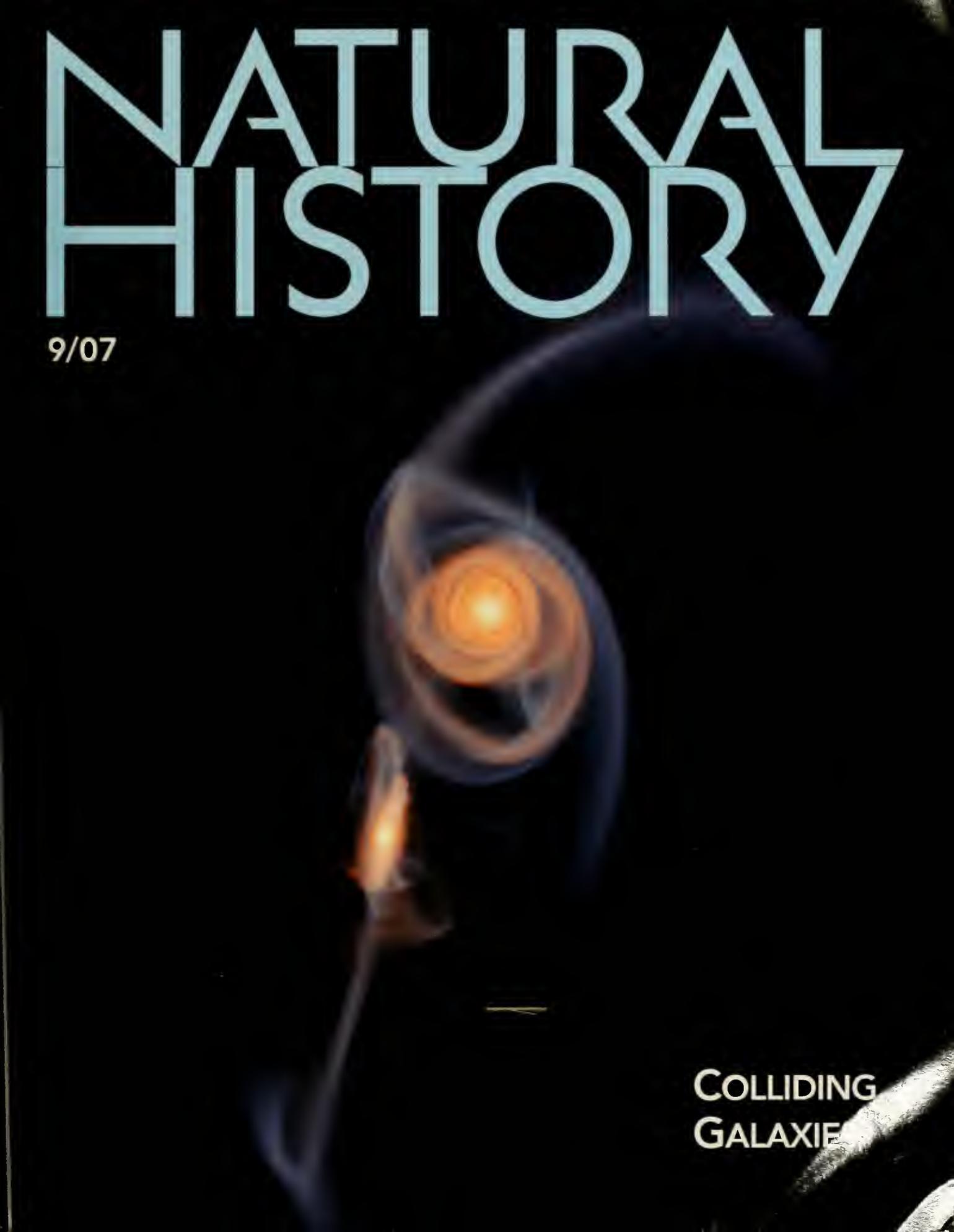


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SEPTEMBER 2007

VOLUME 116

NUMBER 7



32

FEATURES



18 DARK MATTER

Most of the stuff of the universe is invisible and rarely interacts with "ordinary" matter. Experimenters are racing to answer the question, What is it made of?

DONALD GOLDSMITH



24 ALTRUISM AMONG AMOEBAS

How can evolution explain the self-sacrificing behavior of nonhuman organisms whose genes are "selfish"?

JOAN E. STRASSMANN AND
DAVID C. QUELLER

DEPARTMENTS

2 THE NATURAL MOMENT

Over Easy

Photograph by Peter Blackwell

6 UP FRONT

Editor's Notebook

8 CONTRIBUTORS

10 LETTERS

12 SAMPLINGS

News from Nature

32 THIS LAND

Rendezvous at Red Rock

Robert H. Mohlenbrock

34 REVIEW

Literary Gould

Laurence A. Marshall

35 nature.net

That Gnawing Feeling

Robert Anderson

COVER STORY

38 OUT THERE

Surprise Package

Charles Liu

44 AT THE MUSEUM

48 THE SKY IN SEPTEMBER

Joe Rao

ON THE COVER: Computer simulation of collision between our Milky Way galaxy (lower left) and Andromeda galaxy (center), billions of years in the future (image by John J. Dubinski)

PICTURE CREDITS: Page 8

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32



2



34





THE NATURAL MOMENT

Over Easy

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THE NATURAL MOMENT

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Not many mothers would interrupt an afternoon nap and leave behind their six-week-old youngsters to seek out a thundering herd of wildebeests. But for this lioness in Kenya's Masai Mara National Reserve late one September afternoon, such a stampede was worth it. Peter Blackwell, who had been photographing the dozing feline family, trailed behind her.



Only a few hundred feet away from her cubs, the lioness came across an ostrich nest in the dirt, and promptly caused another female to ditch the young in her care. The ostrich on incubation duty wasn't prepared to fight for the nests' eggs, for several reasons. Only one ostrich egg in ten actually hatches—even in the absence of marauders. The few chicks that do emerge stand a good chance of being pilfered by other ostrich parents seeking to enlarge their broods. Finally, some of the eggs probably didn't even belong to the runaway ostrich: typically, several females lay their eggs in a single nest, scraped out by a male.

So with nothing but the eggs' size (six by five inches) and thickness (one-eighth inch) to slow her down, the lioness pincicked away. Blackwell watched her gorge on "many good eggs, but also several bad eggs, which exploded when she clamped down on them, leaving a rather disgusting smell." Unfazed and energized, the lioness resumed the wildebeest chase and made a successful kill.

—Erin Espelie

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UP FRONT

New Light on Dark Matter

You would think the first confirmed existence of vast amounts of dark matter in the universe would have been a big embarrassment for astrophysicists, the people who brought you the Milky Way, “island universes” of distant galaxies, and galactic superclusters. With all their attention to such luminous stuff, it turned out they were focusing on only a small fraction of what’s really out there. Still, there seemed little reason for astrophysicists to apologize for their ignorance: matter might be dark simply because it was too far away to see—just as a lot of stray rock in the solar system would be undetectable from the nearest star. And all the early evidence for the “missing mass” of the universe came from observations of incredibly distant objects: galaxies millions of light-years from Earth, clusters of galaxies a thousand times that far away.

But as Donald Goldsmith tells the story (“Dark Matter,” page 18), the real mystery emerged when cosmologists realized that dark matter is much darker, both observationally and metaphorically, than anyone had suspected. The success of big bang cosmology made it possible to calculate the abundances of the various atomic nuclei that formed in the first half hour after the primordial explosion that gave rise to everything. When protons and neutrons condensed out of a quark soup as the universe expanded, the strong nuclear force mediated their interactions, creating the earliest nuclei of hydrogen, helium, and a small smattering of heavier elements. Taking into account the primordial densities, the billion-degree temperatures, the strength of the nuclear force, and the expansion rate of the early universe, cosmologists came to the startling conclusion that most of the matter created in the big bang was not the stuff the things we know are made of, the ordinary matter built up out of the primary constituents of ordinary atoms. Instead, the dominant matter was “extra-ordinary,” and it was surely most of what later became known as “dark.”

• • •

That realization set the stage for a race that’s on today in the particle-physics community to learn the true identity of dark matter. The prize to the winner, aside from recognition by the administrators of Alfred Nobel’s estate, will be to become known as the discoverer of a universe even grander than the one we know. Experimental physicists at CERN, the European Center for Particle Physics just outside Geneva, expect to put the world’s most powerful particle accelerator into operation next year. If the CERN physicists confirm so-called supersymmetry, one of the leading theories of elementary particles (as many expect will happen), they will have the first evidence that the dark matter, so far detected only in distant galaxies, may actually be all around us. Millions of particles, each perhaps hundreds of times heavier than the proton, could be passing through our bodies—harmlessly, it should be emphasized—every second.

Before the great machine at CERN can turn on and rev up, there is still hope among experimenters working with smaller and simpler apparatuses that the glory of discovery could be theirs. They, too, are looking for a signal, a minivibration in a crystal or a microspike in the temperature of an inert gas, that would tell us all that dark matter—like a ghost from a parallel universe—is present here on Earth. The next few months will be an exciting time for the dark-matter sleuths.

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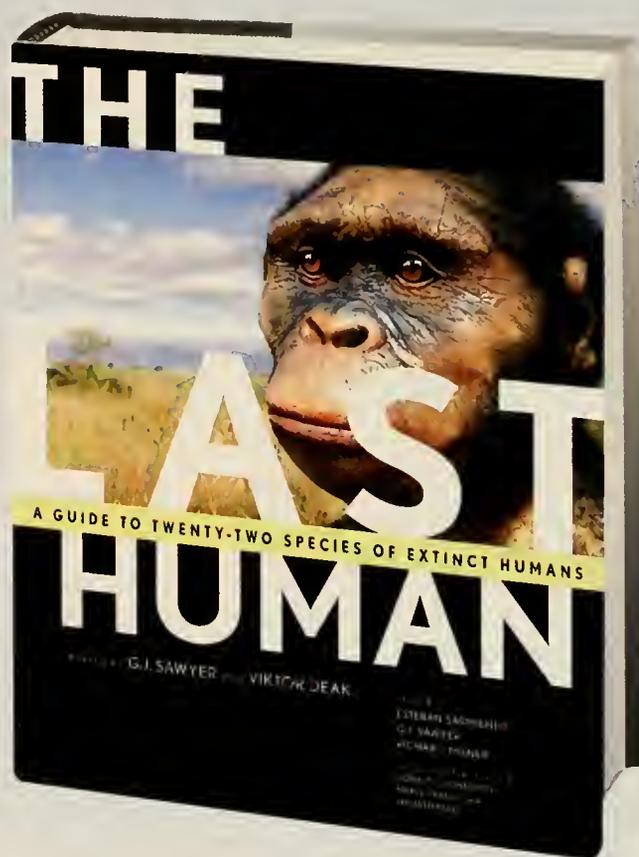
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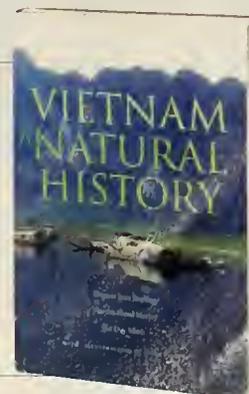
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CONTRIBUTORS

PETER BLACKWELL (“The Natural Moment,” page 2) knows Masai Mara Reserve (MMR) and its inhabitants well. He was born in Kenya, grew up on a farm in the country’s northern bushland, and spent many years as the resident naturalist at Siana Springs Tented Camp in the MMR. He has lent his expertise to a variety of international visitors, including the film crews for the BBC/Discovery Channel productions of *Big Cat Diary*, filmed twice a year since 1996. His own photographic work has been featured in several publications and has won awards in the United Kingdom and South Africa, but most often it serves as reference material for his paintings. Blackwell began attracting attention with his watercolors of African birds; now he works in many mediums, and chooses his subjects from a variety of wildlife in the African bush. Visit www.natureartists.com/peter_blackwell.asp to view some of his artwork.



DONALD GOLDSMITH (“Dark Matter,” page 18) is a frequent contributor to *Natural History*. Trained both as a research astronomer and as an attorney, he devoted himself to popularizing astronomy more thirty years ago. In the ensuing years he has watched the dark-matter hypothesis develop from speculation to confirmation. Goldsmith has written or co-written more than twenty books, including *Connecting with the Cosmos* (Sourcebooks, 2002) and, with Neil deGrasse Tyson, *Origins: Fourteen Billion Years of Cosmic Evolution* (Norton, 2004), which was the companion book to the PBS NOVA series. Among his recent contributions to *Natural History* are “Turn, Turn, Turn” (December 2006/January 2007) and “Ice Cycles” (March 2007), both of which explain how the slow but periodic wobbles in Earth’s journey through space may influence climate change. He lives in Berkeley, California.



JOAN E. STRASSMANN and **DAVID C. QUELLER**, a wife-and-husband team (“Altruism among Amoebas,” page 24), focus their work on the evolution of altruism, cooperation, and the control of “cheating” (selfish) behavior. They point out that those issues lie at the heart of some of the most important transitions in evolution: the emergence of chromosomes, cells, eukaryotic (nucleated) cells, and multicellular organisms. After devoting twenty-five years to studying the behavior of social wasps—conducted in Tuscany with colleagues from the University of Florence—they have shifted most of the focus of their work to the study of microscopic social amoebas of the genus *Dictyostelium*, which they track through the soils of North America. The amoebas serve well as model organisms because they offer the right combination of sociality, short lifespan, and well-understood genetic features. Both Strassmann and Queller are Harry C. and Olga K. Wiess professors of ecology and evolutionary biology at Rice University in Houston, Texas, and both have held John Simon Guggenheim Fellowships.



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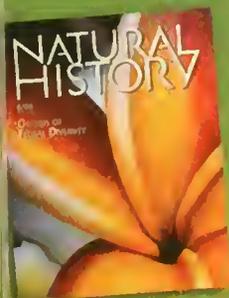
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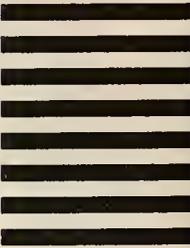
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LETTERS

Evolution on Trial

I congratulate Richard Milner for his review article ["Darwin in Court," 6/07]. As it happens, Randy Olson's film *Flock of Dodos*, which Mr. Milner discusses, was screened at "Evolution 2006," a meeting of evolutionary biologists held last year at Stony Brook University. Our audience did not need the cheerful determination of the creationists in the film to remind us of the threat they pose. Evolutionary biologists need to communicate the undeniable fact of evolution to the public. Creationism is not just a threat to a few intellectuals; it is the cutting edge of a broad attack on science

that endangers America's security, public health, prosperity, and liberty.
Michael A. Bell
Stony Brook University
Stony Brook, New York

I thoroughly enjoyed Richard Milner's article. I am a home educator and a Bible-believing Christian who holds to the Creation model. I find it very sad that the only educational setting that allows my children the freedom to examine both sides of the creation-evolution issue is home school. As a public school student in the 1970s and 1980s, I was never taught that evolution is theory, not fact. I also know people who grew up

in homes where questioning the Bible was never allowed. Both circumstances are deplorable. Challenging children to a debate sparks interest, creativity, observation, experimentation, and logical thinking.
Joelle White
Des Moines, Washington

RICHARD MILNER REPLIES: When I perform my own show, "Darwin Live," I often feel as if I'm preaching to the choir; the program at Stony Brook that Michael A. Bell describes was likely a similar tribal gathering of evolution supporters. As he suggests, the challenge is to reach out to those who are convinced that evolutionary studies promote moral

and social chaos, and attempt to convince them that, as Darwin famously stated, "there is grandeur in this view of life."

I appreciate Joelle White's willingness to explore these issues. If one is interested in teaching critical thinking, however, one shouldn't promote a false debate, which results when "intelligent design" is treated as science. The how, why, and wherefore of evolution are what scientists debate, not whether it is opposed to another "model" called creationism (Christian or otherwise).

I want to correct an error that crept into my text: William Paley, famous for the watchmaker anal-



ogy, lived from 1743 until 1805, and thus was not a "seventeenth-century" theologian.

Pregnant Response

In his article "Pregnancy Reconceived" [5/07], Gil Mor did not mention the extreme fatigue most women feel during the first trimester of pregnancy. That would seem to add further support for the inflammation hypothesis; the fatigue of early pregnancy appears very similar to that caused by severe influenza or by interferon treatment. Is there a measurable increase in interferon secretion during pregnancy?

Also, Dr. Mor did not

mention the trigger for the inflammatory process during the third trimester. What is the hypothesis about that?

*Nurit Patt, M.D.
Albuquerque, New Mexico*

GIL MOR REPLIES: For space and simplicity, the description omitted many symptoms, such as fatigue. At the implantation site there is an increase in the expression of interferon-gamma, which could enter the mother's circulation and, along with other cytokines, give rise to the symptoms described. The implantation site resembles an open wound, and inflammation is necessary to repair it.

We hypothesize that

in the third trimester the increasing cell death in the "aging" placenta may trigger the inflammatory response. But we have little relevant information about that stage of pregnancy.

Runs with Elephants

Adam Summers reports that the top speed of a running elephant is fifteen miles an hour, "no faster than a reasonably fit person could run in terror" ["A Spring in Its Step," 5/07]. I have a number of running friends who are considered "reasonably fit," and none of them could come close to running a four-minute-mile pace (fifteen miles an hour). I plan to keep my distance should I encounter

an elephant in the wild.
*Pamela Maher
La Jolla, California*

ADAM SUMMERS REPLIES: People can sprint for cover far faster than they can run a mile. Nearly all of us could have caught Roger Bannister as he ran by on his way to the first four-minute mile; keeping up is the hard bit.

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SAMPLINGS

Poor Bird, Rich Bird

Big gaps between rich and poor put species at risk, according to a new report that provides a subtle view of how wealth correlates with biodiversity.

Gregory Mikkelson of McGill University and his colleagues compared local biodiversity with the distribution of wealth in forty-five countries, as well as in forty-five U.S. states. To rank biodiversity worldwide, Mikkelson counted the number of plant and vertebrate species threatened with extinction; to measure biodiversity by state, he determined the fraction of each state's resident bird species that have suffered statistically significant

population declines during the past forty years. Economic equality was encapsulated in the "Gini ratio" of a country or state (a low Gini ratio signals a relatively equal distribution of wealth).

Mikkelson's group discovered a significant correlation between equality and biodiversity both around the world and across the forty-five U.S. states. Where wealth is inequitably distributed, biodiversity suffers; where wealth is more evenly distributed, the natural environment benefits. It seems that a society that cares for its struggling human members also cares for its wildlife.

(*PLoS ONE*) —Nick Atkinson



Chile con Pollo

When the Spanish conquistador Francisco Pizarro arrived in what is now Peru in 1532, he found chickens already integrated into the local culture. But his observations of their presence sparked an academic controversy centuries later about how the chickens got there. Most historians think they arrived in the New World with Europeans around 1500,

but new evidence suggests an altogether different origin.

Alice Storey and Elizabeth Matisoo-Smith of the University of Auckland, along with their collaborators, radiocarbon-dated a chicken bone found among others several years ago at a Chilean archaeological site and analyzed its mitochondrial DNA. The site, El Arenal 1, lies on Chile's western seaboard and predates Co-



Motion of air around a flying bat is depicted by a computer-generated field of arrows.

Flip-Flop Flap

Given our human fascination with flight, it's no wonder that birds and their aerodynamics have been studied in great detail. Not so, however, the bat. And the mechanics of bat flight is at least as different from the mechanics of bird flight as . . . a bat is from a bird.

On the downstroke of a bird's wing during slow flight, for instance, the primary feathers form a solid plane that pushes downward and backward on the air, propelling the bird upward and forward. On the upstroke, the primaries separate, and much of the air that would push the bird back down rushes through the gaps instead. The wing of a bat, however, is a membrane that offers continuous resistance. What happens during its upstroke?

Anders Hedenström of Lund University in Sweden and his colleagues studied vortices in the wake of the Pallas's long-tongued bat, *Glossophaga soricina*, in the fog-filled air of a wind tunnel. At slow speeds, they discovered, both the downstroke and the upstroke push the animal up and forward. To move the bat forward and upward during the upstroke, the outer part of the wing flips upside down and flicks quickly backward. (At high speeds, the wing doesn't flip and part of it does push the bat down during the upstroke, but that resistance is at least partly compensated for by continuous lift on the front of the wing at the higher speed.)

Whether the flip-flop is common to all bats or an adaptation special to the ones that hover—such as *G. soricina*, a nectar-eater—remains to be seen. (*Science*) —Stéphan Reeb

lumbus. The bone, dated to the 120-year range between 1304 and 1424, suggests the ancient inhabitants of South America's western coast were probably feasting on roast drumsticks well before the Spaniards arrived.

So how did the chickens get to South America before Columbus? (They are clearly not native; domestic chickens are believed to be descended from

wild birds of the Indian subcontinent.) Storey's DNA analysis identified a genetic sequence in the El Arenal bone identical to one that occurs only in prehistoric chickens unearthed at archaeological sites in Tonga and American Samoa. The finding indicates that early Polynesian explorers likely sailed the Pacific with their favorite food on board. (*PNAS*) —N.A.

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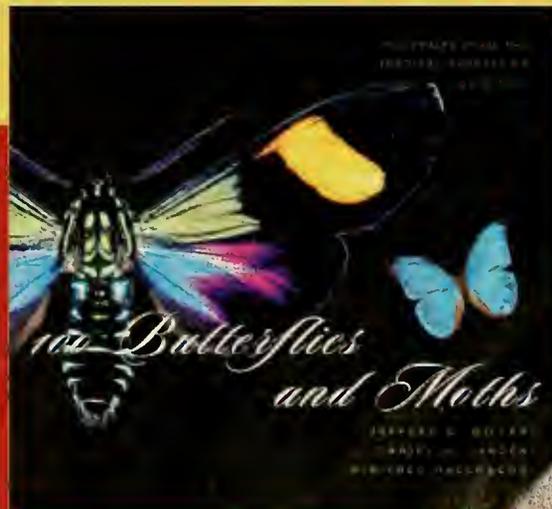
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Russian double burial (artist's depiction)

A Lonely Future

The universe is expanding, and many cosmologists think the expansion will continue forever. Paradoxically, though, a new analysis shows, billions of years from now—if anyone is around to care—the evidence for both the expansion and the big bang will vanish and the universe will appear deceptively static.

Lawrence M. Krauss of Case Western Reserve University and Robert J. Scherrer of Vanderbilt University base their remarkable conclusions in part on Hubble's law, the strongest case for universal expansion. The law summarizes the observation that the greater the distance between Earth and a faraway galaxy, the faster they are moving apart. Krauss and Scherrer calculate that during the next 100 billion years, the expansion will take

galaxies beyond our local cluster so far away that they will be separating from the Milky Way faster than the speed of light. In effect, the more distant galaxies will become invisible—taking with them perhaps the most straightforward evidence for expansion.

What about the cosmic background radiation, a relic of the big bang and another key piece of evidence for universal expansion? Nope, its wavelength will increase beyond detectability as the universe expands. Tongue slightly in cheek, Krauss and Scherrer point out how lucky today's astronomers are to live in an era—admittedly a long one—when evidence of the true nature of the universe is still out there for us to see. (*Journal of Relativity and Gravitation*) —S.R.

Deaths, Foretold

Did Stone Age Europeans practice ritual human sacrifice? The large number of graves holding multiple dead, including some with abnormal skeletons or lavish funerary ornaments, have led Vincenzo Formicola of the University of Pisa to think they might have.

Six of the thirty graves known in Europe from between 28,000 and 23,000 years ago hold more than one skeleton—a higher-than-expected frequency if the deaths were natural. In one Russian grave, two children were buried head-to-head, along with spears and ivory ornaments: pendants, carvings, and some 10,000 beads. The abundance of goods implies either that the children enjoyed the wealth of high class—unlikely in a hunter-gatherer society—or that the goods took so long to craft that the ceremony was planned well in advance. And that suggests the children were sacrificed.

The Russian grave as well as two others—a Moravian triple burial and an Italian double burial—each held one young person with abnormal skeletal development, who would have been noticeably impaired in life. Formicola notes that the burial of such “select” individuals together with physically normal people is consistent with ritual sacrifice. Many scholars contend, however, that less remarkable practices could account for the unusual graves. (*Current Anthropology*) —S.R.

Radiation: It's What's For Dinner

Fungi are well-known for breaking down organic material, not creating it from scratch, as plants do. But a fungus that might break that mold has been discovered thriving at one of the most toxic sites in the world: the defunct Chernobyl nuclear reactor.

The black fungus *Cladosporium sphaerospermum* was collected from the reactor walls by a robot touring the radioactive site, and it caught the attention of Arturo Casadevall of the Albert Einstein College of Medicine. Intrigued by the phenomenon, Casadevall, Ekaterina Dadachova, also of Einstein, and their colleagues exposed colonies of *C. sphaerosper-*



mum and two other species of fungus to extravagantly high levels of radiation in the laboratory. Radiation, they discovered, increases the growth of species that have melanin, the dark pigment that also occurs in human skin. Furthermore, when the investigators irradiated melanin in isolation, they noted dramatic changes in its electronic properties. Melanin seems to capture energy from radiation and convert it to chemical energy, much the way chlorophyll in plants captures the energy of sunlight.

If *C. sphaerospermum* and the numerous other fungi that make melanin are indeed able to “radiosynthesize,” fundamental equations describing the Earth's energy balance might need to be recalculated. (*PLoS ONE*)

—Graciela Flores

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Green for the Green

The European Union's "cap-and-trade" system for regulating carbon dioxide (CO₂) emissions is being hailed as an important first step in addressing global warming. Beginning in 2005, the twenty-five (now twenty-seven) EU countries have each been assigned an annual CO₂ quota, a maximum allowable amount of CO₂ emissions, which the countries then apportion among various large indus-

trial emitters. If one company needs to exceed its allowance, it can buy unused allowances from another. The market for allowances effectively puts a price on CO₂ emissions.

A. Denny Ellerman of M.I.T. coordinated a symposium of papers to examine how well the system—called the Emissions Trading Scheme—is working. In 2005, nineteen of the participating countries released less CO₂ than their

quotas allowed. Overgenerous allowances, now slated for reduction, may account for some of that success. But the high cost of over-emitting probably helped too. In the first year of trading, emissions allowances sold for as much as U.S. \$33 a ton and about \$19 billion in allowances have been traded to date. Furthermore, analysts estimate, under the cap-and-trade system the EU pumped about 4 percent less CO₂ into

the atmosphere than it otherwise would have.

Why do countries adhere to a scheme that forces their industries to pay if they're not green? In Europe, having a green conscience and securing the full economic benefits of EU membership seem incentive enough. The trick will be to make something similar work on a global scale. (*Review of Environmental Economics and Policy*) —S.R.

Heat Waves

Oceanic planetary waves, just an inch or two high at the surface but thousands of feet deep and hundreds of miles apart, sweep slowly but steadily across Earth's oceans: a surfer who caught one in Acapulco would take four years to wash up on a Chinese beach. The waves are speeding up, though, thanks to global warming, and as they do, they could affect weather patterns around the world.

The waves are constantly generated by surface winds and pushed westward by the Earth's eastward rotation. They advance by between four and ten inches a second in the tropics, more slowly toward the poles. But that's about 10 percent faster than oceanic planetary waves traveled at the start of the Industrial Revolution 200 years ago, according to John C. Fyfe and Oleg A. Saenko, both at the Canadian Centre for Climate Modelling and Analysis in Victoria, British Columbia. What's causing the speedup? Global climate models point to the temperature increase in the upper ocean—a consequence of increased atmospheric carbon dioxide. By 2100, the investigators add, if carbon dioxide levels rise as predicted, the waves will travel 35 percent faster than they did in preindustrial times.

Oceanic planetary waves affect ocean currents, which strongly influence continental weather and climate. As the waves speed up, Fyfe and Saenko forecast big changes that may include more frequent El Niño events and heat waves across western North America and Europe. (*Geophysical Research Letters*) —Harvey Leifert

A surfer catching one of the waves in Acapulco would take four years to wash up on a Chinese beach.

No Place to Hide

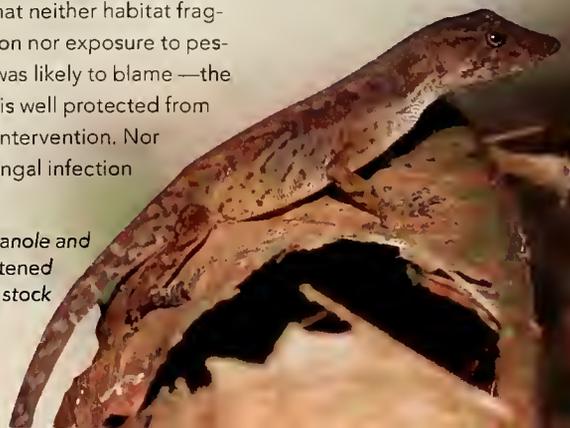
No ecosystem, it seems, is immune to the effects of climate change. Take La Selva Biological Station, an old-growth forest reserve in the lowlands of Costa Rica. Night temperatures there have risen, an effect of global warming, and the annual number of dry days has dropped by half since 1970. In the same period the abundance of frogs, salamanders, and lizards has plummeted by 75 percent.

Coincidence? Steven M. Whitfield and his graduate advisor Maureen A. Donnelly of Florida International University don't think so. As they and a team of colleagues documented the animals' decline, they found that neither habitat fragmentation nor exposure to pesticides was likely to blame—the reserve is well protected from human intervention. Nor was a fungal infection

that has decimated frog species in mountain areas: at La Selva there is no sign of the disease, and reptiles are impervious to it anyway.

Whitfield and Donnelly suspect that the increasingly warm and wet weather has resulted in fewer leaves falling and has hastened the decomposition of leaf litter on the ground. That litter is what the frogs, salamanders, and lizards call home, and so those two effects would lead to a shortage of real estate. Moreover, because the drastic population decline has happened gradually, it may be going on unnoticed elsewhere in the tropics. (*PNAS*) —S.R.

Ground anole and its threatened housing stock



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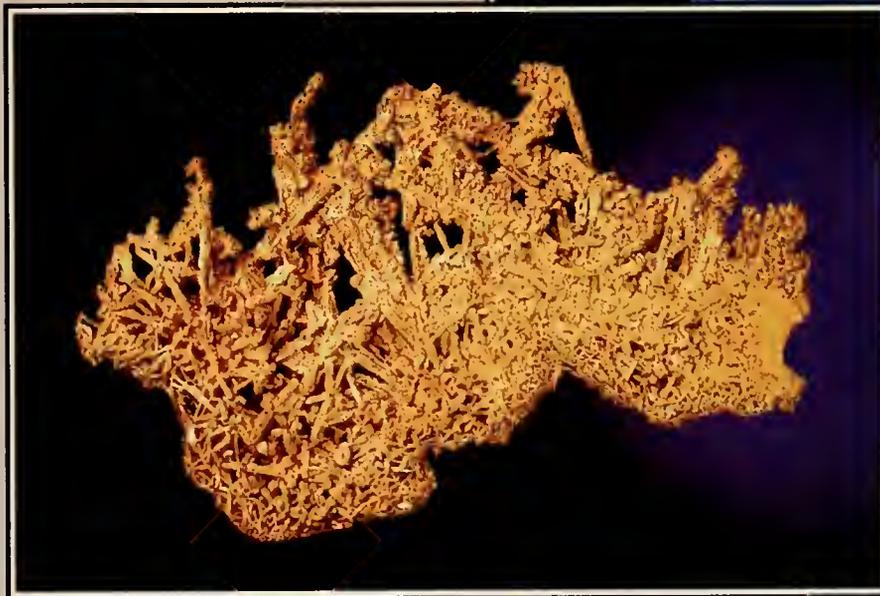
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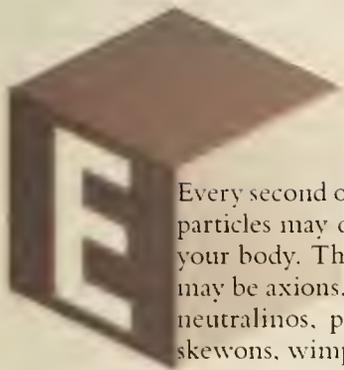
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DARK MATTER

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OF "ORDINARY" PARTICLES.
EXPERIMENTERS ARE RACING
TO ANSWER THE QUESTION,
WHAT IS IT MADE OF?

By DONALD GOLDSMITH



Every second of every day, millions of dark-matter particles may course through every cubic inch of your body. The particles may be WIMPs, or they may be axions. They may be higgsinos, majorons, neutralinos, photinos, pyrgons, quark nuggets, skewons, wimpzillas, or zinos. If you choose, you can ignore these whimsically named creatures of the cosmos, just as they ignore you: they steadfastly refuse to interact with any of the particles that form you. Then again, maybe these strange particles don't exist at all.

Astronomers readily admit that they don't know what dark matter is—just that it dominates the universe. You might conclude that this predicament has plunged astronomers into a pit of professional confusion, from which they are trying to escape by creating a virtual cosmos out of hypothetical matter. And you'd be partly right. But astronomers have also gained remarkably firm knowledge of dark matter, hard as that seems to square with the continuing obscurity of its identity.

First and foremost, dark matter—matter that emits neither light nor any other detectable form of radiation—is real, notwithstanding the struggles of a small minority of physicists to explain it away. It was created immediately after the big bang, 14 billion years ago, and has persisted ever since, forming the bulk of all the matter in the cosmos. In spite of its mysteries, dark matter is detectable through a web of observations that complement and support one another. In fact, American and European physicists are racing to catch its invisible particles in new, ever improving detectors. What excites them is the sense that they are closing in on the answer to one of the great cosmic riddles: What is most of the universe made of?

What makes astronomers so sure that dark matter exists? The answer is gravity. All matter, including invisible matter, exerts gravitational forces on the matter we can see.

Fritz Zwicky, the prickly Bulgarian-Swiss-American astronomer who was the first to conclude that dark matter must exist, introduced the concept in 1933. By applying Newton's laws and measuring the speeds of individual galaxies within a cluster of galaxies, Zwicky could deduce the mass of the cluster. He also determined the amount of visible matter in the clusters by measuring the brightness of the galaxies that form them. Those two measurements showed that a typical giant cluster of galaxies comprises at least ten times more invisible matter than what is visible. Later observations would rule out the possibility that the invisible matter is all made up of diffuse gas floating among the galaxies. Such intergalactic gas does exist, but in nothing remotely like the quantities needed to account for most of the dark matter.

Zwicky's conclusions gained scant attention from his colleagues. The snub was partly provoked by his cantankerous nature—he referred to fellow astronomers as “spherical bastards,” meaning that they were bastards no matter how you looked at them. But a greater hurdle was the revolutionary implication of his idea: few could accept that most of the universe remained to be discovered.

So dark matter suffered three decades of neglect. Then in the 1970s two astronomers at the Carnegie Institution of Washington (D.C.), Vera S. Rubin and W. Kent Ford Jr., mapped the motions of stars within galaxies close to our own Milky Way. They reached essentially the same conclusion as Zwicky had: each galaxy includes enormous amounts of

dark matter, far more than all the luminous stuff in the galaxy's stars. The bulk of it forms a giant, dark halo extending far beyond the star-strewn galactic expanses that we see.

Astronomers today, applying Zwicky's logic, are still detecting vast quantities of dark matter in distant galaxy clusters. Among the clusters, they have observed clouds of hot gas, which would have escaped the clusters' gravitational pull billions of years ago if the clusters had no more mass than that of their stars.

Impressive as those observations are, there's even more evidence for the unseen presence of dark matter: the phenomenon of "gravitational lensing." Because gravity bends space itself (Einstein's finest insight into nature), light passing close by a massive object deviates from a straight-line trajectory. Hence if a massive object happens to lie almost directly along our line of sight to a more distant source of light, such as a galaxy, the light we see will be bent or even focused, much as if the intermediate object were an optical lens [see illustration on opposite page]. A small

amount of light bending, or "lensing," can distort the galaxy into an unusual shape, just as the thick glass bottom of an old Coke bottle distorts the shape of a light bulb when you look at the bulb through the bottle. Stronger lensing can actually create multiple images of the same light source. Gravitational lensing enables astronomers to map the distribution of all matter, not just visible matter, because all matter can give rise to a lensing effect.

What, then, is this dark matter that makes up by far the bulk of all the matter in the universe? No one knows. But cosmologists do know one thing for sure: most of it cannot be anything like the matter familiar to us.

Cosmologists classify all matter into two kinds: baryonic and nonbaryonic, or, basically, the ordinary and the exotic. "Baryon" comes from the Greek root *barys*, meaning "heavy"; the term was coined to refer to the heavy particles that fuse together in the nuclei of ordinary atoms—neutrons and protons. They far outweigh the electrons, which are leptons, or "light" particles, not baryons. With the realization that matter exists in more exotic forms, the term "nonbaryonic" came to denote not only leptons but also all other particles that do not participate in nuclear fusion. One of the most important clues to the mystery of dark matter comes from the growing evidence that the bulk of it—and thus, most of the matter in the universe—is nonbaryonic matter.

Baryonic matter forms stars, planets, moons, and even the interstellar gas and dust from which new stars are born. Nonbaryonic matter includes neutrinos, tiny particles each having less than a millionth the mass of the already diminutive electron. Neutrinos were once regarded as likely candidates for dark matter because they exist in such prodigious numbers, but they have now been excluded from the dark-matter sweepstakes. Detailed studies of how galaxies form suggest that dark matter is most likely made of particles whose masses range from roughly that of the proton to several hundred times as much.

How do astrophysicists infer that such hypothetical particles of dark matter must be nonbaryonic? They can estimate the total amount of matter from the effects of gravitational lensing and the distribution of cosmic background radiation. The baryonic part of that total then comes from the current understanding of how the cosmos behaved during its earliest epochs. The big bang, with which the universe began, opened an era of nuclear-fusing fury, a time when all particles



Map of dark matter (light blue), digitally superposed on a photograph made by the Hubble Space Telescope, shows that a giant ring of invisible mass surrounds the dense core of a giant cluster of galaxies called ZwC10024+1652, about 5 billion light-years from Earth. Astronomers mapped the distribution of mass in the galaxy cluster by observing the effects of gravitational lensing on background galaxies.

crowded together at unimaginably high densities and temperatures. All creation then resembled the cauldron at the core of a star, only far more so. From the countless nuclear fusions that took place in those first few minutes after the big bang, there emerged the basic ratio of nuclei in the universe today: almost entirely hydrogen and helium, with only a minute smattering of all heavier nuclear varieties.

By the end of its first few minutes, the universe had expanded and cooled, dipping below the billion-degree temperatures needed for nuclear fusion. Only in much later, highly localized events did the stars cook up almost all the heavier elements, such as the carbon, nitrogen, oxygen, silicon, and iron that make up our planet and ourselves. Those heavier nuclei, however, comprise no more than 2 percent of the mass of all baryonic matter. The other 98 percent is still made up of hydrogen, helium, and their isotopes, created immediately after the big bang. By measuring the relative amounts of the various isotopes of hydrogen and helium nuclei, cosmologists can deduce how much baryonic matter took part in the great crucible of cosmic nuclear fusion in the first half hour of the universe.

Those results, now confirmed by detailed studies of the cosmic background radiation, lead to a startling conclusion. Baryonic matter—some of it in stars, but much more in diffuse interstellar gas—forms no more than a sixth of all matter in the universe. The other five-sixths must be nonbaryonic matter, either in the form of elementary particles or clumped into much larger objects.

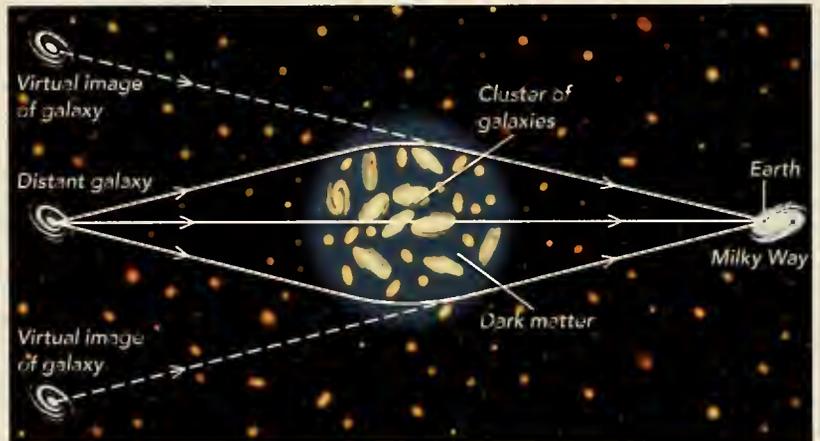
The fascination with the unruly properties of dark matter—its distribution in space, and most of all its predominantly nonbaryonic nature—has given rise to a flourishing dark-matter community. Some members can point to achievements such as improved maps of dark matter and its distribution in intergalactic space [see illustration on the following two pages]. Others strive to design, build, and operate experiments that may someday determine the nature of nonbaryonic dark matter, or at least eliminate from contention some of the hypothetical particles that elementary-particle physicists have proposed.

Before surveying those experiments and the hypotheses that motivate them, it's worth noting that a few ingenious minds will have none of the dark-matter mystery. Instead, they suggest, the observations show merely that physicists don't yet

fully understand gravity. Suppose that at the greatest cosmic distances, gravitational forces deviate slightly from what Newton proposed and Einstein refined. In that case, the motions of stars and galaxies might not reflect the existence of enormous quantities of dark matter, but rather the simple refusal of the universe to obey what physicists presume to be the laws of nature.

The Israeli physicist Mordehai Milgrom of the Weizmann Institute in Rehovot, Israel, proposed that approach, and for a time his idea seemed to explain the observational results without recourse to much dark matter. But to many astronomers now, Milgrom's idea seems on the verge of being disproved. Increasingly accurate observations of stellar and galactic motions at various distance scales seem to confirm existing theories of gravity.

If Einstein's theory of gravity is correct, as appears to be the case, then nonbaryonic matter—matter



Gravitational lensing can occur when light from a distant galaxy, center left, passes through a dark-matter halo around a cluster of galaxies. Here the gravitational pull of the dark matter deflects the light in such a way that an observer on Earth sees two additional images of the galaxy. The diagram is highly idealized; the distances and angles are not drawn to scale.

forever different from all known matter—has always ruled the universe. And the best hope for discovering just what form it takes now rests on finding some of it—at least a tiny amount!—here on Earth. But that poses a dilemma. The basic nature of nonbaryonic dark matter, its extreme unwillingness to engage in any interactions with ordinary particles, makes it extremely difficult to detect.

The dark-matter community, fully aware of the difficulties, has concentrated on experiments designed to find the leading dark-matter candidates. The candidates come in two categories: relatively large objects, and submicroscopic elementary particles, which would have to exist in huge quantities. The sizable dark-matter candidates

have the generic name MACHOs, short for “massive compact halo objects.” MACHOs might be black holes with masses something like that of a star; or smaller, more numerous black holes with masses similar to those of planets; or perhaps the cores of burned-out stars that collapsed but did not form black holes. Gravitational lensing can reveal MACHOs, and astronomers have even found a few with starlike masses. But the results so far imply that MACHOs cannot supply the bulk of the cosmic mass.

If so, the best hopes lie with nonbaryonic elementary particles, which exist so far only in theory. But some of the theories predicting their existence display promising elegance and symmetry, so particles are the favored dark-matter candidates. Two kinds of hypothetical particles seem the most appealing.

First is the axion, a particle named after a laundry detergent, because its hypothetical properties cleaned up a conflict between a theory known as quantum chromodynamics and certain experimental results. Each axion would have an exceedingly small mass—less than a millionth of the electron’s own tiny mass.

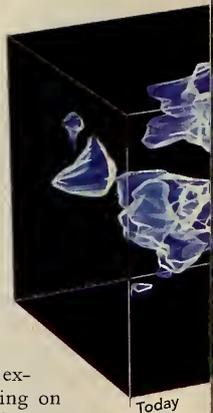
If axions do exist and throng our galaxy, they must occasionally be scattered by the magnetic fields that permeate the Milky Way. The scatterings would generate radio waves at a frequency that depends on the small (and unknown) mass of the axion. The world’s most advanced axion detector, at the Lawrence Livermore National Laboratory in California, seeks those radio waves by searching a wide band of possible frequencies with supremely sensitive amplifiers. So far, all axion searches have proven fruitless, but the search goes on.

If not axions, why not WIMPs? The name stands for “weakly interacting massive particle”—a concise description of the second leading candidate among hypothetical dark-matter particles. “Weakly interacting” means interacting mainly via the weak force, the force responsible for certain kinds of atomic “decay” and the least familiar of

the four fundamental forces in nature. “Massive” in this context means “at least a few dozen times the mass of a proton.” (The name “MACHOs,” for dark-matter black holes, was chosen to contrast with “WIMPs,” which was proposed first.) Because WIMPs arise from the predictions within a class of persuasive theories of elementary particles called supersymmetric, many particle theorists think WIMPs exist.

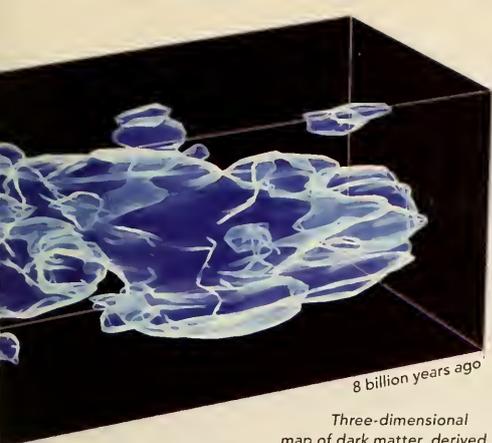
To find the elusive WIMPs, experimental physicists are betting on the likelihood that, once in a blue moon, a WIMP will collide with ordinary matter. Such a collision would lead to a wimpy—as in “amazingly small”—effect in the bowels of a WIMP detector, so extraordinary measures must be taken if physicists hope to notice it. Experimenters reduce the normal atomic vibrations of the sensors within the detector as far as possible by cooling the sensors close to absolute zero. Placing the apparatus deep underground shields it from interference from less penetrating potential sources of spurious signals, such as the cosmic rays that continuously bombard the Earth.

At least half a dozen competing teams of experimenters from Europe and the United States are now operating and improving their WIMP detectors, which build on two basic designs. In the first design, the sensors are several dozen crystals, each weighing about a kilogram, made of highly purified germanium or silicon. Two detectors employ that design, one inside the Gran Sasso tunnel, nearly a mile beneath Italy’s Apennine mountains, and the other at the bottom of a decommissioned mine in northern Minnesota. If a WIMP strikes an atom in one of the crystals, the crystal should ever so slightly heat up and vibrate. So far the crystal detectors have found no WIMPs, but the crystals may well fail to provide



Attempts to find the elusive particles that form dark matter have so far yielded only hope and construction contracts.





Three-dimensional map of dark matter, derived from observations of the effects of gravitational lensing, reveals vast "isles" of dark matter that dominate the large-scale structure of the universe. The map covers a patch of sky 1.6 degrees on a side, out to 8 billion light-years from Earth. The ancient light from distant galaxies enables astronomers to reconstruct how dark matter has evolved (right to left) since early in the history of the universe.

a sufficiently large target to succeed in only a year or two of operation.

To increase their chances of registering WIMP impacts, the experimenters naturally would like to enlarge the target, but with crystal-based detectors, that poses technological difficulties. Enter the second, and newer, kind of WIMP detector, whose target is a pool of ultra-pure, liquefied inert gas. Ongoing experiments with liquefied argon or xenon detectors now operate within the Boulby mine in Yorkshire, England, and in the Gran Sasso tunnel.

Like the crystal detectors, the inert-gas detectors have yet to register a single WIMP. Nevertheless, experimenters have high hopes for success with the design, because they can scale up inert-gas detectors with relative ease. The next generation will deploy not a few kilograms but a few hundred kilograms of target material. Elena Aprile, a physicist at Columbia University who leads the attempt to find a xenon-bumping WIMP in the Gran Sasso tunnel, hopes for a sizable gain in sensitivity by the end of 2008.

In short, attempts to find the elusive particles of dark matter have so far yielded only hope and construction contracts. In more scientific language, the experimentally established upper limits on the tendency of WIMPs or axions to interact with ordinary matter have grown progressively smaller. So far those upper limits do not rule out the viability of either of these dark-matter candidates. No one can say, just yet, that axions or WIMPs do not exist

in sufficient numbers, and with enough mass per particle, to account for the bulk of the nonbaryonic dark matter.

Experimenters working with both kinds of dark-matter detectors know that a formidable competitor looms on the horizon. The Large Hadron Collider (LHC), built at CERN, the European Organization for Nuclear Research, just outside Geneva, is now scheduled to begin serious operation in mid-2008. Once up and running, the LHC will be the world's biggest particle accelerator. Dug several hundred feet under the Swiss and French countryside, it will accelerate two clumps, or "beams," of particles many times around a ring more than five miles across, before smashing the two beams into each other.

Although the LHC was not designed to search for dark matter, its collisions will give birth to the most massive particles ever generated in any machine. If the LHC can verify supersymmetric particle theories, as expected, it will confirm WIMPs as real. Naturally, the builders of dark-matter detectors, currently stymied in their searches for axions and WIMPs, would like nothing better than to find the dark matter before the LHC can make its roundabout confirmation-by-implication.

They must hurry. Bernard Sadoulet, a physicist at the University of California, Berkeley, who has become the grand old man of dark-matter detection, thinks physics has a "decent chance" of ruling axions and WIMPs in or out of contention in the next five years.

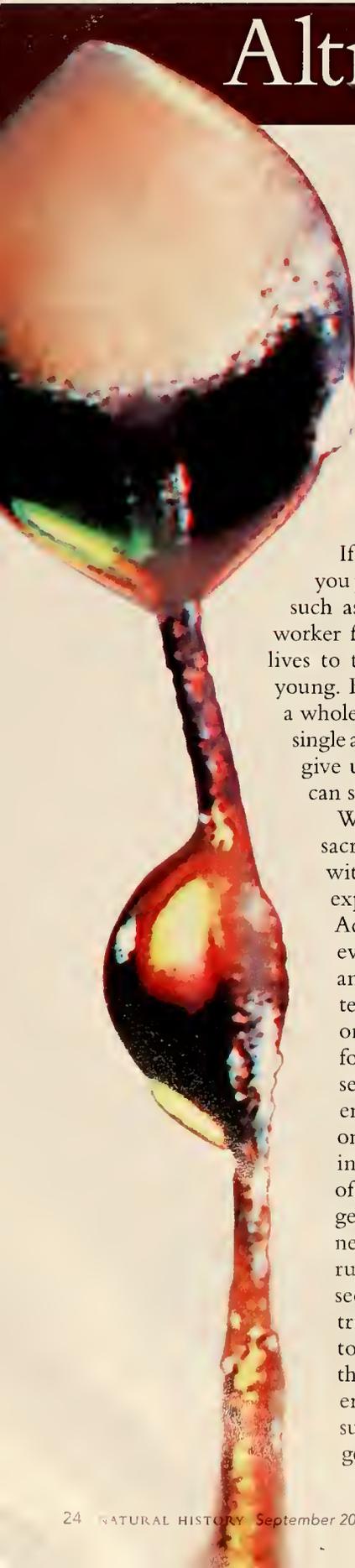
And what if more sensitive experiments show that neither axions nor WIMPs can explain the dark matter? Life will go on, and so will the universe, most of it made of dark matter of unknown form, just as it is today. Inventive theorists will suggest new possibilities, and experimentally minded particle physicists will improve their detectors and their analyses. And both theorists and experimenters will continue to work in the hope that they will be the fortunate ones to resolve this fundamental cosmic mystery. Two hundred fifty years ago, the town of Whitby, in Yorkshire, produced James Cook, arguably the greatest explorer of Earth. Perhaps in the next five years the dark-matter experimenters in the Boulby mine, near Whitby, will be able to announce one of the greatest discoveries about the cosmos: the nature of dark matter. □

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Altruism among Amoebas

A person who dies so that others can escape starvation is a hero. But how can evolution explain the same behavior in a nonhuman organism whose genes are “selfish”?

By Joan E. Strassmann and David C. Queller



Can you think of a species, other than our own, in which some individuals sacrifice their own interests for the sake of others? If you're like many other nature lovers, you probably thought of the social insects, such as ants and wasps. In those species, worker females devote their long, complex lives to the service of their queen and her young. But another group takes altruism to a whole new level: the social amoebas. In a single act of self-sacrifice, certain individuals give up their lives so that other amoebas can survive and later multiply.

Why should that be puzzling? If self-sacrifice is a characteristic that persists within our own species, wouldn't you expect to find its roots deeper in nature? Actually, all the way up and down the evolutionary scale, from single-celled amoebas to human beings, the persistence of a tendency to help others at one's own expense is a conundrum for natural selection. After all, natural selection normally acts on the genetic endowments of individuals, one by one, not on groups as a whole. If an individual does not pass on its genes to offspring, for whatever reason, those genes will be that much scarcer in the next generation. The process is blind, ruthless, and competitive, and it would seem to shut the door on genes for altruism. In particular, genes that tend to produce freeloaders—individuals that take advantage of altruism in others without sharing the cost—should survive and quickly crowd out any genes for altruism. Such “cheater” genes

ought to be favored by natural selection, and spread through any population. So how can self-sacrifice be a successful strategy?

Our curiosity about that question led us to the Appalachian Mountains of Virginia, where social amoebas of the species *Dictyostelium discoideum* had been collected before. *Dictyostelium* amoebas feed on bacteria, so we asked ourselves where bacteria might be most abundant. And sure enough, we discovered a “fruiting body” of social amoebas on the very first pile of not-so-fresh deer pellets we examined under a field microscope. A tiny golden orb, held up by a slender white stalk, seemed to float a millimeter or so above its circular base, glued onto the dung. The light from our microscope made it gleam. The sight was both exotic and commonplace: Hundreds of biologists around the world work on this social amoeba in the laboratory. But we were apparently the first to see a *D. discoideum* fruiting body in its natural habitat [see photographs on this and opposite pages].

Our discovery marked both a departure and a continuity in our careers as biologists. Early on, we each developed a deep interest in biological altruism, inspired by the work of the English evolutionary biologist William D. Hamilton. In the 1960s Hamilton argued that altruistic behavior could evolve if the genes responsible for that behavior benefited relatives that shared copies of the same altruistic genes. (Relatives are more or less likely to share a gene depending on how closely or distantly the individuals are related.)

Hamilton pointed out that an individual can pass on altruism genes even if it has no offspring—by helping a relative pass on copies of genes they share. If that helping, or altruistic, behavior is more effective at passing on the individual's genes than some alternate behavior, Hamilton reasoned, the genes for altruism are likely to propagate, through a process

called kin selection. He argued, for instance, that the unusual three-quarters relatedness among ant sisters could help explain their altruism. Richard Dawkins, an evolutionary biologist at the University of Oxford, later popularized Hamilton's idea in his best seller, *The Selfish Gene*.

With our mutual interest in altruism, it was natural for us to collaborate. We spent a quarter century studying the social behavior of wasps in places such as the olive groves of Tuscany and the rain forests of Venezuela. Yet having become experts in the habits and habitats of wasps, we decided to switch to social amoebas, a group of organisms we knew little about. But what was so compelling about these tiny creatures that, in midcareers, we veered onto an entirely new path that soon had us genuflecting before dung in the Appalachians?

What we saw was the chance to remedy a major deficit in the study of selfishness and altruism. The selfish-gene account of altruism has been pursued largely without knowing anything about the actual genes that underlie social behavior. The social amoeba *D. discoideum* had the advantage of being a model laboratory organism, cultured in great numbers and studied by a large community of biologists. The organism's genome has been sequenced. Investigators have developed a superb toolkit for manipulating its DNA. Experimenters can selectively knock out, or inactivate, any genes of interest, or even replace them. In social amoebas we could study real selfish genes.

Social amoebas are also known as "cellular slime molds," but the name is a misnomer. The creatures are not slimy, and they are not molds. They comprise a hundred or so species belonging to the Amoebozoa, an ancient taxon which arose perhaps a billion years ago when it split off from the evolutionary branch that later gave rise to animals and fungi. Thus the cellular slime molds are no more closely related to any fungal mold than they are to your Aunt Alice.

Most of the time social amoebas do what most people think amoebas do: they move through soil by extending their pseudopods, or amorphous "feet" of protoplasm, and engulf prey along the way. We think of them as slow-motion cheetahs on the microbial equivalent of the African plains, feasting on bacteria, the even slower equivalent of gazelles. Each unicellular amoeba eats, grows, and



Tens of thousands of individual social amoebas of the species *Dicystostelium discoideum* join together to form a fruiting body that is just visible to the naked eye. The fruiting body is the hairlike structure with what appears to be a shiny droplet at its top, in the center of the photograph above, magnified 26x; a closeup of the "droplet" is shown on the opposite page, magnified 1,100x. The droplet is made up of many fertile spores. The "hair," or stalk, is made up of individual amoebas that died after producing strong cellulose walls. The altruistic self-sacrifice of the amoebas in the stalk raises the spores to a more prominent position, increasing the likelihood that the spores will be dispersed and survive.

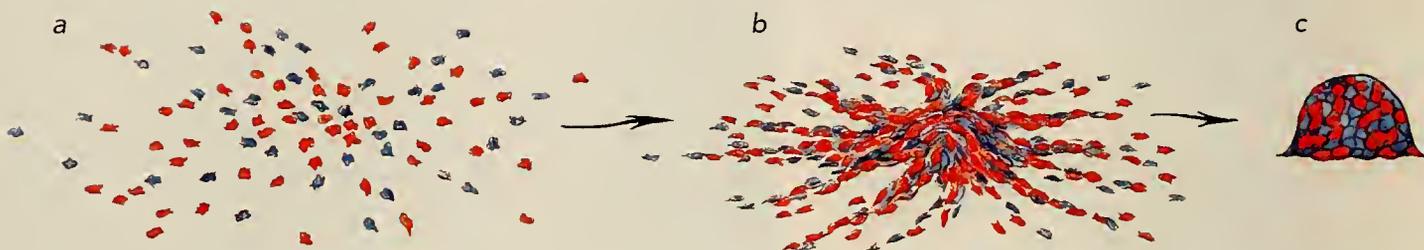
then, as every schoolchild knows, splits down the middle to make two genetically identical cells.

Social amoebas live nearly everywhere there is soil, decaying vegetable matter, and a little bit of moisture. On the abundant bacteria in a deer pellet, social amoebas can persist through many generations of eating and dividing. In that stage of their lives they are not even particularly social; still, they constantly send out and receive signals that keep them informed about the presence and abundance of others of their kind, as well as about any nearby herds of bacteria.

Social life gets interesting only when food gets scarce. When *D. discoideum* amoebas begin to starve, they release a small molecule known as cAMP, which attracts other amoebas. Chains of hundreds of amoebas move up the cAMP concentration



Solitary, unicellular *D. discoideum* amoebas of two genetically distinct strains, or clones (red, blue), begin to aggregate when food is scarce (a). Forming long chains (b), the two clones move toward a common, central area, where a visible mound arises (c). The amoebas then elongate into a "slug" (d) that lifts its "head" and crawls toward heat and light (e). Amoebas in the front 20 percent of the slug later form a stalk and die; the blue clone is cheating by not sending its fair share to the front. When the slug reaches a suitable place for producing



gradient and merge into a mound made up of tens of thousands of individuals [see illustration above]. The minute but now visible mound elongates into a "slug," which crawls as one multicellular body across the forest floor toward heat and light, and away from ammonia, a common waste product.

When the slug finds a suitable place, it stops and reorganizes. The individual amoebas that formed the front 20 percent of the slug arrange themselves into a stalk, laying down tough cell walls of cellulose, just as plants do. Individuals from the back 80 percent flow up the stalk, then reorganize at the top into a ball of hardy spores—the orb we spotted with our field microscope in Virginia. The amoebas that form the stalk die, but the spores, elevated by the self-sacrificing stalk amoebas, are thereby put in a good position to stick to passing insects or other organisms that can carry them to "greener pastures," richer in bacterial food.

The multicellular fruiting body is not unusual in being cooperative. After all, the cells in your own body cooperate as well, altruistically doing their jobs and dying without getting into the next generation. But that altruism is easy to understand because your body is one big clone of genetically identical cells, derived from the division of a single fertilized egg cell. A gene that causes a liver cell to cooperate dies when the liver cell dies, but identical copies of the gene are passed on through sperm and eggs. The genes in liver cells destined to die would gain no evolutionary advantage by, say, sneaking into the gonads and getting into the next generation.

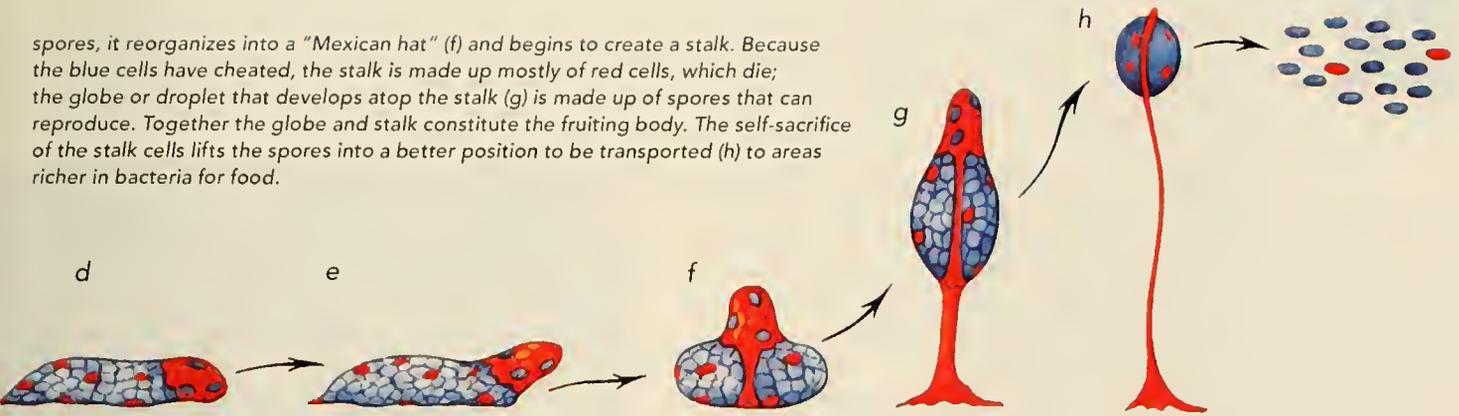
What is unusual about the *D. discoideum* slug and fruiting body is that they form from dispersed cells that aggregate even though not all of them are

genetically identical. Such an aggregate is called a chimera, and in a chimera, one genetic type can gain an evolutionary advantage by outcompeting the others. For example, a clone of genetically identical *D. discoideum* cells can leave more descendants if it cheats and makes more than its share of spores, forcing cells of other clones into the doomed stalk. We wanted to understand how altruism can be a successful strategy in the face of such cheating.

Our switch from wasp studies to social-amoeba research paralleled, in a curious way, the behavior of the amoebas themselves. We were accustomed to the rather solitary mode of field biology, but to get to greener research pastures, we had to work more cooperatively with the larger *Dictyostelium* community. Not only were we switching research organisms, but we were also switching scale, from macroscopic to microscopic, and switching to work that would involve the unfamiliar areas of cell biology and molecular genetics. Would we find the "dicty" community welcoming and cooperative, or skeptical and distrustful of admittedly ignorant outsiders like us?

We made our first efforts to find out via the Internet. Most dicty investigators are signed up for a listserv, and so we began to "send out signals" by posting elementary questions there, which were patiently answered by leaders in *Dictyostelium* molecular biology. When we first made contact, we did not yet know whether genetically distinct clones grouped together. But unfortunately, our new colleagues could shed no real light on that question or some of the others we were keenest to answer: If genetically distinct clones group together, do individuals in each clone get an equal chance to become fertile

spores, it reorganizes into a "Mexican hat" (f) and begins to create a stalk. Because the blue cells have cheated, the stalk is made up mostly of red cells, which die; the globe or droplet that develops atop the stalk (g) is made up of spores that can reproduce. Together the globe and stalk constitute the fruiting body. The self-sacrifice of the stalk cells lifts the spores into a better position to be transported (h) to areas richer in bacteria for food.



spores, or is one clone unfairly consigned to serving primarily as altruistic stalk? Can social interactions among amoebas be studied in the wild?

Instead of answers, one of the dicty biologists, Dennis Welker of Utah State University in Logan, gave us something far more valuable: a genetically diverse collection of wild-caught clones. Such a collection might not seem special, since hundreds of molecular biologists work on *D. discoideum*. But a molecular biologist almost always works with the descendants of a single clone, which has been bred to behave well in the laboratory. To us a single clone was of little use, because one would expect a clone to behave purely cooperatively, for the same reasons the cells in the human body do.

The wild clones enabled us to run some simple tests to see whether cooperation among the amoebas was vulnerable to cheating. We mixed cells of two clones together, then examined the resulting fruiting bodies for the presence of both. Sure enough, each fruiting body included cells from both clones. Yet in some pairs of clones, one of the clones cheated by contributing disproportionately to the spores.

If this earliest work had indicated that *D. discoideum* sorted by clone—as we later found to be true of its relative *D. purpureum* [see photograph at right], we might not have pursued the study of *Dictyostelium* further. But the mixing and cheating confirmed that the aggregate is a complex social system rather than just another genetically uniform multicellular organism.

The very existence of cheating suggests that individuals can distinguish their clone-mates from unrelated clones. Members of our laboratory, led by Kevin Foster, a postdoctoral investigator, cor-

roborated that hunch experimentally by showing that chimeras behave differently from pure clones. Foster's team mixed amoebas from two, five, or ten distinct clones, and compared them to pure clones in their ability to cross a Petri plate. Taking advantage of their attraction to light, we covered the plates with dark paper, leaving a pinhole at the opposite end from where we put down the cells. The amoebas formed slugs and moved across the plate toward the light from the pinholes. The pure clonal slugs traveled farther than chimeric ones did before stopping and forming fruiting bodies.

Why are those results consistent with the idea



Social amoebas of the species *Dictyostelium purpureum* form fruiting bodies in the laboratory primarily with clone-mates. Although two clones of *D. purpureum* may aggregate during a collective migration, they later separate into two fruiting bodies. The image is magnified 32x.



that amoebas can distinguish clone-mates from unrelated clones in chimeras? We suspect that as the clones in a mixed slug compete to stay at the rear, where the spores will develop, the mixed slug as a whole moves forward more slowly than a slug made up of amoebas from a single clone.

We have also identified a different and unusual kind of recognition among *D. discoideum*. Hamilton noted that, in principle, recognition could be based not on overall kinship, but on the sharing of a single gene. Such a gene, he argued, would have to code for three things: a trait, the recognition of that trait in another individual, and altruism toward others with that trait. Dawkins whimsically compared such hypothetical genes to men with green beards who recognized other men with green beards and behaved altruistically toward them; he called them greenbeard genes. Most biologists, however, thought that such recognition was probably too complex to exist in nature: how could a single gene code for all three things?

Yet in the literature on *D. discoideum* we found a gene called *csaA*, for “contact site a,” that seemed to qualify. The gene codes for a cell-adhesion protein that sticks out of the cell membrane and binds to identical cell-adhesion proteins protruding from other cells. The binding of like to like satisfies the first two requirements of a greenbeard gene: *csaA* codes for a trait as well as the recognition of that trait in others. But what about the altruism part?

To find out, we contacted Salvatore Bozzaro, a molecular biologist at the University of Turin in Italy, who had studied the gene. Bozzaro’s group worked with a strain of *D. discoideum* in which the *csaA* gene was knocked out, and so his strain of amoebas lacked the adhesion protein. What would happen, we wondered, if we mixed the two otherwise identical strains, with and without *csaA*, fifty-fifty in a Petri plate? Would one of them act altruistically? Would the other one cheat?

It turned out that the knockout is a cheater—it contributes more than its share to spore tissues. The strain with intact *csaA*, known as the wild-type strain (so called because it is the typical form), ended up in the stalk. Hence in that mixture the wild-type amoebas are the more altruistic ones.

But there is more to the story. When we placed the knockout and the wild type together on the rough natural surface of soil, the weaker adhesion of the knockouts caused them to get left behind when other amoebas began to aggregate. In contrast, the wild types tended to bind to each other and pull each other into the aggregation. Thus the greenbeard recognition by the *csaA* gene ensures that the sub-

sequent altruism of the amoebas that carry the gene only benefits other amoebas that also carry the gene. The *csaA* gene is the only known example so far of a single greenbeard gene that can control altruistic behavior toward other genes of the same kind.

As it happens, the *csaA* gene is carried by all *D. discoideum* individuals we have examined so far. Hence it does not currently fully function as a greenbeard gene, because it is useless as a way to discriminate degrees of kinship within the species. But when it first arose, it could have survived as a minority gene for several generations, before it swept through the species as a result of the way it recognized and benefited itself. (It can, of course, discriminate against the rare mutants that lose the gene.) We suspect that there are other genes that do function as recognition genes. Such a gene would have to be highly variable in the species and would probably code for a molecule that protrudes from the cell membrane. The search is on for such molecules.

We had another good reason to suspect that social amoebas can identify and thereby help their close kin. The spores that aggregated on any given fruiting body we collected in the wild usually belonged to the same clone. Some mixing took place, but on average the amoebas in wild fruiting bodies were very close kin, closer than the workers in colonies of social insects.

We do not know precisely why such close kinship is the rule, but it is important for controlling cheaters. In the laboratory of Richard Kessin, a cell biologist at Columbia University, workers isolated a single-gene mutant that cheats. The cheater was highly effective in our experimental mixtures. It contributed hardly any cells to the stalk at all and instead ended up almost entirely in the spores. But the cheating, from a wider perspective, came at a high price. The cheater, on its own, cannot assemble into a viable fruiting body, and so it cannot propagate its spores. It reproduces only by mixing and forming fruiting bodies with a non-mutant strain of amoebas; in those mixed fruiting bodies, however, the presence of the mutant also lowers the total spore production. Yet despite the low spore production, the mutant can still spread in populations of mixed fruiting bodies because it cheats.

In the wild, however, relatedness is high; most



fruiting bodies form from a single clone. But for the mutant, being excluded from mixing would be disastrous; it would simply fail to produce spores. We therefore predicted that cheaters whose reproduction depends on forming mixed aggregates with other amoeba strains would not be present in the wild. Our



Aggregations of *D. discoideum* are pictured in the Mexican-hat stage, though some of them are beginning to elongate. The image is magnified 25x.

subsequent searches confirmed that prediction, suggesting that high relatedness does play an important role in limiting cheaters in nature.

Another important collaboration for us began in 2000, when we first met Adam Kuspa and Gad Shaulsky of the Baylor College of Medicine in Houston, Texas. Their expertise in genomics and cell and molecular biology seemed the perfect complement to ours in evolutionary biology and behavior. Some of the first results of our collaboration were initiated by Christopher R. L. Thompson and Foster, then postdoctoral investigators in our laboratories.

One way aggregating cells become altruistic stalk cells is by responding to a small molecule called DIF, or differentiation inducing factor. (Intriguingly, DIF seems to be produced by better-fed cells, and it induces weaker cells to become stalk. So perhaps the stalk cells are coerced into becoming stalk and are less altruistic than we thought.)

In any case, Thompson had identified a gene he called *dimA*, which, when knocked out, causes its bearer to ignore the DIF signal. We reasoned that the *dimA* knockout would be a cheater. Sure enough, when we mixed the knockout with wild-type cells, the knockout was overrepresented among the spore-forming cells at the slug stage. To our great surprise, though, when the spores developed, the knockout was underrepresented compared to the wild type. That told us the *dimA* gene must have a second function, besides recognizing DIF signals, that is important to slug-stage amoebas for transforming them into spores. That second unknown function probably evolved first, whereas receiving DIF signals, a cooperative social function, likely evolved later.

Notice that piggybacking the cooperative social function on a gene that controls another essential function is a good way to defeat cheating. A cheater that simply dropped the gene for responding to a signal such as DIF would also lose control of the second, essential function. The cheater would not survive. Building cooperative functions out of otherwise essential pathways may turn out to be a general way that many organisms control cheating.

Our stories about *csaA* and *dimA*, two genes important to cooperative social functions in *D. discoideum*, offer a glimpse of what might be learned via the genetic approach about the evolutionary benefits, and costs, of cooperation and conflict. Of course human cooperation is more complex; it often depends on reciprocation. Our own scientific experience is instructive. Our molecular biology colleagues from the dicty community have helped us learn more about evolution. But we also think our experience as evolutionary biologists brings a fresh perspective to genetics, and we hope to repay our new colleagues in their preferred currency, by illuminating gene function.

In conventional genetic studies, all the genes involved in multicellularity are studied in a single clone. Given the potential for conflict between clones, we think that is akin to studying the function of an army by watching it in peacetime. Parades and pushups give little idea of an army's actual purpose. Likewise, if social amoebas have cheater genes, the function of such genes may be impossible to discern until we examine them in the context in which they evolved: in competition with other clones. □

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Rendezvous at Red Rock

Nestled in a dry landscape, an Oklahoma canyon harbors a lush woods.

By Robert H. Mohlenbrock

Travelers speeding along Interstate 40 between Oklahoma City and Amarillo, Texas, may not realize that the mostly flat and sparsely vegetated terrain they see on both sides of the highway is pierced here and there by colorful canyons. One of those gems is Red Rock Canyon, just a five-mile detour off exit 101. From the exit, follow U.S. Highway 281 south through the town of Hinton, Oklahoma, and take the turnoff to Red Rock Canyon State Park. The road leads to a small visitor center and then switchbacks down into a narrow canyon whose sheer, red sandstone cliffs rise fifty feet or more above the canyon floor.

Red Rock Canyon reflects the region's complex geological history. About 360 million years ago a shallow sea extended across what is now the western half of the southern United States.

Ancient sections of the Rocky Mountains bordered its western shores, while the Ouachitas and the Ozarks stood at the far eastern edge. Marine sediments, together with mud and sand washed down by rivers, formed deposits on the seafloor. From time to time as the sea contracted, some sand deposits in the river deltas were exposed to the air and became windblown, covering other kinds of exposed deposits. By

215 million years ago the sea receded, and the various sediments consolidated into layers of dolomite, sandstone, shale, and other rocks.

Red Rock Canyon formed during the Pleistocene, the epoch of intermittent ice ages that lasted from about 1.8 million until 10,000 years ago. Although the glaciers never penetrated as far south as Oklahoma, streams from the north cut channels in



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Spore-bearing structures arise on stems of rough horsetail, *Equisetum hyemale*.

the rocks, particularly during the interglacial periods, when melting ice increased their flow. The canyon may have formed where it did because a stream that was gradually etching its bed in sandstone encountered a local, underlying deposit of shale. Because shale is softer than sandstone, the stream would have dug into it more deeply, creating a waterfall off the sandstone rim bordering the hollowed-out area. As erosion progressed at the rim, the waterfall would have slowly migrated upstream, lengthening the canyon.

Today Red Rock Canyon is roughly two and a half miles long and between eighty and 750 feet wide. In much of the canyon, where sandstone once overlay shale, the waters undercut the sandstone to form rock overhangs and other contours, including an eye-catching one called Balanced Rock. No longer scoured

HABITATS

Mesic woods Some of the largest trees are Kentucky coffee trees. Also common are black locust, bur oak, eastern redbud, netleaf hackberry, red mulberry, slippery elm, southern sugar maple, western soapberry,

and woolly buckthorn. Locally the southern sugar maple is called the Caddo maple. Although it is not scientifically named as a separate variety, it has a distinctive characteristic: the undersides of the leaves are a chalky white

instead of the usual pale green. Among the shrubs are common hop tree, red buckeye, roughleaf dogwood, and wild plum. Vines are abundant, including American bittersweet, American hog peanut, bristly greenbrier,

common moonseed, eastern poison ivy, roundleaf greenbrier, summer grape, trumpet creeper, and Virginia creeper. **Streamside** Common trees are American elm, box elder, eastern cottonwood, green

by heavy flows, the bedrock floor of the canyon is covered to a depth of about forty feet with loose sand and mud carried in from the surrounding area by streams.

The Rough Horsetail Trail—four-tenths of a mile round trip—offers visitors a good introduction to Red Rock Canyon State Park and the canyon's forest vegetation. It follows a meandering stream through a mesic (moist) woods at the foot of red cliffs. The trail is named for *Equisetum hyemale*, or scouring rush horsetail, often called rough horsetail, a species that grows abundantly along the first part of the trail. It belongs to an ancient order of spore-producing plants known as the Equisetales, which were much more prominent at the time dinosaurs

roamed the earth. Fossil records show that some members of the group grew forty feet tall and had trunks more than a foot in diameter. Today the order comprises only fifteen species, all in the genus *Equisetum*, and the tallest of them grows just ten feet high.

The fifteen extant species, ten of which occur in the U.S., all have jointed, hollow, green stems above the ground as well as rhizomes, or horizontal underground stems. The stem tissue can store deposits of silicon dioxide (silica) that the plant has taken up from the soil. The crystalline silica gives the stems a rasping texture, which discourages herbivorous animals from eating them. Pioneers in the American

West would break the stems apart at their joints to make short pieces, tie them together, and use them as scouring brushes for pots and pans.

The Rough Horsetail Trail ends in a box canyon where, after a heavy rain, you will find yourself at the bottom of a twenty-five-foot-high waterfall. Other, moderately steep trails lead from the base of the canyon to its rim. There one can observe the drier habitat at the top of the cliffs.

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



Sandstone cliff, carved by swift ice-age waters, looms over a pond along the present-day creek.

ash, and Shumard oak. Small trees and shrubs include common buttonbush and elderberry. A pretty spring flower is Missouri violet, with blue flowers and arrowhead-shaped leaves. Watercress grows in the clearer streams. A plant to

avoid is woodland nettle, with stinging hairs on its leaves, stems, and flowering stalks.

Cliff-top Blackjack oak, eastern red cedar, and post oak are the most common trees, but chinquapin oak and

smooth sumac are also present. Coralberry and other shrubs occur here and there, but Adam's needle and prickly pear are more typical. Grasses such as broomsedge bluestem, Indian grass, little bluestem, and switch grass

make up much of the vegetation. Most of the wildflowers, including black-eyed Susan, eastern purple coneflower, flowering spurge, green milkweed, and hairy false golden aster, bloom in late summer and in the fall.

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REVIEW

Literary Gould

By Laurence A. Marschall

*The Richness of Life:
The Essential Stephen Jay Gould*
edited by Steven Rose;
Foreword by Oliver Sacks
Norton; \$35.00

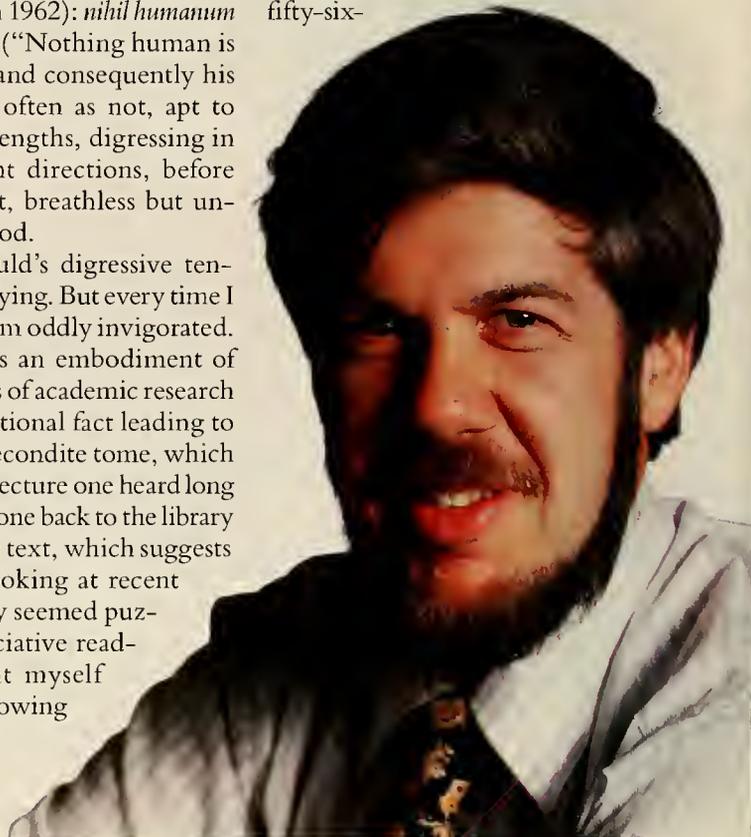
Stephen Jay Gould's 300th and last essay appeared in the pages of this magazine in January 2001, and there has been, frankly, no one to replace him. Gould was a master of the bon mot, the short, pithy phrasing that summarized a complex scientific idea in a few choice words. But he was also a man of many passions—baseball, Beethoven, biology, books—a polymath whose motto might have been the famous line from the second century B.C. Roman playwright Terence (a catchphrase of the liberal arts I recall first seeing in a mosaic in the foyer of Willard Straight Hall on the Cornell Campus when I was a freshman in 1962): *nihil humanum a me alienum puto* (“Nothing human is alien to me”)—and consequently his sentences were, often as not, apt to run on to great lengths, digressing in a dozen different directions, before coming to a halt, breathless but unbroken, at a period.

To some, Gould's digressive tendency could be trying. But every time I read his work, I am oddly invigorated. Each essay seems an embodiment of the joyful process of academic research itself: an observational fact leading to a reference in a recondite tome, which brings to mind a lecture one heard long ago, which sends one back to the library to reread a classic text, which suggests a new way of looking at recent facts that initially seemed puzzling. For appreciative readers, and I count myself among them, following

the thread of a Gould essay is a bit like tracing the tree of evolution: it branches unexpectedly, and one is never clear where it will end up or what novel realization will appear along the way.

Steven Rose, a biologist at the Open University in the U. K., clearly shares my appreciation of Gould, and so he must have found it daunting to select a representative sample of Gouldiana. Gould's work as a whole can be taken as a continuing argument for the power of a simple process—evolution—to create the profusion of forms that life has taken. But Gould engaged that theme in such a large number of variations that surely Rose was forced to arbitrarily omit immense amounts of worthy material.

What Rose has chosen, though, is bound to please Gould's fans. There are, of course, the wonderful baseball articles, such as his examination of Joe DiMaggio's incredible fifty-six-



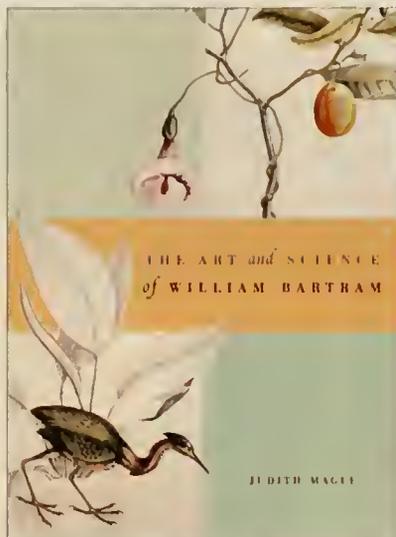
Stephen Jay Gould in 1982, at the age of 41

game hitting streak in 1941. In typical Gould fashion, his meditation on Joltin' Joe's achievement is not only a chance to show how remarkable it was, but also to call for a sense of humility in confronting the transience of species and the fragility of life: "The history of a species, or any natural phenomenon that requires unbroken continuity in a world of trouble, works like a batting streak."

Classic Gould themes are present throughout. Explicating the mechanism of evolution, of course, is central. Rose includes a long selection from Gould's magnum opus, *The Structure of Evolutionary Theory*, along with Gould's well-known essay, "The Spandrels of San Marco," about how seemingly purposeful results can emerge as by-products of random processes. Wonderful pieces on figures in the history of science have also found their place here. Paul Broca, for instance, the nineteenth-century surgeon who popularized the field of "craniology," the study of the size and shape of skulls, expected his work would lead to a science of intelligence. But as Gould notes, Broca even in his heyday had trouble explaining why a study revealed the brains of murderers and thieves to be statistically larger than those of honest men, or why the brain of the great mathematician Karl Friedrich Gauss weighed only slightly more than average.

For readers who missed Gould's quarter century of essays in *Natural History*, this anthology cannot be recommended highly enough—it's a great way to make the acquaintance of a fine teacher and a fascinating writer. For those of us who already know his works, it's like an old family scrapbook, reminding us how much we miss a man who enjoyed life so fully, and who enriched our own lives in so many ways.

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



THE ART AND SCIENCE OF WILLIAM BARTRAM

Judith Magee

Co-published with the Natural History Museum, London

William Bartram's love of nature led him to explore the environs of the American Southeast between 1773 and 1777. Here he collected plants and seeds, kept a journal of his observations of nature, and made drawings of the plants and animals he encountered. The completed drawings were sent to his patron in London, and these make up the bulk of the collection held at London's Natural History Museum.

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That Gnawing Feeling

By Robert Anderson

Recently I've been replacing my deck, which was devoured by colonies of drywood termites (as distinct from subterranean and other kinds). With termite damage and control costing U.S. homeowners and businesses billions of dollars a year, I know I'm not alone. On the Internet you not only can find advice on coping with these home wreckers, but also learn about the biology of the world's 2,761 termite species. Please visit the *Natural History* Web site (www.naturalhistorymag.com), to explore my review of termite sites. You'll discover that the destructive pests are not all bad.

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

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Surprise Package

A supermassive black hole may lie at the heart of an intergalactic collision.

By Charles Liu

Galaxies come in a bewildering variety of shapes and sizes. Spiral and elliptical galaxies are the two best known. The spiral is essentially a disc, and its arms are regions of the disk brightened by hot young stars; the elliptical is shaped like a rugby ball. The so-called peculiar galaxies are tougher to classify, mainly because they're, well, peculiar. Wispy tails, loops, bridges, and other long and short aggregations of stars gather within those galaxies and stretch out beyond them. Beginning in the 1930s, when the variety of galaxy shapes first became evident, astronomers argued about how such peculiarities came about. Some hypothesized that they were shaped by the gravity of a neighboring galaxy, but there was no hard evidence to back that up.

The answer came when a new technology was added to the astronomer's toolkit: the computer. In 1972 the astrophysicists Alar Toomre of the Massachusetts Institute of Technology and his brother Juri Toomre, then at New York University and the Goddard Institute for Space Studies in New York City, published an article that launched modern computational astrophysics. "Toomre and Toomre" (as the paper is commonly known) showed that the wide variety of strange-looking structures could be accounted for entirely by the gravitational tides that arise when two galaxies collide.

It's important to emphasize that as galaxies crash into one another, the individual stars that make them up remain generally unscathed. That's

because the stars within each galaxy are scattered so far apart that they simply stream past one another, like cosmic bees in two colliding swarms. But the gravitational chaos of the collision throws stars off course, disrupting the elegant spiral or elliptical galactic shapes.

Five years after "Toomre and Toomre" appeared, Alar Toomre pondered what would happen when two colliding galaxies merged into one. He proposed that the merging system might follow an evolutionary sequence that would just about run the gamut of galaxy peculiarities, until it finally settled into a large elliptical. In a 1977 paper, Toomre sketched images of eleven real galaxies, placing them in an order that illustrated the merging process from the beginning nearly to the end. In its essentials, the so-called Toomre sequence has since been confirmed by computer simulations on machines many millions of times more powerful than the ones available back in the 1970s.

Of course, we astronomers can run all the computer simulations we want. But if, in the end, we can't connect the results of our virtual experiments with real galaxies, we haven't actually learned anything. And for many years, one kind of galactic formation that showed up in the simulations was conspicuously absent from the lineup of real galaxies: the shape of two galaxies at the very end of a simulated collision, the last transition between "still merging?" and "all done merging."

That changed in 1991. William R. Oegerle, then at the Space Tele-



Computer simulation depicts how our Milky Way galaxy might merge with the Andromeda galaxy. Beginning some 3 billion years in the future (top), the two disk-shaped galaxies approach each other—the Milky Way edge on and Andromeda in the foreground. As they collide, tidal forces rip streams of stars and gas out of the main disks and fling them far into intergalactic space (middle three images). More than a billion years after initial contact (bottom image, above), the two galaxies have essentially merged into one. The simulation was made by John J. Dubinski, an astrophysicist at the University of Toronto.

scope Science Institute in Baltimore, Maryland, and his colleagues discovered a galaxy that seemed to fit the description of the wanted object. They called it G515; and as far as anyone knows, it is the only object out of the 100 million or so galaxies within 1.5 billion light years of Earth that looks exactly like a nearly completed galaxy collision.

When I read about that rare find, I resolved to learn all I could about it. It took me a while, but now, sixteen years later, I've led a new study of G515. Our study confirms what the simulations had predicted: that the system is just about to finish merging, a billion years after a collision started. But as so often happens in science, the work to resolve the initial question has opened up a new and perhaps even more intriguing mystery. At its heart, G515 may harbor a supermassive black hole.

Our suspicions about a black hole arose, in a roundabout way, from our attempts to pin down the age of G515. What made us so sure that G515 was the result of a collision that began a billion years ago?

Real collisions between galaxies are far too slow for people to observe. Thanks to ever more powerful computer simulations, however, we astronomers can make pretty good predictions about what merging galaxy systems would look like at any given stage of the process. From basic physics, our knowledge of galaxy sizes and shapes, and lots of computer time, we now know that when galaxy collisions lead to mergers, it takes about a billion years to consummate the union; and we can calculate what any given merging system might look like after 100 million years, 200 million years, and so on.

Once we have run a simulation, we search the vast cosmic firmament for a galaxy system that looks like it has reached one of the simulated stages. Working backward, that gives us a good idea of how much time has elapsed since the collision

began. But we can't stop there; we need an independent check. It's like guessing the age of a random woman in Times Square on New Year's Eve based solely on a sense of what people look like as they age. You can't be sure you're right until you confirm your guess, say by checking the woman's birth certificate.

The closest thing we astronomers have to a birth certificate for a galactic merger is its electromagnetic spectrum. As I noted earlier, when galaxies collide, the stars don't hit one another. But the puffy clouds



G515, a galaxy 1.2 billion light-years from Earth, was formed by a pair of galaxies that have nearly finished merging. The shadowy wisp in the lower half of this negative image, taken in infrared light, is made up of stars that still haven't settled into the main mass.

of cold gas in those galaxies do; and when their orbits are disrupted, the gas clouds can spiral inward toward the center of gravity of the merging system, where they are consumed in a tremendous, short-lived burst of star formation. When that happens, we can measure the spectrum of the stars formed in the burst and compare it with the spectra of other stars of known ages. By that method, we've confirmed that the flurry of star formation in G515 took place almost exactly a billion years ago.

Here's where the new mystery arises. My colleagues and I had to make sure that no substantial star formation continues today in G515, because that would throw off our esti-

mates for the age of the post-collision starburst. We looked through the archival database of the National Radio Astronomy Observatory for excess radio-energy emissions from the galaxy. Such energy could be emitted by hot, young stars that might have been born more recently than a billion years ago. What we found instead was a surprise: In 1995 the Very Large Array (VLA) telescope in New Mexico had detected substantial radio emission from G515. But measurements made by the same telescope in 2000 showed none!

Two possible explanations come to mind. The two VLA measurements were made with two different instrumental setups, so in 2000 the radio emission might simply have been missed. Our statistical analysis of the data, however, shows that possibility is remote. The other possibility is that we have detected a supermassive black hole. Radio emissions from such objects can vary widely, or even shut down and restart, in periods as short as a few years or even a few months.

Supermassive black holes have been detected at the centers of just about every large elliptical galaxy ever examined, and large elliptical galaxies are almost always created by mergers. Understanding what such a black hole is like just as an elliptical galaxy matures could reveal unexpected insights into the process of galaxy transformation. With that in mind, this past June my colleagues and I trained the VLA once again on G515. The new, more detailed data, which we are still analyzing, will help us determine whether the radio emission is back—and, if it is, whether or not it's coming from the center of the system, where any supermassive black hole should be lurking. If we find something, we'll definitely let you know.

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

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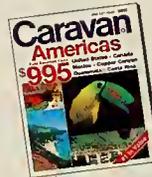
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Professor John J. Renton says that predictions of the inevitable decrease and disappearance of worldwide oil supplies appear all too accurate. On the other hand, he notes, "Coal is to the United States what oil is to Saudi Arabia. We have more coal than anybody in the world." While other options certainly will be pursued, coal seems destined to play an important role in America's energy economy.

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On May 18, 1980, Mt. St. Helens exploded in the most deadly volcanic eruption in the history of the United States.

Image courtesy of USGS/Volcano Observations

Like many geologists, Dr. Renton is plainspoken, no-nonsense, rugged, and with a tinge of romanticism. He is also an award-winning educator with 40 years of experience teaching introductory geology at West Virginia University. You will find him spontaneous, well-organized, funny, and easy to follow.

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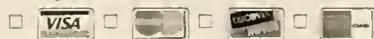
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At the Museum

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Young Naturalist Awards 2007

A research-based essay contest to promote participation and communication in science

Every year scientists from the American Museum of Natural History travel far and wide on expeditions to learn more about the natural world. The Young Naturalist Awards, now in its tenth year, invites students in grades 7–12 throughout the United States and Canada to follow in those footsteps, embarking on their own expeditions in the areas of biology, Earth science, or astronomy. Their research can be conducted as close to home as their backyard or a local pond or stream.

After identifying a question, students plan how they will gather information, conduct outside research to learn more about their topic and possible methodologies, observe their subjects, and record their findings. Finally, their data analysis results in conclusions that either answer the original questions or lead to further inquiry.

Included here are descriptions of and excerpts from the winning essays. Full-length versions of the winning essays and information on how to enter the contest are published on the Museum's Web site at www.amnh.org/youngnaturalistawards.

The Young Naturalist Awards program is sponsored by the Alcoa Foundation.



The 2007 Young Naturalist Awards winners

Algae in the Wekiva River: Is It Helping or Hurting Water Quality? by Ashley Hunt (Grade 7)

When a local newspaper reported that algae was threatening the Wekiva River, Ashley collected algae samples and conducted a macroinvertebrate survey at three sites along the river. She discovered that the healthiest sites had the least amount of algae.

"My family has a boat docked there so we can enjoy the peaceful river anytime we want to. Never once had the thought crossed my mind that the river might possibly be polluted."

The Toads of Delaware County, by Noah McDonald (Grade 7)

After finding a nearly eight-centimeter-long toad in his backyard, Noah wondered what type of habitat toads

preferred. He did a site survey, chose four different park preserves in which to carry out toad surveys, and, after analyzing his data, determined which park provided the best toad habitat.

"One summer afternoon I found this gigantic toad in the grass. I had lots of questions about this huge toad. I wanted to know all about its life cycle, and where and how it lives."

An Analysis of Water Quality on the Severn River over Two Years, by Alexandra Day (Grade 8)

Concerned that sediment runoff into the Severn River would find its way to the Chesapeake Bay, Alexandra decided to investigate the connection between rainfall and the amount of sediment in the Severn. In a two-year study, she collected water samples from two sites; inconclusive results led Alexandra to consider other factors, such as nearby construction and development.

“On the surface, a little rain may seem like a harmless thing. Where I live, on the Severn River, a tributary of the Chesapeake Bay, rain can cause excess erosion, which presents a major problem to the bay’s health.”

Lighter, Brighter, and Cooler: An Analysis of the Effect of Roofing Albedo on Ambient Temperatures, by Ryan Wham (Grade 8)

Ryan investigated whether high-albedo, or reflective, roofing material would lessen surrounding air temperature. He built four doghouses, some with high-albedo roofing and others with standard roofing, and measured surface and interior temperatures over several months. His data indicated that high-albedo roofing results in lower surrounding temperatures.

“It is becoming increasingly obvious that our climate is warming. I decided to do some research to try to better understand what is happening to our Earth.”

Investigation of Water Quality in Mercer County Lake, by Alex Nagler (Grade 9)

When a local park ranger chased Alex and his dog out of Mercer County Lake, Alex became curious about the safety of the lake water. He tested the lake’s water at four different sites over five weeks, and concluded that the data did not support his hypothesis that the water was safe, and that additional

data was needed before he could confirm that the lake was healthy.

“Given the natural beauty of Mercer Lake and its surroundings, it’s easy to forget that it is situated within a densely populated part of the state. Heavily trafficked roads surround it, and two golf courses adjoin its shores. . . . I decided I would do my own investigation and find out more about the water in Mercer Lake.”

Barn Owls on the Side of the Road, by Jon Atkinson (Grade 9)

Finding dead barn owls along a stretch of highway compelled Jon to search for the cause. He did research on barn owls and collected and dissected owl pellets. He hypothesized that owls flying low over the highway were hit by trailer trucks [see illustration below]. Jon plans to continue gathering data he hopes will provide a more conclusive answer.

“In science everything is related. Solutions to problems might be in places that we do not expect, like studying mice in order to save owls. What makes science so interesting is that there are so many angles to a problem.”

From the Desert to the Subalpine Forest, by Viola Li (Grade 10)

On a family vacation to the Grand Canyon, Viola hypothesized that the higher the elevation, the greater amount of flora would be present, but that at 7,000 feet, that diversity would begin to decline due to the harsher climate. Her data, collected from sites spanning 1,749 to 10,371 feet in elevation, supported her hypothesis.

“Every day, hundreds of people experience a phenomenon while gazing down into the almost 9,000 foot drop of the Grand Canyon. Yet, for me, as my eyes scanned the cliffs, this phenomenon was not only the expected hues and shadows of the cliffs that varied with every passing second, but also the diverse vegetation growing in there.”

Thigmomorphogenesis in Pisum Tendril Development, by Nikola Champlin (Grade 10)



COURTESY JON ATKINSON



COURTESY NOAH McDONALD

fouling communities in the discharge creek.

“My four brothers and I spend summers along Barnegat Bay. We learned to kayak to the sedge islands in the bay and explore the islands’ riches. Along the shore of the bay we watched more extraordinary sunsets than I can count, as the days ended and the mysteries of night enveloped the estuary.”

Nikola studied a pea plant’s ability to alter its growth form in response to an environmental condition such as wind. She discovered that the pea plant, a climbing species, has “searcher” tendrils, which search for support and “support” tendrils, which cling tightly to a support. Nikola found that, when subjected to an oscillating fan, pea plants produce a greater ratio of searcher tendrils.

“Phenotypic plasticity and thigmomorphogenesis are new areas of focus in research and there are still many unanswered questions about these topics. Hopefully, finding the answers will lead to a more knowledgeable breeding and selecting of plants and a greater understanding of how the environment impacts the development of plants.”

Human Factor IV: The Impact of a Boiling Water Nuclear Reactor on the Plankton, Benthic, and Biofouling Communities in the Reactor’s Intake and Discharge Creek, by Anastasia Roda (Grade 11)

Over the last four years, Anastasia has explored the impact that a boiling water nuclear reactor has had on its intake and discharge creeks. After studying microbial communities and water quality in the creeks, Anastasia compared her findings to those of a control creek. She concluded that the Oyster Creek Nuclear Generating Station has reduced the number and diversity of plankton, benthic, and bio-

A Survey of the Birds of Indroda Nature Park in Gujarat, India, by Arjun Potter (Grade 11)

During a summer vacation to India, Arjun decided to use his bird identification skills to conduct a field survey of the avifauna in Indroda Nature Park. Each day Arjun and his guide, the park warden’s son, went to different habitats within the park; in all, they counted 1,451 birds representing 78 species.

“The Asian koel calls incessantly from the folds of the neem tree outside, and I open my eyes. A house sparrow dodges the whirring fan blades and lands daintily on top of the ceiling fixture. Oblivious of my gaze, she tucks another blade of dry grass in the nest above the fan. A house sparrow worthy of its name, I think.”

More Than Meets the Eye: Do *Himasthla* sp. B Cercariae Use Chemo-orientation, by Joanna Nishimura (Grade 12)

Joanna wondered how parasitic flatworms were able to find their specific hosts in each part of their life cycle—through trial and error? Or did they, as Joanna suspected, respond to chemicals released by their hosts? Data she collected on the behavioral changes in the parasite when in the presence of its host supported her hypothesis.

“I start out prostrate on the mud, my nose mere inches away from the

ground. Gradually my knees sink almost a foot beneath the surface, making odd squelching noises each time I attempt to move. Equipped with small mesh bags, I search for the most elusive organism of the Carpinteria Salt Marsh, the tiny, four-millimeter-long sea slug, *Acteocina*.”

Lichens as Indicators of Vehicle Pollution, by Jeremy Koelmel (Grade 12)

Jeremy questioned whether certain lichen species could be used as indicators of traffic-related air contamination in a large urban area such as New York City. He chose low-, medium-, and heavy-traffic sites, surveyed the lichens found in each zone, and concluded that *Punctelia rudecta* (speckled shield lichen) is a good indicator of vehicle-based pollution.

“As vehicle exhaust increases or decreases depending on our future choices, we will be able to determine its quantity in certain areas through indicative lichen species such as the ones that may be determined in this experiment.”



COURTESY ASHLEY HUNT

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Mythic Creatures: Dragons, Unicorns, and Mermaids
Through January 6, 2008
Mythic Creatures traces the origins of legendary beings of land, sea, and air. Cultural artifacts bring to light surprising similarities—and differences—in the ways peoples around the world have depicted these beings, and fossil specimens suggest a physical basis for the many forms they have taken.

Mythic Creatures: Dragons, Unicorns, and Mermaids is organized by the American Museum of Natural History, New York (www.amnh.org), in collaboration with The Field Museum, Chicago; Canadian Museum of Civilization, Gatineau; Australian National Maritime Museum, Sydney; and Fernbank Museum of Natural History, Atlanta. *Mythic Creatures* is proudly supported by MetLife Foundation.

Undersea Oasis: Coral Reef Communities
Through January 13, 2008
Brilliant color photographs capture the dazzling invertebrate life that flourishes on coral reefs.

Beyond
Through April 6, 2008
Exquisite images of our planetary neighbors from unmanned space probes.

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

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LECTURE

An Evening with Wangari Maathai
Tuesday, 9/25, 7:00 p.m.
Nobel Peace Prize laureate Wangari Maathai, celebrated political activist, feminist, and environmentalist, will share the story of her life as told in her autobiography, *Unbowed*.

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

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THE SKY IN SEPTEMBER

By Joe Rao

Mercury remains a poor evening apparition in the Northern Hemisphere all this month, despite the increase in its angular separation east of the Sun throughout most of September. That's because the planet sets unfavorably early, only about forty-five minutes after sunset. Nevertheless, Mercury is worth a look with binoculars on the evenings of the 21st and 22nd. That's when it makes a close approach to Spica, the brightest star in the constellation Virgo, the virgin. Look for the pair just a few degrees above the west-southwestern horizon about thirty minutes after sunset.

Venus erupts into view in the eastern morning sky as September opens, rising just after dawn's first glow at around 5:00 A.M. local daylight time. With each passing day, this morning "star" rises higher and becomes a little brighter. By month's end, it is rising at around 3:30 A.M., some three and a half hours before sunrise. Venus was at inferior conjunction on August 18, in line between the Earth and the Sun. Now it is swinging away from that line, speeding ahead of Earth in its faster orbit. So through a telescope, the planet displays a large, brilliant crescent that wanes in phase all month while it shrinks in size.

Mars rises about four and a half hours after sunset and is high in the south-southeast by dawn. The planet begins the month in the constellation Taurus, the bull, seven and a half degrees to the lower left of the bright star Aldebaran—easy to mistake for Mars because of its similar hue. By month's end, Mars has shifted eastward to the feet of the constellation Gemini, the twins. We are slowly catching up to Mars in our orbit around the Sun. As a result, the Red Planet brightens by almost 50 percent this month, from magnitude +0.3 to -0.1, and, viewed in a telescope, its apparent size is slowly growing.

Jupiter, shining steadily in the southwest, five or six degrees above the ruddy but much dimmer star Antares, is the

first "star" to appear in the darkening sky. That makes an ideal test for the old adage that stars twinkle, whereas planets (usually) don't.

Saturn rises as morning twilight begins on the 12th, just after 5:00 A.M. local daylight time, and is one and a half degrees to the lower left of the bluish star Regulus. By the end of the month, a telescope of at least thirty power shows the ring system tilted 8.8 degrees from edge-on, with the south face visible—the closest to edgewise the rings have appeared since 1995.

The Moon is at last quarter on the 3rd at 10:32 P.M. and further wanes to new on the 11th at 8:44 A.M. Our satellite waxes to first quarter on the 19th at 12:48 P.M. and to full on the 26th at 3:45 P.M. That full Moon is called the Harvest Moon, because it is the one nearest in the calendar to the autumnal equinox.

On the morning of the 1st the Alpha Aurigid meteors seem to dart from the bright star Capella, in the constellation Auriga, the charioteer. Normally the Alpha Aurigid shower is too minor to be worth mentioning, but Peter Jenniskens, an astronomer at the SETI Institute in Mountain View, California, is forecasting a dramatic outburst of as many as hundreds of meteors an hour. If the display does come to pass, however, it will only be visible from the western United States and Canada. The peak is due at 4:37 A.M. PDT, when the rest of North America is already in daylight.

The equinox takes place on the 23rd at 5:31 A.M. Autumn begins in the Northern Hemisphere; spring in the southern.

A partial eclipse of the Sun takes place on the 11th, but it is visible only from about half of Antarctica and the southern two-thirds of South America.

Unless otherwise noted, all times are eastern daylight time.

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