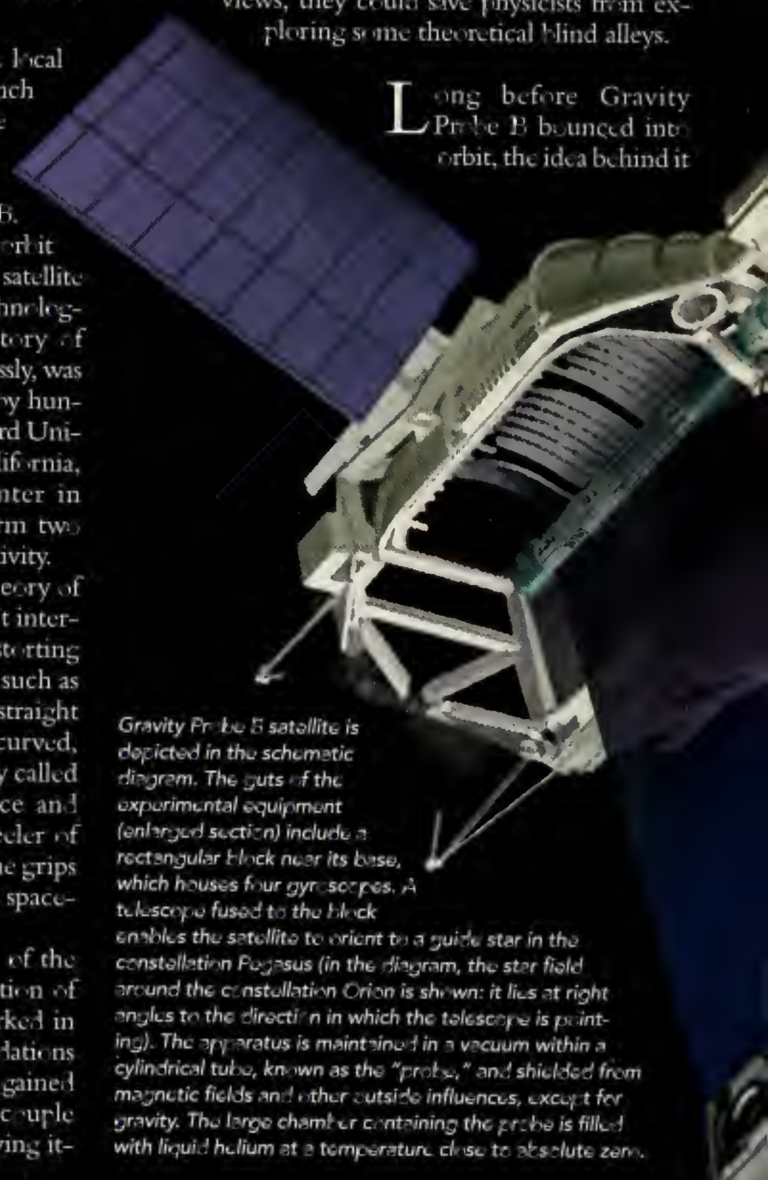
—George Bernard Shaw (1930)

On April 20, 2004, at 9:57:24 A.M. local time—meeting a one-second launch window—a Delta II rocket rose from Vandenberg Air Force Base in California, bearing a payload with the less-than-evocative name Gravity Probe B, or GP-B. Launched into a 97.5-minute, pole-crossing orbit 401 miles above the Earth was a three-ton satellite designed to accomplish one of the most technologically challenging experiments in the history of physics. The launch, which proceeded flawlessly, was the culmination of forty-five years of effort by hundreds of physicists and engineers from Stanford University, Lockheed Martin in Sunnyvale, California, and NASA's Marshall Space Flight Center in Huntsville, Alabama. Its purpose: to perform two new tests of Einstein's general theory of relativity.

Publicly presented in 1915, the general theory of relativity was a spectacular intellectual feat. It interprets gravity not as a force but as a field distorting space and time. It holds that massive objects such as planets follow geodesics—paths that act as straight lines, or shortest "distances"—through a curved, four-dimensional generalization of geometry called space-time, which encompasses both space and time. As the physicist John Archibald Wheeler of Princeton University once wrote: "Spacetime grips mass, telling it how to move. . . . Mass grips spacetime, telling it how to curve."

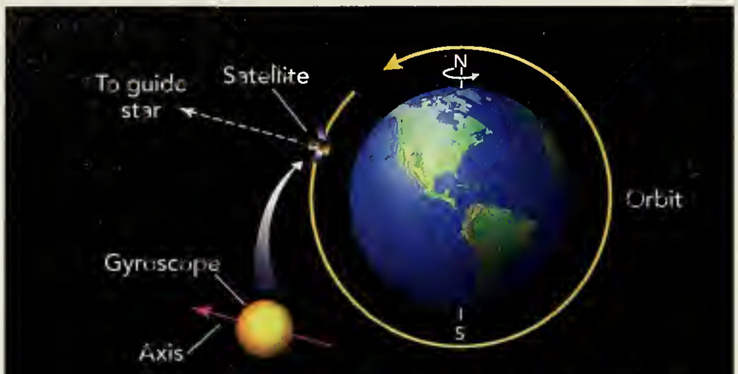
"I do not consider the main significance of the general theory of relativity to be the prediction of some tiny observable effect," Einstein remarked in 1930, "but rather the simplicity of its foundations and its consistency." One reason the theory gained rapid acceptance, however, is that it passed a couple of experimental tests with flying colors, proving itself superior to existing theories of the universe. No one doubts, by now, that it is a powerful theory. But undertaking new tests of its predictions is no idle exercise. Even if all they do is confirm Einstein's views, they could save physicists from exploring some theoretical blind alleys.

Long before Gravity Probe B bounced into orbit, the idea behind it



Gravity Probe B satellite is depicted in the schematic diagram. The guts of the experimental equipment (enlarged section) include a rectangular block near its base, which houses four gyroscopes. A telescope fused to the block enables the satellite to orient to a guide star in the constellation Pegasus (in the diagram, the star field around the constellation Orion is shown: it lies at right angles to the direction in which the telescope is pointing). The apparatus is maintained in a vacuum within a cylindrical tube, known as the "probe," and shielded from magnetic fields and other outside influences, except for gravity. The large chamber containing the probe is filled with liquid helium at a temperature close to absolute zero.

Delta II rocket launches Gravity Probe B, April 20, 2004.



Circular orbit of Gravity Probe B passes over the Earth's poles at an altitude of 401 miles. An onboard telescope enables the satellite to track a guide star, which serves as a point of reference for the gyroscopes aboard the satellite. At the start of the experiment, the gyroscopes are set spinning with their axes aligned to the guide star. The general theory of relativity predicts that the gyroscopes will change their orientation with time.

was bounced around in a conversation among three naked professors sunbathing at a males-only Stanford University swimming pool. Leonard I. Schiff, executive head of the physics department, had been working out a way to use gyroscopes to test two obscure, minute effects predicted by the general theory of relativity. The experiment he had in mind would have to be performed in space because there the gyroscopes are weightless and better isolated from extraneous disturbances. He and his companions, William M. Fairbank, an authority on superconductivity, and Robert H. Cannon, an expert in gyroscopes, met at the pool in December 1959, to talk over the idea and its engineering difficulties. The three later learned that George E. Pugh, a Department of Defense scientist, had articulated the same idea independently in a November 1959 memo.

Nursed along for four decades, the project has cost nearly $700 million and has followed a turbulent path, suffering technical setbacks, suspensions, threatened cancellations, and intense political and academic criticism. In the intervening years, both Schiff and Fairbank have died, and Cannon is only indirectly involved. The principal investigator is C.W. Francis Everitt, who signed on in 1962, when he was just a twenty-eight-year-old postdoc from England. Now seventy, with a cascade of long gray locks, Everitt says, "I would never have joined GP-B if I'd had any idea of how long it would take."

The eminent English physicist Patrick M. S. Blackett, with whom Everitt had studied in London, once told him, "If you don't know what kind of physics you want to do, invent some new technology. It will always lead to new physics." Inventing the technology required for Gravity Probe B has turned out to be a supreme test for the ingenuity of the project's scientists and engineers. Happily, the technology is now doing its job, collecting data methodically and with exquisite sensitivity. Will it lead to new physics? If the experiment reveals that Einstein's calculations were even slightly off, the quest for a more exact theory could transform human understanding of the physical universe.

Einstein formulated two theories that interweave space and time. His special theory of relativity, published a hundred years ago this year, describes the behavior of objects moving close to the velocity of light; it also predicts the equivalence of mass and energy, according to the famous equation $E=mc^2$. The special theory has been confirmed repeatedly, in the innards of particle accelerators, in nuclear power plants, and, of course, in atomic weapons. But it was Einstein's second theory, the 1915 general theory of relativity, that was first put to a public test, making the name "Einstein" a household word.

In spite of Einstein's insistence that the importance of his theory was its conceptual simplicity, he was keenly aware that every scientific theory must make observable predictions. In 1915, however, most conceivable tests of general relativity were too subtle to be practical. One experiment was technically feasible. The theory predicted that starlight would be deflected when it passed close to the Sun on its way to Earth. Isaac Newton's classical theory of gravity, together with his particle theory of light, also predicted a deflection, but the magnitude of the effect Einstein calculated was readily distinguishable from Newton's.

How could star positions be measured accurately, however, when the stars appeared close to the Sun? Answer: observe them during a total solar eclipse. Astronomers knew an eclipse would take place in 1919, presenting a golden opportunity for a test. Photographs of stars near the edge of the Sun, made during the eclipse, could be compared with photographs of the same stars made when the Sun was absent from that region of the sky.

The eminent English astronomer Arthur Eddington led an expedition to an island off the west coast of equatorial Africa, where the eclipse viewing was predicted to be excellent. On the day of the eclipse, May 29, there was a tremendous rainstorm, and Eddington was in despair. But the storm lifted before totality, and the pinpoints of five stars were photographed. When the eclipse photographs were compared with a photographic plate taken at the University of Oxford before the expedition, Einstein's ideas were confirmed, at least as well as they could be at the time. On November 7 the *London Times* headlined: "Revolution in

Science/New Theory of the Universe/Newtonian Ideas Overthrown." And on November 10 *The New York Times* proclaimed: "Lights All Askew in the Heavens/Men of Science More or Less Agog over Results of Eclipse Observations/Einstein Theory Triumphs."

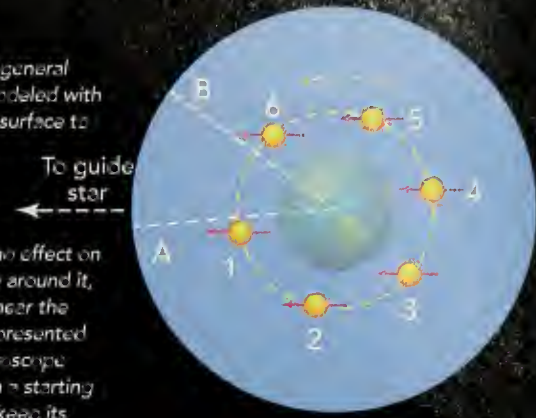
Even before Eddington's dramatic announcement, Einstein himself had pointed out that his theory could solve a longstanding problem in astronomy. Like the other planets in the solar system, Mercury moves in an elliptical orbit around the Sun. Along with that primary motion, Mercury's perihelion, its closest approach to the Sun along the orbit, gradually migrates as well, drifting around the Sun in the same direction as its primary motion. This wobble, comparable to that of a toy top, is called precession, and is caused by external forces—in the case of Mercury's orbit, by the gravity of the other planets orbiting the Sun.

In 1859 Urbain-Jean-Joseph Le Verrier, the director of the Paris Observatory, published his observations of an anomaly in Mercury's orbit. Le Verrier had found that Mercury's precession is 574 arc seconds per century (an arc second is 1/3,600th of a degree). In other words, the precession would complete a full 360-degree cycle around the Sun in some 2,260 centuries. When Le Verrier applied Newton's theory to calculate the gravitational effects of the other planets on Mercury, however, he arrived at a precession rate of only 531 arc seconds per century. The discrepancy perplexed astronomers for more than fifty years.

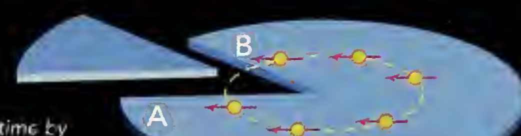
Relief came in 1915, when Einstein was working out ways to test his own theory of gravity. The theory maintained that space-time near the massive Sun would be distorted in previously unforeseen ways. Taking that distortion into account in calculating Mercury's precession, lo and behold, the results matched the observed amount. "I was beside myself with joyous excitement," Einstein wrote later.

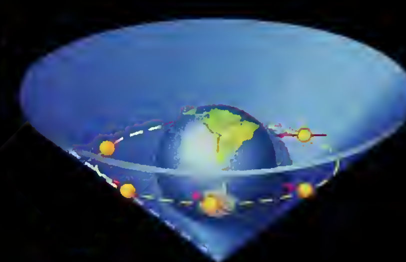
There things stood, notwithstanding numerous technical advances, until June 18, 1976. On that day, NASA and the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, confirmed, with high accuracy, Einstein's equivalence principle—one of the fundamental assumptions of the general theory of relativity. The experiment, known as Gravity Probe A, confirmed that clocks in gravitational fields of differing strengths do not keep the same time. The investigators compared the frequency of an atomic clock that stayed on the ground with that of an identical clock that was lofted 6,200 miles above the Earth, atop a rocket. Consistent with Einstein's theory, the clock aboard the spacecraft, in the weaker gravitational field, ran slightly faster.

Later in 1976, another space-age test became feasible, when two Viking landers arrived on Mars. As

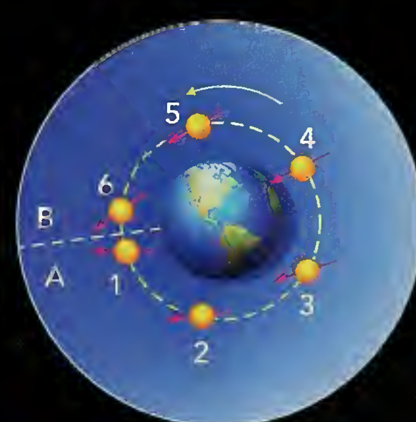


Geodetic effect of general relativity can be modeled with a two-dimensional surface to represent space-time. If Newton's theory of gravity were correct, the Earth would have no effect on the space and time around it, and so the region near the planet could be represented as a flat disk. A gyroscope orbiting Earth from a starting position (1) would keep its initial orientation.



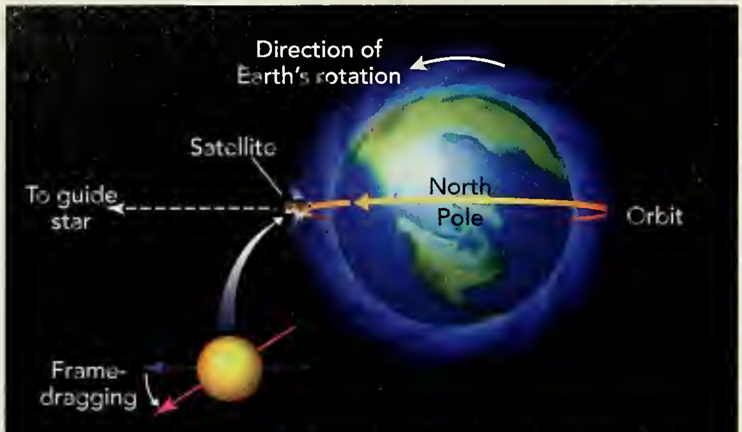


Curvature of space-time by the Earth's mass—a tenet of the general theory of relativity—can be represented by slicing a section (A-B) from the disk, then joining the edges to form a cone. The shape of the cone shown here is greatly exaggerated for clarity; the actual geometry of space-time near the Earth resembles that of a highly "flattened" cone.



Direction of the gyroscope on the surface of the cone, as viewed from above the cone, progressively rotates in the plane of orbit. The extent of the rotation after one orbit is greatly exaggerated for clarity.

Actual rotation of the gyroscope caused by the geodetic effect, given Earth's mass and the height of the orbit, is predicted to accumulate at the rate of 6.6 arc seconds (18 ten-thousandths of a degree) per year.



Frame-dragging—a distortion of space-time near Earth caused by the planet's rotation—is another effect predicted by the general theory of relativity. If the theory is correct, a gyroscope aboard the satellite should turn in the direction of Earth's rotation at a rate of 0.041 arc second (11 millionths of a degree) per year.

Earth and Mars traced their orbits around the Sun, signals from Earth were bounced off the landers and back to Earth, and each signal's round trip was precisely timed. When Earth and Mars were on nearly opposite sides of the Sun, the signals were slightly delayed, by an amount predicted by Einstein's theory. Known as the Shapiro time delay (after the physicist Irwin I. Shapiro of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts), the effect is related to the bending of light by the Sun.

Gravity Probe B seeks to test, with very high accuracy, two further, very small effects predicted by the general theory of relativity. The first, known as the geodetic effect, is a consequence of the calculated curvature of space-time near a massive object such as Earth. The Dutch astronomer Willem de Sitter first derived the effect mathematically from Einstein's theory in 1916, but it was Schiff who extended the theory to the case of a spinning gyroscope. Translated into the behavior of a gyroscope aboard Gravity Probe B, the geodetic effect should be detectable as a rotation of a gyroscope in the plane of its orbit—or to use a nautical term, a deviation in its pitch. Given Earth's mass and the height of the satellite's orbit, the gyroscope should rotate slightly more than 6.6 arc seconds per year. [*To visualize how the warping of four-dimensional space-time is predicted to change the orientation of a gyroscope, see the illustration on preceding page.*]

The second effect GP-B is looking for, known as frame-dragging, is an even smaller one. According to Einstein's theory, a massive rotating body such as the Earth should drag nearby space-time around itself. Imagine a soccer ball spinning in a viscous fluid such as honey. As it spins, the ball pulls the honey around as well, creating a vortex. Similarly, the Earth's rotation exerts a pull on space-time, which in turn affects any orbiting satellites.

Frame-dragging was derived in one form from the general theory of relativity in 1918 by two Austrian physicists, Josef Lense and Hans Thirring, and thus is also known as the Lense-Thirring effect. Their calculations concerned the effect of frame-dragging on a moon's orbit. Schiff, instead, calculated the effect of frame-dragging on the axis of a gyroscope. To return to the analogy of the soccer ball spinning in honey, the effect would show up as a gradual change in direction of a pointer immersed in the honey [*see illustration at left*].

In both cases the effect of frame-dragging is very small. For a gyroscope in polar orbit, it works out to be about 0.041 arc second per year. If you walked "up" a slope at that angle, you would have to walk nearly eighty miles to climb an inch. But in 1959 Schiff calculated that an ideally constructed gyroscope would be able to detect not only the geodetic effect but also frame-dragging. Aboard Gravity Probe B frame-dragging should cause a gyroscope to turn, or yaw, in the same direction as Earth's rotation.

Conducting the experiment, however, requires much more than a near-perfect, drift-free gyroscope. Every force that might affect the gyroscope, except gravity, must be understood and excluded. Minute changes in the gyroscope's spin angle have to be measured without disturbing the gyroscope. A point of reference is needed, in the form of a bright, nearby star whose motion is known, and an onboard telescope is needed to keep track of the star. Each of those challenges at first seemed insurmountable.

The heart of GP-B is a twenty-one-inch-long block of fused quartz bonded to a quartz telescope [*see illustration on pages 52 and 53*]. For redundancy, the block of quartz houses four gyroscopes, each a gemlike sphere the size of a Ping-Pong ball, also made of fused quartz. The four gyroscopes are the most perfectly round objects ever manufactured, honed to within forty atomic layers, or 0.6 millionth of an inch from the highest "peak" to the deepest "valley." Each sphere is coated with a uniform layer of niobium, a metallic element that becomes a superconductor at 9.3 degrees Kelvin (–442.9 degrees Fahrenheit).

To reduce friction on the spheres, they are levitated by voltages applied to saucer-shaped electrodes. Jets of helium gas spin the gyroscopes up to a speed of 5,000 revolutions per minute. Then, to further minimize friction, the gas is evacuated from around the spheres. The gyroscopes are isolated from external magnetic fields by a succession of magnetic shields.

The telescope itself is kept rigorously aimed at the guide star, IM Pegasi, in the constellation Pegasus. Because the satellite loses sight of the star when it passes behind the Earth, the telescope must be able to reliably reacquire, or locate, the star after every orbit.

The entire gyroscope-telescope assembly is maintained at high vacuum within a nine-foot-long chamber, known as the "probe." The probe in turn is enclosed within a kind of large thermos bottle known as a Dewar. Filled with 645 gallons of liquid helium, the Dewar maintains the probe at a temperature of only 1.8 degrees Kelvin (–456.4 degrees Fahrenheit). The temperature is kept from rising by gradually venting helium from the Dewar.

The problem of measuring changes in the gyroscope's spin axis without disturbing the gyroscope has a particularly clever solution. Attaching a pointer to it is not feasible. Enter the spherical coating of niobium: when niobium becomes superconducting, and the spherical superconductor spins, it does something very handy. It generates a small magnetic field that is proportional to the rate of spin and precisely aligned with the spin axis. Hence every tiny shift in the gyroscope's spin axis can be measured by an exquisitely sensitive magnetometer.

Originally, Everitt explains, the gyroscopes were to be arranged so that one pair would detect frame-dragging, and a second pair, whose spin axes would be perpendicular to those of the first pair, would measure the geodetic effect. For technical reasons, that approach was abandoned, and all four gyroscopes were set spinning along the telescope's line of sight to the reference star. Each gyroscope senses both axis-shifting effects. Clever mathematics then enables the Gravity Probe B team to sift them apart.

Albert Einstein, left, met with the astronomer Arthur Eddington in Cambridge in 1930. Eddington's observation of a solar eclipse in 1919 confirmed Einstein's prediction of how the mass of the Sun would bend the light from stars.

For all the advanced technology aboard Gravity Probe B, frame-dragging may have already been observed. Two NASA satellites, LAGEOS (Laser Geodynamics Satellite) I and LAGEOS II, each studded with 426 minute reflectors, have been tracked for years with laser range-finding equipment. In 1998 Ignazio Ciufolini of the University of Lecce, Italy, and Erricos Pavlis of the University of Maryland, in Baltimore, reported an analysis of the satellite orbits over a period of eleven years. The data suggested the orbits have shifted as a result of frame-dragging, though the measurements had a large margin of error. More recently, Ciufolini and Pavlis have refined their calculations, based on new data on Earth's gravitational field. They maintain that frame-dragging has wrenched the LAGEOS satellites out of their expected orbital positions by two meters a year. There have also been hints of frame-dragging in observations of neutron stars and black holes.

Does that finding mean NASA wasted $700 million on Gravity Probe B? Hardly. The mission is expected to measure frame-dragging directly with an accuracy of 1 percent—good enough, for many experts, to prove the physical reality of Einstein's prediction. For LAGEOS the displacement of two meters per year, expressed as an angle, is just 0.03 arc second (1/120,000th of a degree). It seems at least questionable whether such a vanishingly small signal can be isolated from the overwhelming noise of the panoply of ordinary Newtonian effects, which amount to 120 degrees a year. In addition to measuring frame-dragging, of course, Gravity Probe B is also investigating the geodetic effect.

What about the possibility that Gravity Probe B will show the way to new physics? According to one Nobel laureate, the physicist Chen Ning Yang of Stony Brook University in New York, Einstein's general theory of relativity is likely to be amended in a way that somehow entangles spin and rotation. "The Stanford experiment is especially interesting in that it focuses on the spin," he writes. "I would not be surprised at all if it gives a result in disagreement with Einstein's theory."

Given such high stakes, Everitt is on guard against any premature release of his own data. The Gravity Probe B team expects the helium on board to be exhausted by the end of July. "Then," he says, "it will be four to six months after that before we publish any results." After forty-five years, that might almost seem like rushing into print. □

The Flower and the Fly

Long insect mouthparts and deep floral tubes have become so specialized that each organism has become dependent on the other.

By Laura A. Sessions and Steven D. Johnson

The meganosed fly *(Moegistorhynchus longirostris)* of southern Africa, like its literary counterpart, Pinocchio, has a bizarre appearance that reveals an underlying truth. Its proboscis, which looks like a nose but is actually the longest mouthpart of any known fly, protrudes as much as four inches from its head—five times the length of its bee-size body. In flight the ungainly appendage dangles between the insect's legs and trails far behind its body.

To an airborne fly, an elongated proboscis might seem a severe handicap (imagine walking down the street with a twenty-seven-foot straw dangling from your mouth). Apparently, though, the handicap can be well worth its aerodynamic cost. The outlandish proboscis gives the meganosed fly access to nectar pools in long, deep flowers that are simply out of reach to insects with shorter mouthparts.

But that poses a conundrum: why would natural selection favor such a deep tube in a flower? After all, nectar itself has evolved because it attracts animals that carry pollen, the sperm of the floral world, from one plant to another. And since pollinators perform such an essential service for the flower, shouldn't evolution have favored floral geometries that make nectar readily accessible to the pollinators?

Yet the story of the long proboscis of the meganosed fly and the long, deep tubes of the flowers on which it feeds is not quite so straightforward. There are subtle advantages, it turns out, to mak-

Tangle-veined fly (Prosoeca ganglbaueri) *visits a small flowering herb called the mountain drumstick* (Zaluzianskya microsiphon) *in the Drakensberg Mountains of southern Africa. The flower and the fly are caught in a cycle of coevolution: plant pollination benefits from long floral tubes, because nectar-seeking insects must press their bodies closely against pollen-bearing floral parts to reach nectar pools at the end of the floral tube. As floral tubes become longer, however, insects with longer proboscises, or mouthparts, are also favored by natural selection; those flies are the most efficient at gathering nutrients. The result is a cycle of lengthening organs in both flower and fly; moreover, each species can become dependent on the other, to the exclusion of other, less specialized organisms.*

Meganosed fly, an insect native to southern Africa, visits a Pelargonium suburbanum *flower, a member of the geranium family. Dangling from its proboscis (the lengthy mouthpart that gives the insect its somewhat misleading name) are yellow pollinaria, or sacs of pollen, from an earlier visit to an orchid.*

ing nectar accessible to only a few pollinators, and nature factors those advantages into the evolutionary equation as well. In fact, the evolution of those two kinds of organisms, pollinator and pollinated, presents an outstanding example of an important evolutionary phenomenon known as coevolution. Coevolution can explain the emergence of bizarre or unusual anatomies when no simple evolutionary response to natural selection is really adequate. It can help conservationists identify species that could be vital in maintaining a given habitat. And it can help naturalists investigating novel plants predict what kinds of animals might pollinate their flowers.

The coevolution of the meganosed fly and the plants it pollinates is a tale of extreme specialization. Each species has adapted to changes in the other in ways that have left each of them, to some degree, reliant on the other. The idea that a plant species might become dependent for pollination on a single species of animal goes back to the writings of Charles Darwin. For example, Darwin noted, the flower spur of the Malagasy orchid *(Angraecum sesquipedale)* contains a pool of nectar that is almost a foot inside the opening of the flower. (A flower spur is a hollow, hornlike extension of a flower that holds nectar in its base.) In pondering the evolutionary significance of those unusual flowers, Darwin predicted that the orchid must be adapted to a moth pollinator with a long proboscis.

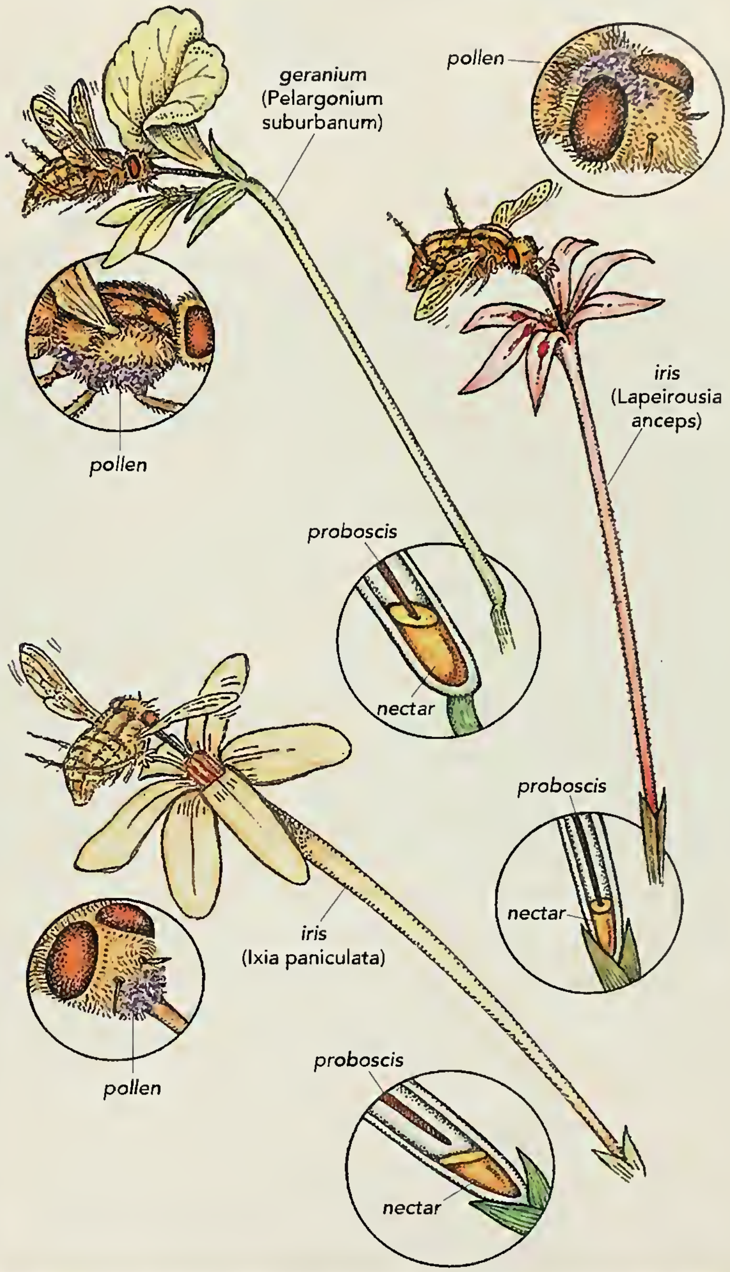
Critical to Darwin's prediction was his suspicion that pollination could take place only if the depth of a plant's flowers matched or exceeded the length of a pollinator's tongue. Only then would the body of the pollinator be pressed firmly enough against the reproductive parts of the flower to transfer pollen effectively as the pollinator fed. Thus, as ever deeper flowers evolved through enhanced reproductive success, moths with ever longer proboscises would also, preferentially, live long enough to reproduce, because they would most readily reach the available supplies of nourishing nectar. Longer proboscises would lead yet again to selection for deeper flower tubes.

The result would be the reciprocal evolution of flowers and pollinator mouthparts. That coevolutionary process would cease only when the disadvantages of an exaggerated trait balanced or outweighed its benefits. Given enough time, the process might even produce new species: an insect tht specializes in feeding on nectar from deep flowers, and a deep-flowered plant specialized for being pollinated by insects with long mouthparts.

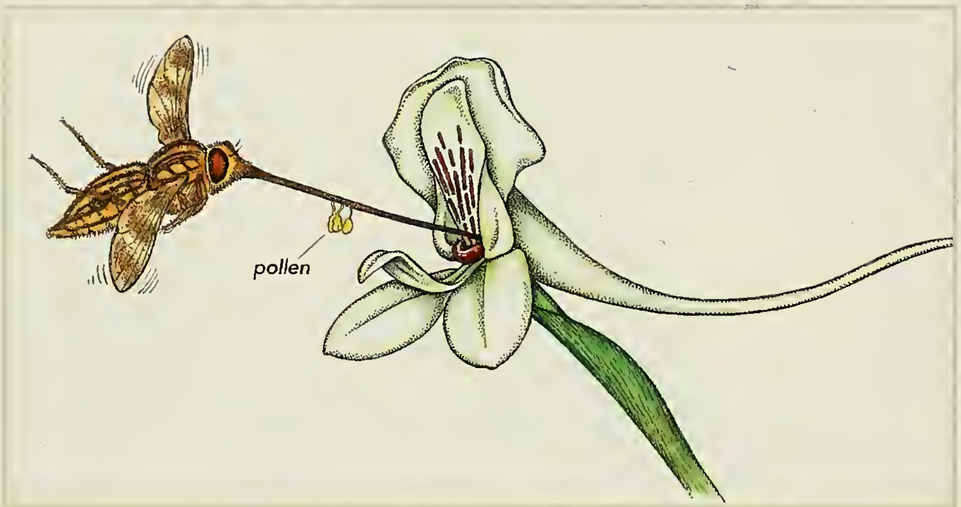
In the early twentieth century it seemed that Darwin's prediction had been borne out. A giant hawk moth from Madagascar, *Xanthopan morganii praedicta,* was captured, with a proboscis that measured more than nine inches long. Although no one has actually seen the insect feeding on the flower, the discovery is still remarkable, and strongly suggestive of the coevolution of the orchid and moth. Other insects that have relationships with highly specific plants, such as the meganosed fly and other, related long-nosed fly species of southern Africa, provide even better evidence of the reciprocal links between plants and their pollinators.

Darwin would have been amazed that some flies in southern Africa have longer tongues than most hawk moths do. After all, the flies' bodies are several times smaller than the hawk moths' are. Flies are described as long-nosed if their mouthparts are longer than three quarters of an inch. By that criterion, more than a dozen long-nosed fly species are native to southern Africa. They belong to two families. The nemestrinids, or tangle-veined flies (which include the meganosed fly), feed solely on nectar, whereas the tabanids, or horseflies, feed mostly on

drome of the long-nosed fly (and indeed, in all pollination syndromes of long-nosed insects) is a deep, tubular flower or floral spur. One of us (Johnson) and Kim E. Steiner of the Compton Herbarium in Claremont, South Africa, studied the orchid *Disa draconis,* a southern African plant with a deep, tubu-



Plant tactic to minimize the possibility that the pollen of one species will be wasted by ending up on the female reproductive parts of another species is shown in the diagram. Plant species belonging to the "pollination guild" of the meganosed fly all risk distribution of their pollen by the fly to plants of different species. The members of the guild have evolved to deposit their pollen on differing parts of the nectar-seeking fly, each part characteristic of the plant species.



Orchid Disa draconis *is a member of the pollination guild of the meganosed fly, and so the orchid depends on the fly for pollination. Like other, similarly adapted flower species, it has a long tube, but unlike the others, it provides no nectar to the fly; the fly is simply fooled into visiting the flower. As the drawing shows, the pollen of the orchid, enclosed in sacs, is deposited uniquely along its proboscis.*

lar floral spur. The two investigators artificially shortened the spurs of some orchids in a habitat where the only pollinators present were long-nosed flies. The plants whose spurs remained long got more pollen, and were more likely to produce fruits, than the ones whose spurs were shortened.

Yet short floral spurs are not necessarily a reproductive disadvantage. Shorter spurs would make it possible for a wider range of pollinators to access the nectar, if various potential pollinators are present. Instead, longer spurs only seem to be an advantage when long-tongued insects are the sole pollinators. Johnson and Steiner found that differences in spur length among populations cannot be blamed on differences in moisture or temperature, thus reinforcing their conclusion that spur length was an adaptation to the local distributions of long-tongued flies.

Not only does spur length correlate statistically with pollinator traits, but a direct causal connection can be demonstrated. Johnson and Ronny Alexandersson, a botanist at Uppsala University in Sweden, studied South African *Gladiolus* flowers pollinated by long-tongued hawk moths. When the hawk moth proboscises were long compared to the length of the flower tube, the hawk moths did not efficiently pick up pollen, and the flowers did not reproduce well. When the hawk moth proboscises were relatively short, pollen was more readily transferred, and the plants were more likely to be fertilized and bear fruit. Thus the length of the pollinator's proboscis exerts a strong pressure on the reproductive success of the flowers.

Those studies and others suggest that what Darwin predicted of the Malagasy orchid is a rather general phenomenon: hawk moths and long-nosed flies coevolved with their plant partners. As floral tubes became longer, so did the pollinators' proboscises, and those led, in turn, to even longer flowers. As the lengths of the flower tube and the insect proboscis converge, a remarkable degree of specialization develops. The plants come to rely for pollination on the few insect species that can reach their flowers' nectar supplies.

There are advantages for the specialists on both sides of this relationship. The long-nosed flies obviously get privileged access to pools of nectar. And the plants pollinated by long-nosed flies benefit from a near-exclusive pollen courier service—or at least one that minimizes the risk of delivery to the wrong address. But specializing can also be a risky strategy for the plants if the pollinators are less interested in fidelity than the plants are. Long-nosed flies could not survive on the nectar they could get by visiting just one plant species; the flies must visit several plant species to gather the energy they need. Johnson and Steiner observed meganosed flies visiting at least four species with deep flowers.

Such promiscuous behavior could be detrimental to the plants. A fly might end up carrying pollen from one species to a different species in the guild, thereby wasting the pollen. Worse, the foreign pollen could end up clogging the stigmata, the female reproductive structures, of the receiving flowers, preventing them from getting the "right" pollen. But the stigmata of plants in the guild of the meganosed fly do not clog, because among those plants yet another clever adaptation to specialized pollination has evolved. Each plant species arranges its anthers, the male reproductive structures, in a characteristic position. That way, the pollen from each species sticks to the pollinator's body in a distinct but consistent, plant-specific location. The fly becomes an even more efficient courier, carrying pollen from various plant species simultaneously, say, on its head, legs, and thorax.

The risks of specialization are not confined to the flowers. Just as the flies are unfaithful partners, some flowers are dishonest about signaling a nectar reward. The orchid *D. draconis,* for instance, is not the mutualistic partner it seems. The flower attracts the meganosed fly because it looks like other members of the fly's guild. But, whereas the fly carries the orchid's pollen, the orchid offers no nectar in return.

The risk of falling for such a trick seems a small price for the flies to pay for the benefits of specialization. But specialization also carries a much graver risk—in fact the ultimate risk—for both members of the partnership because the disappearance of either partner is likely to doom the other one, as well. Some plant species have mechanisms, such as vegetative reproduction or self-pollination, that may help sustain their populations in the short run. But in the long run, without their pollinators, the species will slowly and irrevocably decline. Pollinating insects may be more flexible in some cases, but are still vulnerable if a key food source disappears.

Unfortunately, in southern Africa that is just what is happening to many plants and their long-nosed fly partners. Often not even closely related insect species can help in pollination. For affected plants, the loss of a single fly species means extinction. And examples of that gloomy cascade have already been observed. Peter Goldblatt of the Missouri Botanical Garden in St. Louis and John C. Manning of the Compton Herbarium have reported that many populations of long-nosed flies are threatened by the loss of their wetland breeding habitat, and also, possibly, by the loss of other insects they parasitize during their larval stages. In some habitats, flowers in the long-nosed fly guild already produce no seeds, because their pollinator is locally extinct.

Naturalists have accepted the concepts of guilds and pollinator syndromes for many years, and predicting which pollinators regularly visit which plants has become something of a cottage industry. But just how common is pollinator specialization in southern Africa? Promiscuity could turn out to be a more successful—and more widespread—strategy than specialization, even among plants that seem to fit into identifiable guilds.

In recent years ecologists have discovered that just because plants and insects appear to form a pollination guild does not guarantee they never venture outside it. For example, ecologists have noted that in years when hummingbird populations are low, flowers ordinarily pollinated by hummingbirds can fill up with nectar and become pollinated effectively by bees. Likewise, bees once thought to specialize in only one or two plant species turn out to forage on a variety of plants.

The take-home lesson has been that the syndrome concept is no substitute for careful field observation. Some investigators even think that the concept has caused botanists to overlook generalists. In the Northern Hemisphere, for instance, studies suggest that generalization is the norm, not the exception. Johnson and Steiner recently completed a study showing that members of the orchid and asclepiad families in the Northern Hemisphere tend to rely on between three and five pollinators each. In contrast, plants from the same families in the Southern Hemisphere rely on just one pollinator each.

So why might generalization be more common in the Northern Hemisphere than it is in the Southern Hemisphere? Perhaps the reason is that social bees, which are largely opportunistic, dominate pollinator faunas in northern regions. In the Southern Hemisphere, by contrast, social bees are mostly absent, replaced instead by more specialized pollinators such as the long-nosed flies and hawk moths.

Hawk moth (Agrius convolvuli) *visits a lily* (Crinum bulbispermum). *The hawk moths of the Southern Hemisphere, like the meganosed flies, are often tightly associated with the flowers they pollinate. The lily is one of some twenty African plant species with floral tubes that match in length the four-inch proboscis of that hawk moth, suggesting the plants and the hawk moths have coevolved in response to each other.*

But that is just a broad generalization itself. More data on the geographic distribution of pollinator specialization needs to be gathered, particularly in tropical countries. The data is vital, not only to advance the specialization debate, but also to protect as many of these unique species and relations as possible, lest they disappear forever. □

Peak Experience

The Caribbean island of Saint Lucia harbors rainforest reserves and a drive-in volcano.

By Robert H. Mohlenbrock

Beginning in my high school days, whenever I happily browsed through books on geography and travel, I was fascinated by pictures of the Pitons, two pyramidal volcanic peaks that rise along the coast of the Caribbean island of Saint Lucia. My chance to see them "in the flesh" finally came in January of last year, when my wife Beverly and I traveled to the island. We flew to the capital city, Castries, on the island's western coast, and headed south in our rental car toward Soufrière, Saint Lucia's third largest city. The journey along the narrow, crooked, but well-paved road took about an hour. Although our route never strayed far from the coast, it passed almost entirely through mountainous terrain, only occasionally dipping down to a picturesque fishing village.

The final leg of our drive took us through rainforest, virtually announced by tree ferns as high as forty feet. As we rounded one sharp curve, I could not contain my own excited announcement, as the mighty Pitons came into view through a forest opening: "There they are!" I exclaimed. The two peaks, Gros Piton (French for "large peg") and Petit Piton ("small peg") made a striking couple. They also recall Saint Lucia's checkered colonial past, reminding the visitor that many locals still speak a French patois, even though English is the island's official language.

The Pitons—Petit (left) and Gros (right)—as seen from a coastal viewpoint to the north. The two peaks are the remains of a complex of volcanoes.

We continued through the rainforest, then descended to the sea and the city of Soufrière, on the west coast of the island. The two Pitons lay to our south, though from some vantage points we could not see Gros Piton, taller than its 2,461-foot sibling by 158 feet but often concealed behind it. The Pitons are probably what is left of a complex of volcanoes. Their steep slopes extend 250 feet below sea level.

In Soufrière we visited the Diamond Botanical Gardens, where trails offer close-up views of vegetation, including many native species, along with mineral springs and a waterfall. Saint Lucia is a popular destination for divers and snorkelers, who report seeing lots of sponges, including the large barrel sponge, on the Pitons' underwater slopes. Caves, reefs, and peaks, all abounding with colorful fish, also lure the underwater visitor.

Above the water line, coconut palms ring the base of the Pitons, and a little higher up the dominant flora change to dry-loving species, including a number of euphorbias and other semisucculent plants. On their eastern side the Pitons are cloaked in the middle with deciduous tropical dry forest; nearer the summit is a rainforest of mostly evergreen species. At the summits and on the western side, where high winds and cooler temperatures make growing conditions most severe, is a so-called elfin forest comprising dwarf, gnarly trees draped with epiphytes, or air plants, including orchids.

Climbing the Pitons, though, is not the most straightforward way to see Saint Lucia's rainforests. The summit trails are hazardous and difficult—and sometimes closed because of the danger of rockfall. Fortunately, other zones of rainforest are accessible to hikers and drivers within the island's forest reserves, which cover nearly thirty square miles of the island's interior. Mount Gimie, at 3,117 feet Saint Lucia's highest point, lies within the reserves [*see map at right*]. Permission to enter the reserves must be obtained from Saint Lucia's Forest and Lands Department.

The rainforests get more than 150 inches of rain a year, on average, mostly from June through November. The trees forming the upper canopy grow as tall as 180 feet, and many have large girths. The most common species is gommier, a member of the Burseraceae family. Temperate North America has no burseraceous representatives, but two Old World species are familiar, at least in name: frankincense and myrrh. Another tree species on Saint Lucia is *bois canon*, or cecropia, whose large, palm-like leaves decay very slowly when they fall to the ground. The hiker is apt to spot the leaves on the forest floor before noticing the tree itself, towering overhead.

Beneath these and other large trees is a dense mid-canopy of trees and tall shrubs, ranging from twenty to sixty feet high. Among them is *dede-fouden*, or bead tree, whose shiny red-and-black seeds are gathered to make necklaces, earrings, and eyes for teddy bears. Tree ferns (known locally as *fwije*) and bamboo grasses also inhabit the midcanopy layer. Epiphytes cling to the branches of many trees, and vines seeking sunlight climb their trunks.

Hard to spot but at the top of many visitors' watch lists is the Saint Lucia parrot, a green-, red-, and blue-feathered endemic species that lays its eggs in hollows in the tops of the gommier trees. The numbers of the birds in the wild have fallen to critical levels, because of loss of habitat and because they are taken locally for food or captured for the pet industry. Thanks to a conservation effort, however, the population has increased to 800 from a low of about 100 in 1979.

The snake most apt to be seen in the rainforest is the boa constrictor. Two of the island's other snakes are of special interest to herpetologists—though they do not occur in the rainforest. One is the Saint Lucia racer, perhaps the rarest snake in the world, and the other is the worm snake, one of the smallest, measuring less than six inches long.

FOR VISITOR INFORMATION, CONTACT:

The Saint Lucia Tourist Board
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P.O. Box 221
Castries, Saint Lucia
758-452-4094
www.stlucia.org

When Beverly and I drove south on the main road from Soufrière, we passed near the inland side of Petit Piton. The coastal area between that peak and Gros Piton, farther south, was once the site of the Jalousie sugar plantation; now it is occupied by a resort. Beyond the resort turnoff we came to a rough road that led inland through the remains of a volcanic crater (it is touted as the world's only drive-in volcano). In fact, on our initial descent into Soufrière, we had noticed steam rising in the distance from this valley. The sulfurous fumes we now breathed up close gave the city its name (*soufre* is French for "sulfur").

Endemic Saint Lucia parrot has suffered from loss of habitat.

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

Rainforest Plants

In addition to cercropia and gommier, tall native trees include *bois de* masse (a relative of Florida's gopher apple tree), *chataignier*, and incense tree (the last, like gommier, in the Burseraceae family). A nonnative tree is blue mahoe, a kind of hibiscus. A beautiful evergreen tree with red, orange, or yellow flowers, blue mahoe is native to Jamaica. Like so many other plants in the tropics, it has escaped from cultivation and gone wild.

Species that make up the midcanopy layer in the forest, along with the bead tree, bamboo grasses, and tree ferns, include the common palms *gwi gwi* and palmiste, *mahot cochon* (a tree in the same family as the chocolate tree), and *paletuvier* (this last species is also called mountain mangrove, and the stilt roots it forms at the base of its trunk resemble those of the red mangrove, though it is not actually a mangrove). The epiphytes hanging from the tree branches are either bromeliads or orchids. One of the common vines, known as the climbing palm, is not a true palm, but is a member of the closely related Cyclanthaceae family.

The forest floor is a jumble of coarse and delicate herbs, many of them escapees from cultivation. Commonly encountered are *lang poul* (a kind of gentian), several species of lobster claw, tet *neg* (a plant in the same genus as the elephant's-foot of the eastern United States), *venvenn lache wat* (a member of the verbena family), and various species of wild ginger.

By Laurence A. Marschall

Sable Island: The Strange Origins and Curious History of a Dune Adrift in the Atlantic
by Marq de Villiers and Sheila Hirtle
Walker & Company, 2004; $24.00

Battered remains of the trawler Gale, shipwrecked off Sable Island in 1945

Before I picked up this book, I'd never heard of Sable Island. But the seafaring communities of New England and Canada's Maritime Provinces know it all too well. One hundred and seventy-nine miles southeast of Halifax, Nova Scotia, Sable Island is a treeless, crescent-shaped sliver of sand stretching some twenty-five miles from west to east, near the edge of the continental shelf. It has never sustained a resident population of more than a few dozen souls, but this mere spit of land and its surrounding sea has become the final resting place for thousands of unfortunate sailors and fishermen—a veritable graveyard of the Atlantic.

Sable is a perilous place, and not only because it is barely visible above the swells of the sea. Situated along the principal trade route between Europe and North America, and in near proximity to the fishing grounds and oil-rich drilling sites of the Grand Banks, the island is literally in the way of much of the passing maritime traffic. To compound the danger, the island is surrounded by miles of offshore sandbars, whose extent and shape constantly shift under the battering of storms and currents. Even experienced sailors have concluded that the best way to survive Sable is to give it a wide berth.

Yet over the centuries, hundreds of ships, lost or driven by high seas, have gone aground off its coast—an estimated seven wrecks for every mile of coastline. Sable Island has also attracted its fair share of writers over the years. Its most recent chroniclers, Marq de Villiers and Sheila Hirtle, provide a highly readable and intelligent account of the history, geology, and ecology of the island.

Like Cape Cod, Sable is both a remnant of the last ice age—a dollop of sand and gravel left behind as the great glaciers retreated—and an environment surprisingly well-suited for human habitation (albeit only the minimally invasive type). A large though fragile freshwater aquifer underlies its dunes, and plenty of grasses and low-lying shrubs manage to hang on, despite nearly constant winds. A variety of nesting birds, different species of seal, and a resident herd of several hundred feral horses reside within its approximately thirteen square miles.

That's not to say Sable is an easy place to live. As early as the 1600s, French merchants tried to establish settlements on the island, but a chain of supply with the mainland proved hard to maintain. Once you read de Villiers and Hirtle's accounts of winter storms, as recorded by later residents, it's easy to understand why. In the 1860s, one of them told a Halifax newspaper that during one rather strong gale, the only way to move around at all was to crawl on all fours. "When the seas hit Sable," another resident recalled, "you could see the oil in the lamps just quivering from the vibrations of a thousand tons of water hitting the south beach."

By the beginning of the twenty-first century, Sable was home to just two people: a Canadian-government meteorologist and a freelance environmentalist. The island's lighthouses and its various weather and ocean sensors have all been automated, and such modern navigational aids have vastly reduced the incidence of shipwrecks. A preservation trust oversees its management from mainland Canada. Yet the island remains a remote and exotic outpost, its only visitors the occasional naturalist.

If you're fascinated by islands, dipping into this lively book is a great way to visit Sable without getting wet. Then, with your appetite whetted, visit the Web site museum.gov.ns.ca/mnh/nature/sableisland/index.htm for some personal accounts and wonderful old photographs of the island as it was in Victorian days.

Beast of Never, Cat of God: The Search for the Eastern Puma
by Bob Butz
The Lyons Press, 2005; $22.95

There are wild things among us. Who would have thought, just a few decades ago, that suburbanites would come to view the white-tailed deer as a major nuisance to their lawns and gardens? Who would have imagined that peregrine falcons would nest in city high-rises and terrorize squirrels in city parks? The heightened environmental sensitivity of the past century, along with a drastic reduction in the number of rifle-toting frontiersmen, has rescued a host of creatures from the brink of extinction in the eastern United States.

So why not the mountain lion *(Puma concolor)*? Known by many names—puma, cougar, catamount, panther—this large feline predator was once wide-

Puma concolor, variously known as the puma, cougar, catamount, panther, and mountain lion

spread throughout much of North America. A full-grown cougar can weigh more than 150 pounds and can measure seven feet from the tip of its nose to the end of its tail. It stalks everything from rabbits to elk, but its preference is deer—nowadays in plentiful supply. Estimates of the present-day cougar population in North America range between 30,000 and 50,000, but most experts think virtually all of them inhabit the western mountain or Pacific Coast states. A vestigial population of a hundred or so live deep in the Florida Everglades. But except for the Florida felines, as far as one can tell, wild cougars no longer live east of the Mississippi.

At least that's the official version. Bob Butz, a nature writer who lives near Traverse City, Michigan, at the far northern edge of the lower peninsula, has a different story. Butz has spent the past few years among a strange subculture of hunters and outdoorsmen who truly believe, contrary to the stance of state and federal wildlife managers, that cougars have begun to recolonize the East. Butz's principal informant is Patrick Rusz, who has both a Ph.D. in wildlife ecology and a bee in his bonnet about the big cats. Rusz seems to spend most of his weekends in the woods, following up reports of sightings and collecting piles of suspicious scat, which he stores in an ice chest in the back of his pickup to save for DNA analysis.

By immersing himself in the cat-chasers' culture, Butz has put together plenty of evidence pointing to the presence of wild pumas in the eastern woods. Many candid snapshots of purported cougars are no clearer than fuzzy pictures of Bigfoot, but some are sharp and unambiguous. A lot of the tracks seem genuine, and laboratory tests of scat samples often come back positive for puma.

But caution is in order. Wildlife officials seem willing to grant the occasional sighting, but they are reluctant to conclude that such pumas represent a native wild population, as many of the "cat people" believe. One or two strays may have wandered east; an occasional pet puma may have escaped from a zoo or a private preserve. That's a bit different from claiming that dozens of pumas are breeding in the woods.

In the absence of incontrovertible evidence (there's been a notable lack of pumas shot during hunting season), game wardens seem inclined to regard the cougar issue as something of a nuisance. With plenty of well-documented species that need conserving, the official position is that the cougar lobbyists should "get a life." After reading Butz's reportage, I tend to agree. But, recalling the occasional sightings of pumas my local newspaper has reported, I'm going to keep a sharper eye out for the big cats the next time I'm out on the trail.

Mendel in the Kitchen: A Scientist's View of Genetically Modified Foods
by Nina Fedoroff
and Nancy Marie Brown
Joseph Henry Press, 2004; $24.95

It is marvelous how submicroscopic strands of DNA, through their many permutations, can influence the structure, development, and functioning of

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(Continued from page 67)

every living species on the planet. Yet to Nina Fedoroff, a molecular biologist at Pennsylvania State University in University Park, it also seems ironic that the same molecules have played such a powerful role in the recent political life of our species.

Here in the United States, the methods of genetically modified (GM) agriculture have been applied nationwide. Outside the U.S., however, genetic modification is regarded as a horrific form of tinkering with nature—so much so that the chromosomal makeup of fruits and vegetables has been a major bone of contention in agreements between the European Union and its trading partners.

Fedoroff grants that ecological and ethical issues abound. But she still believes that GM foods are no more dangerous than foods were before this particular round of technology became available. A little more understanding of the science behind GM food production and consumption, she seems to think, might cool down the doomsday rhetoric. So with the able assistance of science writer Nancy Marie Brown, she has produced not only an authoritative primer on the science and ecology of agricultural genetics, but a much-needed guide for the perplexed.

The main point Fedoroff makes is that plant manipulation is nothing new to the farmer. Agriculture, from the beginning, has been all about fooling Mother Nature. Millennia before Mendel, the first farmers to domesticate wheat and corn bred their stock selectively to tilt the balance of the gene pool toward features they favored—harvestability, size, flavor, and the like. For centuries, orchard managers have cloned their favorite fruit stocks by grafting branches of a desirable plant onto the trunks or branches of other trees. (Intriguingly, that practice, accepted today even by organic farmers, drew its share of opposition in the late 1700s, when it was first introduced in America by John Chapman, aka Johnny Appleseed.)

By the twentieth century, agricultural scientists were crossbreeding

Tomato grower's dream

plants extensively, according to the trial-and-error method pioneered by Luther Burbank: selecting desirable variants and frequently accelerating variability by dosing the plants with radiation or chemicals.

What is different about modern genetic manipulation, of course, is that it can be accomplished at the molecular level. The outcome is usually predictable and often quite precise, dispensing as it does with so much of the trial and error of earlier techniques. The methods of recombinant DNA make it possible to select desirable genes from widely divergent species, and even to add or delete genes at will. In the 1990s, for instance, workers inserted a gene from the bacterium *Bacillus thuringiensis* into corn and potato chromosomes, creating plants that produce their own insecticides. The new varieties have reduced the need for chemical insecticides. Who knows what new and ingenious organisms may yet be produced?

It's that "who knows?" that will no doubt keep the opposition going. Yet to all but the harshest critics of GM, Fedoroff and Brown certainly seem to have made their case: genetic modification, deployed with the same wisdom as any other agricultural innovation, is more of a boon than a hazard.

LAURENCE A. MARSCHALL, *author of* The Supernova Story, *is W.K.T. Sahm Professor of Physics at Gettysburg College in Pennsylvania. He is the 2005 winner of the Education Prize of the American Astronomical Society.*

EXPLORER GUIDE

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Einsteiniana

By Robert Anderson

This year marks the centennial of Einstein's *annus mirabilis,* a commemoration that, to my mind, is far more significant than the centennial of the great physicist's birth. In 1905 the young Einstein published a remarkable series of four scientific papers, culminating with his special theory of relativity in June and, in September, a report on the consequences of the theory, his formulation for the equivalence of mass and energy, $E=mc^2$. In one year, Einstein produced an outpouring of insights so profound that they set the stage for all of modern physics.

You'll find a good summary of the papers on a Web page of the American Institute of Physics (AIP): go to www.aip.org/history/einstein and click on "The Great Works—1905." To listen to Einstein himself explaining his famous formula in English, go to another page of the AIP site (www.aip.org/history/einstein/voice1.htm).

Where did Einstein's great burst of creativity come from? For one kind of answer, have a look at the research conducted by Sandra F. Witelson, a neuroscientist at McMaster University in Hamilton, Ontario, and her colleagues. Working on sections from Einstein's brain, the team found unusual development in areas of his "gray matter" having to do with visual imagery and mathematical thinking. The Web site www.bioquant.com/gallery/einstein.html includes an image of the famous brain, as part of an excerpt from Witelson's 1999 paper in the journal *The Lancet.*

The citizens of the Swiss capital, Bern, are interested in preserving the apartment at number forty-nine Kramgasse, where Einstein lived between 1903 and 1905. You can find photographs and other information about his years in Bern at their Web site (www.einstein-bern.ch).

Still another source of Einsteiniana is the Einstein Papers Project (www.einstein.caltech.edu). Filed away in the project's archives are copies of more than 40,000 documents from Einstein's estate (the originals were bequeathed to the Hebrew University of Jerusalem). At the site you can browse through the papers that the project has already translated by clicking on "Albert Einstein Archives Online."

If you care less about the facts and events of the man's life and more about his discoveries, you can access the online site (www.amnh.org/exhibitions/einstein) of an exhibition that originated at the American Museum of Natural History in New York City (a special Einstein-for-kids page is at www.ology.amnh.org/einstein/index.html). Another source of facts can be found at the Web site of the PBS *NOVA* TV series, on a page called "Think Like Einstein" (www.pbs.org/wgbh/nova/time/think.html). And if you're looking for Einstein in the here-and-now, you can tune in (einstein.stanford.edu) and follow the week-by-week results of experiments devised to test two yet-unverified predictions from Einstein's general theory of relativity [*see "Testing Einstein (Again)," by Arthur Fisher, page 52*].

One of the most fitting tributes to Einstein's "miraculous year" can be found at the site of the "World Year of Physics 2005: Einstein in the 21st Century" (www.physics2005.org). As part of the worldwide celebration, amateur enthusiasts are invited to participate in the "Einstein@Home" project (www.physics2005.org/events/einsteinathome), which aims to find evidence for another of Einstein's predictions: gravitational waves. The idea is to sift through data from observatories for signals emitted by extremely dense, rapidly rotating stars. Physicists are hoping to enlist the help of a million or more volunteers with personal computers that are "idle" much of the time—such as yours, perhaps. Who knows? Your desktop PC might help confirm one of Einstein's predictions.

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

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ner solar system resembled a shooting gallery. Earth's surface was continually pulverized by crater-forming boulders large and small. Any attempt to jump-start life would have been swiftly aborted. By about 4 billion years ago, though, the impact rate slowed and Earth's surface temperature began to drop, permitting experiments in complex chemistry to survive and thrive.

Older textbooks start their clocks at the birth of the solar system, and typically declare that life on Earth needed 700 million or 800 million years to form. But that's not fair: the planet's chem-lab experiments couldn't even have begun until the aerial bombardment lightened up. Subtract 600 million years' worth of impacts right off the top, and you've got single-celled organisms emerging from the primordial ooze within a mere 200 million years. Even though scientists continue to be stumped about how life began, nature clearly had no trouble creating the stuff.

Many astrobiologists view Titan as a "living" laboratory for studying the young Earth.

In just a few dozen years, astrochemists have gone from knowing nothing of molecules in space, to finding a plethora of them practically everywhere. Moreover, in the past decade astrophysicists have confirmed that planets orbit other stars, and that every exosolar star system is laden with the same top four ingredients of life as our own cosmic home is. Although no one expects to find life on a star, even a thousand-degree "cool" one, Earth has plenty of life in places that register several hundred degrees. Taken together, these discoveries suggest it's reasonable to think of the universe as fundamentally familiar rather than as utterly alien.

But how familiar? Are all life-forms likely to be like Earth's—carbon-based and committed to water as their favorite fluid?

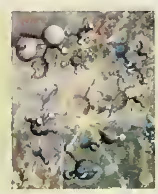
Take silicon, one of the top ten elements in the universe. In the periodic table, silicon sits directly below carbon, indicating that they have an identical configuration of electrons in their outer shells. Like carbon, silicon can bind with one, two, three, or four other atoms. Under the right conditions, it can also make long-chain molecules. Since silicon offers chemical opportunities similar to those of carbon, why couldn't life be based on silicon?

One problem with silicon—apart from its being a tenth as abundant as carbon—is the strong bonds it creates. When you link silicon and oxygen, for instance, you don't get the seeds of organic chemistry; you get rocks. On Earth, that's chemistry with a long shelf life. To have chemistry that's friendly to organisms, you need bonds that are strong enough to survive mild assaults on the local environment but not so strong that they don't allow further experiments to take place.

And how important is liquid water? Is it the only medium suitable for chemistry experiments, the only medium that can shuttle nutrients from one part of an organism to another? Maybe life just needs *a* liquid. Ammonia is common. So is ethanol. Both are drawn from the most abundant ingredients in the universe. Ammonia mixed with water has a vastly lower freezing point (around −100 degrees Fahrenheit) than does water by itself (32 degrees), broadening the conditions under which you might find liquid-loving life. Or here's another possibility: on a world that lacks an internal heat source, orbits far from its host star, and is altogether bone-cold, normally gaseous methane might become the liquid of choice.

This past January 14, the European Space Agency's *Huygens* probe (named after you-know-who) landed on Saturn's largest moon, Titan, which hosts lots of organic chemistry and supports an atmosphere ten times thicker than Earth's. Setting aside the planets Jupiter, Saturn, Uranus, and Neptune, each made entirely of gas and having no rigid surface, only four objects in our solar system have an atmosphere of any significance: Venus, Earth, Mars, and Titan.

Titan was not an accidental target of exploration. Its impressive résumé of molecules includes water, ammonia, methane, and ethane, as well as the multi-ringed compounds known as polycyclic aromatic hydrocarbons. The water ice is so cold it's as hard as concrete. But the combination of temperature and air pressure has liquefied the methane, and the first images sent back from *Huygens* seem to show streams, rivers, and lakes of the stuff [*see photograph on page 15*]. In some ways Titan's surface chemistry resembles that of the young Earth, which accounts for why so many astrobiologists view Titan as a "living" laboratory for studying Earth's distant past. Indeed, experiments conducted two decades ago show that adding water and a bit of acid to the organic ooze produced by irradiating the gases that make up Titan's hazy atmosphere yields sixteen amino acids.



Recently, biologists have learned that planet Earth may harbor a greater biomass belowground than on its surface. Ongoing investigations about the hardy habits of life demonstrate time and again that it recognizes few boundaries. Once stereotyped as kooky scientists in search of little green men on nearby planets, investigators who ponder the limits of life are now sophisticated hybrids, exploiting the tools of not only astrophysics, biology, and chemistry but also geology and paleontology as they pursue life—here, there, and everywhere.

Astrophysicist NEIL DEGRASSE TYSON *is the director of the Hayden Planetarium at the American Museum of Natural History. His latest book, co-authored with Donald Goldsmith, is* Origins: Fourteen Billion years of Cosmic Evolution *(W.W. Norton, 2004).*

Seeing Red

In distant galaxies that shine with a ruddy glow are stars that look older than the universe that begat them.

By Charles Liu

To an astronomer, color is just as important as it is to an interior designer—though in quite a different way. To both, what the eye perceives as red is light of relatively long wavelength; the wavelength of the light the eye perceives as blue is relatively short. The designer, however, seeks the complex balance of wavelengths that, like the notes in a musical chord, gives a unified color tone to create a mood—a crimson, say, a scarlet, or a cardinal. The astronomer's colors are equally complex, but here it is the parts that are important, the individual, single-wavelength colors into which the spectrum of a distant star or galaxy can be analyzed.

The many colors of starlight, it turns out, can reveal a great deal about a star—including its age. Statistically speaking, long-lived stars emit more long-wavelength light than short-lived stars do. The most massive stars in the cosmos are also the bluest and brightest, and they tend to explode, as supernovae, after at most a few million years. Stars of lower mass and luminosity, however, glow dimly with red light for billions of years: the redder the star is, the older it is. So if, for instance, a large population of stars forms in a relatively short time, with a broad mix of stellar masses and luminosities, the combined light from those stars is relatively blue at first and then reddens gradually with age.

Astronomers have long exploited this correlation between age and color to study the ages of stellar populations in star clusters and galaxies. Time and again, such study has led to new and fascinating scientific puzzles. In the past few years, for instance, observations of numerous distant galaxies whose light dates to the earliest years of the universe have posed a bewildering paradox: some of these galaxies appear to be older than the universe that begat them. Yet there's no way these child galaxies can be older than their parent universe.

One possible resolution of the deep-red paradox is as clear as a city sunset.

So why do we astronomers think these galaxies are so old? For one thing, their starlight is very, very red.

If the light emitted from a galaxy looks red, it's a safe bet that most of its stars are long-lived—and at least some of them are billions of years old. Moreover, if such a galaxy is also billions of light-years from Earth, the effects of cosmological redshift make the galaxy look redder still [*see "A Desert No More," by Charles Liu, June 2004*]. Such doubly red galaxies are known as "extremely red objects," or EROs.

Imagine observing extremely red objects between 9 billion and 12 billion light-years away. Among the nearer EROs, based on their redshift, are stars at least 4 billion years old, as indicated by their starlight colors. Among the farther EROs are stars at least 2 billion years old. Now do the math: stars in the closer EROs must have started forming 9 billion plus 4 billion, or 13 billion, years ago; the more distant EROs must have formed 12 billion plus 2 billion, or 14 billion, years ago.

That's the problem. The universe is about 13.7 billion years old, according to the best current measurements. How can distant EROs include stars that were born before the cosmos itself?

Well, of course, they can't. There must be another explanation. One possibility is as clear as a city sunset. Particulates and dust in Earth's atmosphere along the line of sight tend to absorb blue light more effectively than red light. That's why the setting sun looks redder over a polluted urban skyline than it does over a pristine seascape. For the same reason, EROs might be made up simply of younger stars, heavily enshrouded by dusty gas. The dust would redden their outgoing starlight, thereby making them look like an older stellar population.

In some cases, at least, dust may be the solution. A recent study of 275 EROs between 6 billion and 10 billion light-years away, led by Leonidas A. Moustakas of the Space Telescope Science Institute in Baltimore, showed that there's no way to distinguish "dust-free old-star" EROs from "dusty young-star" EROs by looking at galaxy colors alone. Dust, the investigators report, could be causing the EROs' extremely red colors. Furthermore, their study demonstrated that EROs can take any shape, from the ellipsoid traditionally associated with old-star galaxies to the disky or irregular shapes typical of young-star galaxies.

Another recent study, however, led by Natascha M. Förster Schreiber of the Max Planck Institute for Extraterrestrial Physics in Garching, Germany, reached a different conclusion. Schreiber's group examined thirty-four EROs between 10 billion and 12 billion light-years away, comparing ERO colors with color models of starlight and dust reddening. They determined that dust alone cannot account for the extreme redness of many of the EROs in their sample. These galaxies, they report, really do include old stars, and the measured ages of the stars, though imprecise, are still high enough to make cosmologists sweat just a little.

Extremely red objects in the distant universe are reminders of how much astronomers still don't understand about the birth and aging of stars and galaxies. Everyone agrees that EROs probably play a big part in that story. The study by Moustakas and his colleagues, for instance, noted that the number of ellipsoidal EROs in the distant universe is about the same as the number of giant elliptical galaxies in the nearby universe. Are many EROs, then, juvenile ellipticals, destined to grow bigger? Just as children seem ruddier than their parents, some galaxies may show the same tendency until they, too, grow old.

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

THE SKY IN MARCH

By Joe Rao

Mercury is the first planet to look for as the twilight fades in early and mid-March. The little planet is highest and brightest from about March 1 through the 10th. Look low in the west about forty-five minutes after sunset; Mercury is the only bright "star" in the otherwise barren constellation Pisces, the fish.

On the evening of the 1st Mercury shines at magnitude −1.2 and sets more than an hour after the Sun. After the 12th, the planet appears to drop toward the sunset horizon as it moves between the Sun and Earth.

Venus, obscured by the glare of the Sun all month, reaches superior conjunction on the 31st.

Mars, which rises about two-and-a-half hours before sunup, brightens ever so gradually throughout the month from magnitude 1.2 to 0.9. Even at its brightest this month, it still appears as a small, shimmering disk. On the morning of the 6th, about an hour before sunrise, you'll see Mars shining well above the crescent Moon.

Jupiter, in the constellation Virgo, the virgin, rises an hour after dark at the beginning of March and a few minutes earlier every night thereafter. By month's end, the planet is rising almost at sunset, and becomes as big, bright, and close to Earth as it will be all year.

Saturn is in excellent position for evening viewing: near the top of its daily arc across the sky as twilight ends. Shining at magnitude 0.2, the planet appears with Castor and Pollux, the two brightest stars in the constellation Gemini, the twins. The rings of Saturn are tilted to their maximum extent, twenty-five degrees, for 2005. With a high-power telescope and good atmospheric conditions, you may see the shadow of Saturn on the rings just to the east of the planet's limb.

The Moon wanes to last quarter on the 3rd at 12:36 P.M. and to new on the 10th at 4:10 A.M. Our satellite waxes to first quarter on the 17th at 2:19 P.M. and to full on the 25th at 3:58 P.M. Early on the morning of the 3rd the Moon appears to occult, or hide, the bright ruddy star Antares above North America. For Easterners the event takes place during bright twilight or after sunrise, but the sight could be spectacular over central and western regions.

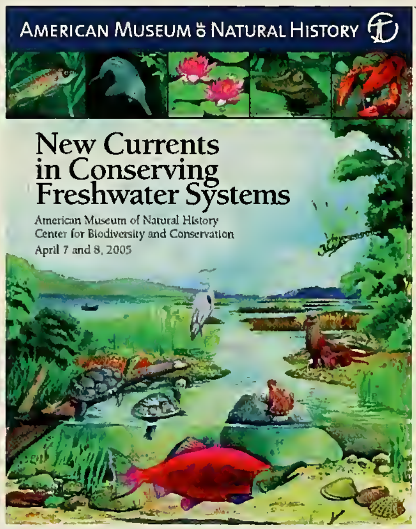
The vernal equinox takes place at 7:33 A.M. on the 20th. Spring begins in the Northern Hemisphere; autumn begins in the Southern.

All times are eastern standard times.

The Center for Biodiversity and Conservation's Tenth Annual Spring Symposium

Freshwater systems—lakes and ponds, rivers and streams, reservoirs, wetlands, and groundwater—are essential for our survival. In addition to providing goods and services such as drinking water, energy, recreation, food, and nutrient cycling, freshwater systems support an immense variety of life. Despite their importance and decades of protection efforts, freshwater species and habitats are being lost or degraded at an alarming rate. Increased demand from industry and agriculture, introduced species (for example, the now-ubiquitous zebra mussel), and ongoing alteration in the form of dams and canals are primary causes. There is an urgent need for the development and application of innovative approaches to freshwater conservation and for the sharing of success stories.

On April 7 and 8, 2005, the Museum's Center for Biodiversity and Conservation will host a forum for scientists and conservation practitioners to showcase recent successful initiatives in freshwater conservation and to discuss how and where cutting-edge ideas and tools can be implemented. The symposium will examine projects that not only integrate scientific fields, but also link science with other disciplines. Talks will highlight innovative methods used by local communities to manage their freshwater resources, the use of economic valuation to support conservation efforts, and the importance of science-based policy and trade initiatives. This cross-disciplinary integration will generate a fertile environment for discussing the future of freshwater conservation. Promising new tools and approaches will be explored, including advances in remote sensing, the application of molecular research, the use of underwater videography, alternative futures analyses, and environmental flow methods.



JAMES LUI

New Currents in Conserving Freshwater Systems
Thursday and Friday,
April 7 and 8
8:30 a.m.–6:00 p.m.
Kaufmann Theater
$150 ($125 Members,
senior citizens; $50 students)
Special early-registration
pricing available until March 18

International participation is expected, with speakers from Asia, Australia, Africa, Europe, and North and South America presenting their work on rivers, lakes, wetlands, and subterranean systems. Each expert will highlight lessons learned from their projects, emphasizing those findings that can transfer to different regions and habitats. Among the three hundred or more speakers, poster presenters, and attendees will be representatives from nonprofit, government, development, and research sectors, among others.

The two-day symposium will be divided into four main sessions, beginning with a focus on innovations in understanding freshwater systems—their species, habitats, and processes, as well as what threatens them. The symposium's two keynote addresses, scheduled during the first day's presentations, will be delivered by the U.S. Fish and Wildlife Service's Assistant Director for Fisheries and Habitat Conservation, Dr. Mamie Parker, and the Museum's Axelrod Research Curator of Ichthyology, Dr. Melanie Stiassny. The second session will highlight new methods of planning for conservation. This will be followed by a discussion of effective ways of putting conservation plans into practice. The closing session will explore innovations in evaluating and monitoring outcomes. The symposium will conclude with a synthesis, identifying important commonalities among the case studies and lessons that might be applied broadly.

New Currents is geared toward a professional audience, and interested members of the public are encouraged to attend. For more information and to register please go to http://cbc.amnh.org/symposia/freshwater/index.html.

New Currents in Conserving Freshwater Systems is sponsored by the Center for Biodiversity and Conservation in collaboration with the World Wildlife Fund, the U.S. Fish and Wildlife Service, and the National Park Service. Funding is provided by Daniel and Sheryl Tishman and by the National Oceanic and Atmospheric Administration. Additional support is provided by The Conservation Trust of the National Geographic Society, the American Society of Ichthyologists and Herpetologists, The Nature Conservancy, and the American Fisheries Society.

2005 Isaac Asimov Memorial Debate

The Enigma of Alien Solar Systems
Wednesday, March 30
7:30 p.m.
LeFrak Theater
$14 ($12 Members)

Before planets around stars other than our Sun were first discovered nearly a decade ago, many scientists expected alien solar systems to resemble our own, with small rocky planets close to their stars and large gaseous planets farther away. But what we've found instead are predominately Jupiter-sized or larger planets as close to their host stars, or closer, as tiny Mercury is from our Sun. These systems force us to question whether our own solar system is the rule or the exception.

Join Neil deGrasse Tyson, Frederick P. Rose Director of the Hayden Planetarium, and this panel of experts in planetary science as they discuss why our solar system looks the way it does and why others we've detected look so different.

Fritz Benedict, University of Texas, longtime observer of planetary systems
Paul Butler, Carnegie Institution of Washington, codiscoverer of more than two-thirds all known exoplanets
Peter Goldreich, California Institute of Technology, theorist with expertise on the formation of planets, asteroids, and comets
Scott Tremaine, Princeton University, expert on the gravitational interactions between a star and its planets
Margaret Turnbull, Carnegie Institution of Washington, planet hunter and expert on habitable zones around stars

The late Dr. Isaac Asimov, one of the most prolific and influential authors of our time, was a dear friend and supporter of the American Museum of Natural History. In his memory, the Hayden Planetarium is honored to host the annual Isaac Asimov Memorial Debate—a panel series, generously endowed by relatives, friends, and admirers of Isaac Asimov and his work. The Isaac Asimov Memorial Panel series brings the finest minds in the world to the Museum each year to debate pressing questions on the frontier of scientific discovery. Proceeds from ticket sales of the Isaac Asimov Memorial Debates benefit the scientific and educational programs of the Hayden Planetarium.

R. MICKENS/AMNH

The first direct evidence that some primitive mammals fed on dinosaurs is shown here. The fossil of a 130-million-year-old opossum-sized mammal, *Repenomamus robustus,* with a juvenile psittacosaur preserved in its stomach area was unveiled at the American Museum of Natural History on January 12, 2005. The remarkable finding was described in the journal *Nature* by Meng Jin, Associate Curator, Division of Paleontology; his graduate student Hu Yaoming; and colleagues at the Institute of Vertebrate Paleontology and Paleoanthropology in Beijing. Exciting new findings such as this are among the topics of the upcoming exhibition, *Dinosaurs: Ancient Fossils, New Discoveries,* opening May 14, 2005. Also, visit www.amnh.org to learn about the public display of *R. robustus.*

R. MICKENS/AMNH

Living in America, the Museum's annual series of weekend programs that focuses each January on a different cultural group in the U.S., this year highlighted Native Americans of the Northeast. Here, the Mohawk Singers and Dancers perform in their colorful traditional regalia.

Museum Events

AMERICAN MUSEUM ō NATURAL HISTORY

www.amnh.org

R. MICKENS/AMNH

Brown bear dish. Artist unknown (Tlingit). Mid-1800s. AMNH collection.

C. CHESEK/AMNH

Katsinas dolls. Ernest Moore, Jr. (Hopi). 2001. AMNH collection.

EXHIBITIONS

Totems to Turquoise: Native North American Jewelry Arts of the Northwest and Southwest
Through July 10, 2005
This groundbreaking exhibition celebrates the beauty, power, and symbolism of the magnificent tradition of Native American arts, examining techniques, materials, and styles that have evolved over the past century as Native American jewelers have transformed their traditional craft into vital forms of cultural and artistic expression.

The Butterfly Conservatory: Tropical Butterflies Alive in Winter
Through May 30, 2005
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.

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 deep southern bayous to northern tundras.

Exploring Bolivia's Biodiversity
Through August 8, 2005
These lush photographs of Bolivia take viewers on a journey through the mountain landscapes of the Andes to the dense lowland tropical forests of the Amazon and the dry forests of the Chaco. Informative captions are in English and Spanish.

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

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.

GLOBAL WEEKENDS

SPRING EQUINOX FESTIVAL
Sunday, March 20

Science of the Sun
11:00 a.m.–1:30 p.m.
Explore the Sun's energy on the Ross Terrace.

Paper from Scratch
12:00 noon–1:30 p.m. (Ages 4–6, each child with one adult)
1:30–2:30 p.m. (Ages 6–8)
3:00–4:00 p.m. (Ages 8–10)
Learn how to make beautiful recycled paper.

Eggceptional Art
12:00 noon–1:30 pm. (Ages 6–8, each child with one adult)
2:30–4:00 p.m. (Ages 8–10)
Learn about the mythology of spring eggs across cultures, and decorate your own delicate creations.

City That Drinks the Mountain Sky
2:30–3:30 p.m.
Arm-of-the-Sea Theater tells the epic story of NYC's water supply through poetry, puppetry, and music.

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

LECTURES

400 Million Years on Six Legs
Tuesday, 3/1, 7:00–8:30 p.m.
David A. Grimaldi, Division of Invertebrate Zoology, on major events in insect evolution.

An Evening with Roger Rosenblatt: "The Narrative Species"
Thursday, 3/10, 7:00–8:30 p.m.
One of America's finest writers discusses the power, sanctity, and mystery of writing and storytelling in human experience.

Diamond Discoveries in Canada: New Frontiers in the Arctic
Thursday, 3/24, 7:00–9:00 p.m.
This panel discussion will explore the geology and human impact of recent diamond discoveries in Canada. Moderated by George Harlow, Division of Physical Sciences. Cosponsored by the Canadian Consulate General.

Obsessive Genius: The Inner World of Marie Curie
Thursday, 3/24, 7:00 p.m.
Barbara Goldsmith offers a fresh look at the life of this famous woman, a scientist, wife, and mother.

FAMILY AND CHILDREN'S PROGRAMS

Space Explorers: Myths and Constellations of the Spring Sky
Tuesday, 3/8, 4:30 p.m.
(Ages 8 and up)
On the second Tuesday of each month, kids (and their parents) can learn under the stars of the Hayden Planetarium.

ID Day
Saturday, 3/12, 1:00–4:00 p.m.
Museum scientists will attempt to identify treasured items and mysterious finds you bring from home.

Southwest Jewelry Arts
Sunday, 3/13, 11:00 a.m.–12:00 noon (Ages 6 and 7, each child with one adult)
Use traditional Native American techniques and materials to create your own jewelry.

Wild, Wild World: Predators
Saturday, 3/26, 12:00 noon–1:00 p.m. and 2:00–3:00 p.m.
Live-animal presentation with a golden eagle, alligator, python, and cougar cub.

Dr. Nebula's Laboratory: Light and Optics
Saturday, 3/12, 2:00–3:00 p.m.
(For families with children ages 4 and up)
Dr. Nebula's apprentice Scooter exposes the mystery of light and its colors.

HAYDEN PLANETARIUM PROGRAMS

TUESDAYS IN THE DOME

Virtual Universe
Messier Tour
Tuesday, 3/1, 6:30–7:30 p.m.

This Just In...
March's Hot Topics
Tuesday, 3/15, 6:30–7:30 p.m.

Celestial Highlights
The Lion King of the Sky
Tuesday, 3/22, 6:30–7:30 p.m.

COURSE

How Do I Picture This? Astrophotography
Four Wednesdays, 3/2–3/23, 6:30–8:30 p.m.

LECTURE

Parallel Worlds
Monday, 3/7, 7:30 p.m.

PLANETARIUM SHOWS

SonicVision
Fridays and Saturdays, 7:30, 8:30, and 9:30 p.m.
Hypnotic visuals and rhythms take viewers on a 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?
Narrated by Harrison Ford

Made possible through the generous support of Swiss Re.

Passport to the Universe
Narrated by Tom Hanks

STARRY NIGHTS
Live Jazz

ROSE CENTER FOR EARTH AND SPACE

Friday, March 4
6:00 and 7:30 p.m.

Starry Nights is made possible by Lead Sponsor Verizon and Associate Sponsor Constellation NewEnergy.

Spend $10 or more at the Planetarium Shop and get a free Rose Center pennant.

INFORMATION

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

TICKETS AND REGISTRATION

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

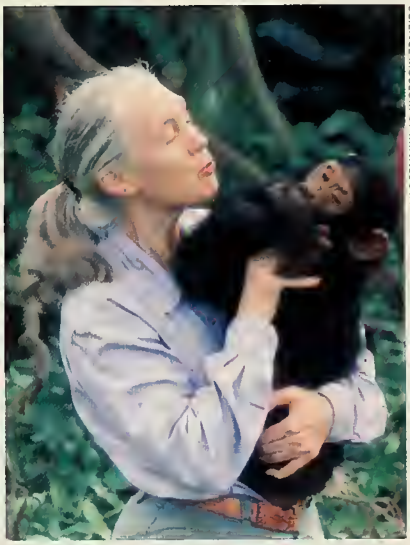
AMNH eNotes delivers the latest information on Museum programs and events to you monthly via email. Visit www.amnh.org to sign up today!

LARGE-FORMAT FILMS

LeFrak Theater

Vikings
Discover the historical and technological achievements of this legendary society of seafaring explorers.

Jane Goodall's Wild Chimpanzees
This breathtaking film takes visitors into the realm of our closest animal relatives.


SCIENCE MUSEUM OF MINNESOTA

Jane Goodall with orphaned chimpanzee ©Science Museum of Minnesota.jpg

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- Invitations to Members-only special events, parties, and exhibition previews

For further information, call 212-769-5606 or visit www.amnh.org/join.

Drama at My Feet

By Don Dailey

On a backpacking trip in the Sierra Nevada some years ago, I was sitting in quiet contemplation at my campsite beside a small alpine lake, when I became aware of a flurry of activity going on around me. Narrowing my senses to ground level, I was drawn into a bustling world of miniature creatures. As I watched, several kinds of ants crossed my view, followed by a tiny red mite, a sizable wolf spider, and two colorful jumping spiders. At least three species of fly landed in plain sight, "tasting" the landscape with their feet. A grasshopper materialized, then several hornets, two shiny black wasps, a drab brown damselfly, and a large azure-blue dragonfly.

Already engrossed in the passing scene, I saw something that was to capture my rapt attention for hours to come. In a shallow depression of granite, I noticed what appeared to be a large black insect. Moving closer, I saw the "insect" was really two large carpenter ants. These giants of the ant family, each at least three-quarters of an inch long, were tightly locked together, jaw-to-jaw, and fiercely immobile except for an occasional twitching leg. Apparently of different species—one was totally black and the other had a black body but maroon legs—the two had been left behind, I surmised, from a major military engagement somewhere close by, an operation probably involving entire tribes of their kind. Once joined in mortal struggle, were they unable, or unwilling, to disengage?

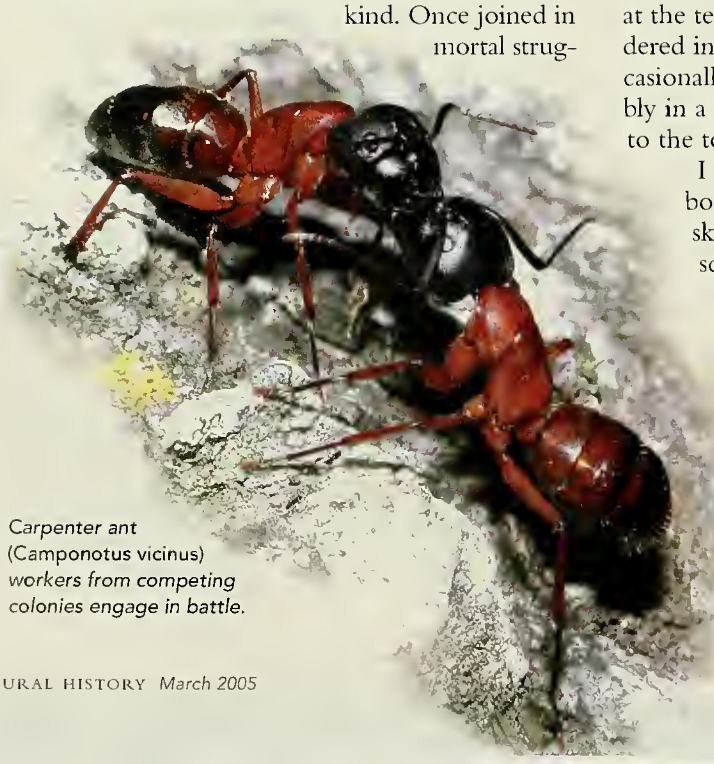
Then I made a grisly discovery: neither ant possessed a complete set of legs. Even more appalling, the severed head of another ant was clamped, by its jaws, in a death-grip to one antenna of the all-black ant. I imagined the epic battle that must have taken place, fought with a ferocity I had only read about as a boy. The two ants remained locked together for nearly two hours, and though I was tempted to poke the gladiators into a more animated contest, I decided not to interfere. I felt privileged to be witnessing such an awesome display of resolve. It seemed that fighting, even to the death, was what eons of evolution had programmed them to do.

Suddenly a much smaller ant appeared. The intruder took a few moments to size up the situation before approaching the all-black ant, grabbing it by the antenna to which the severed head was attached, and dragging it into a nearby bush. Resistance proved futile. The hapless, nearly legless victim was unable to get a firm grip on the rock, and the smaller ant had no trouble hauling the larger ant away.

I returned my attention to the remaining combatant. It had taken a terrible beating. Only one of its antennae was complete, and of its former complement of six legs, only two remained fully intact—one leg was missing, two had been reduced to short stubs, and the last was bent ninety degrees at the terminal joint. Reduced to a crawl, it wandered in circles, unable to set a straight course. Occasionally it threw back its head, jaws agape, possibly in a gesture of frustration, or perhaps in reaction to the torment it must surely have been suffering.

I watched the ant for two hours more, spellbound by its heroic struggle. Eventually the sky began to darken, and I had to leave the scene to prepare my evening meal.

When I came back to my spot a short time later, the ant was gone. The finale of another of life's countless dramas had been enacted, and my minuscule warrior had blended back into its world, one small dimension of this beautiful and peaceful place in the mountains.



Carpenter ant (Camponotus vicinus) workers from competing colonies engage in battle.

Don Dailey is a retired science teacher living in Quincy, California.

Because I can read,

I can understand. I can write a letter.
I can fill out a job application.
I can finally get off welfare.

Because I can read,

I can learn. I can help my daughter
with her homework.
I can inspire her to be better.
I can be a role model.

Because I can read,

I can succeed, I can
contribute. I can live
my life without fear,
without shame.
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