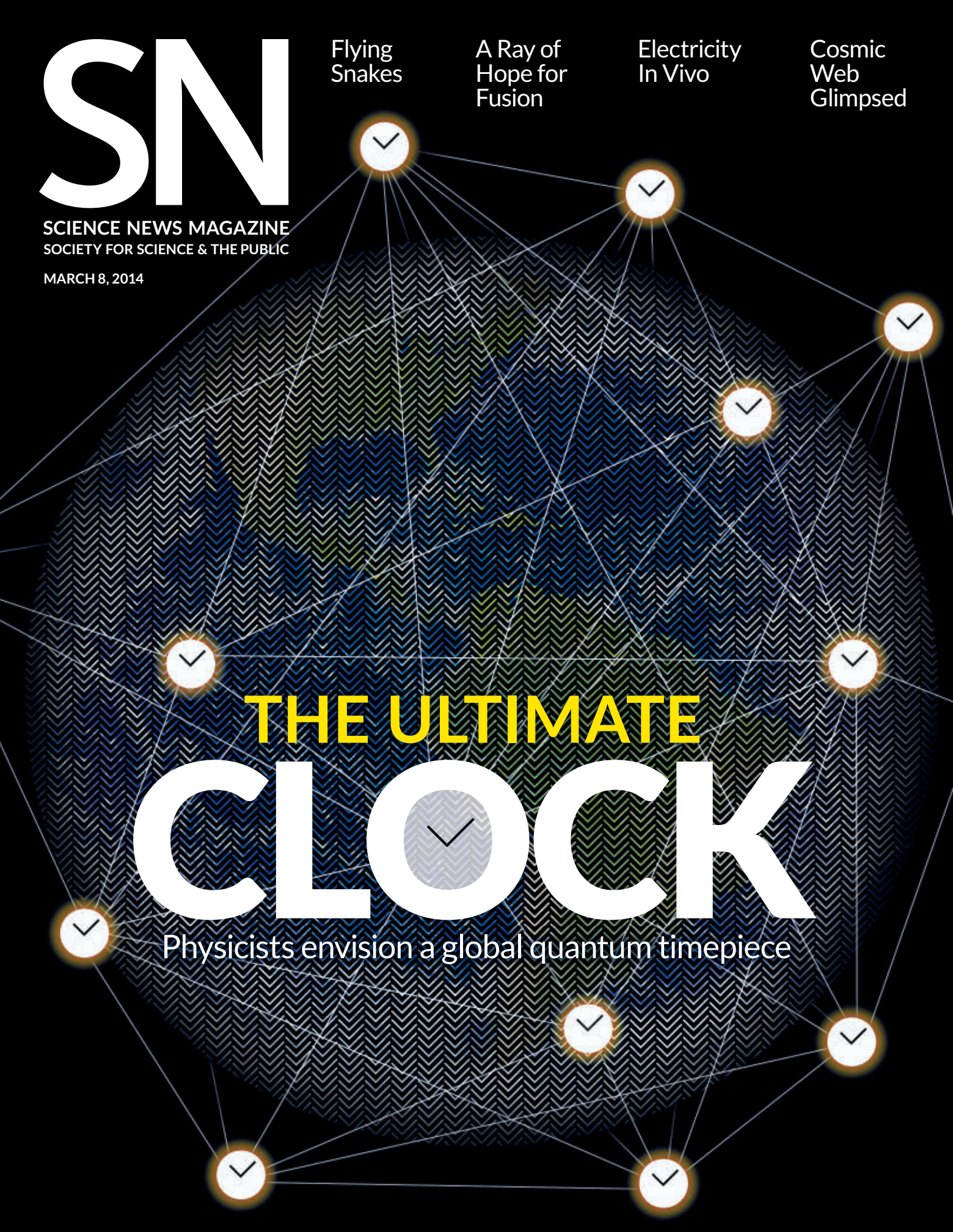
SN
SCIENCE NEWS MAGAZINE
SOCIETY FOR SCIENCE & THE PUBLIC
MARCH 8, 2014

Flying Snakes

A Ray of Hope for Fusion

Electricity In Vivo

Cosmic Web Glimpsed



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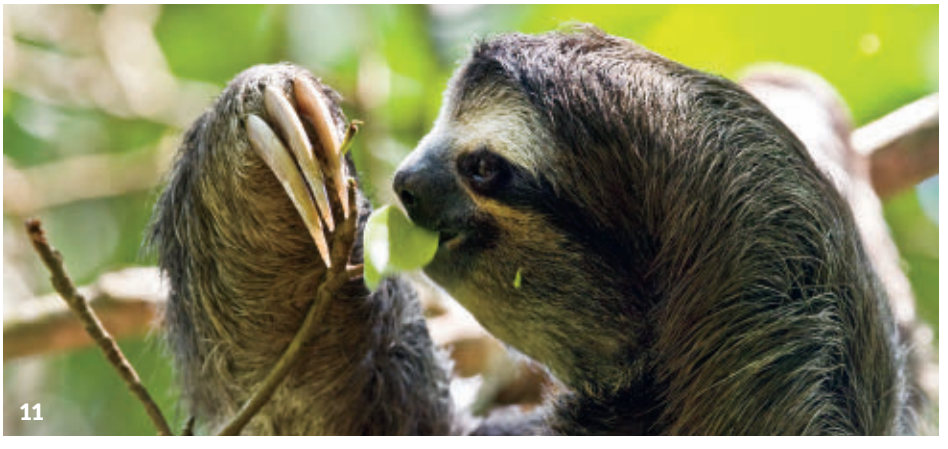
Features

News



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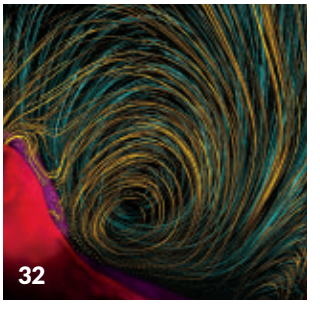

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Departments

COVER Forging quantum links between atomic clocks worldwide would result in a nearly perfect timekeeper. *S. Egts*

CLOCKWISE FROM TOP LEFT: JAMES PROVOST; V. FERNANDEZ, ORR H. SHAPIRO, MELISSA S. GARREN, ASSAF VARDI, ROMAN STOCKER/MIT; CHRISTIAN MEHLFÜHRER/WIKIMEDIA COMMONS

Making it work on paper, and just maybe in practice

Last spring, physics writer Andrew Grant reported on the lack of progress by the main U.S. nuclear fusion effort ("Ignition failed," *SN: 4/20/13, p. 26*). As the researchers said then and still contend, laser-initiated fusion should work. It works on paper. But in practice, even a set of powerful lasers has failed to trigger the fusion of hydrogen nuclei and the concomitant chain reaction and expected net energy release.

In February, National Ignition Facility scientists at Lawrence Livermore National Laboratory in California reported a small, if important, advance, as Grant writes on Page 6. By using a different pattern of laser pulses, scientists were able to cajole some hydrogen atoms to fuse, resulting in more than 5,000 trillion fusion reactions before the effect petered out. The energy released by those reactions was dwarfed by the total energy used by the lasers. But the event did generate an excess of 3,000 joules over the energy that had actually reached the fuel. That's still very far from usable fusion energy, but it's progress nonetheless.

Sometimes the devil is in the details, as I'm sure the fusion scientists would agree. As freelance writer Sam Lemonick reports on Page 18, those attempting to make fuel cells powered by the body's own chemistry have found that to be true. The idea, first dreamed up by artificial heart developers in the 1960s, is to find a way to power medical devices using electricity generated by enzyme-catalyzed reactions in the body. In the last decade, research on biological fuel cells has gained momentum — and has included a menagerie of living power sources, including grapes, lobsters, clams and snails. A major obstacle to getting to a practical body-powered device, however, is the relatively small amounts of electricity produced by fuel cells so far. But, as Lemonick relates, scientists are inspired to keep trying.

The science behind "Quantum timekeeping" is still resolutely on paper, as Grant describes on Page 22. The details haven't even begun to be fretted about. A global quantum superclock run by entangling atoms and then entangling the clocks themselves is, at this point, purely speculative. But before you can build it, you've got to dream it.

— Eva Emerson, Editor in Chief

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Excerpt from the February 29, 1964, issue of *Science News Letter*

50 YEARS AGO

Beatles Reaction Puzzles Even Psychologists

Psychologists are as puzzled as parents over the explosive effect the Beatles are having on American teenagers. There has not been enough serious study on mass adolescent reactions to explain the impact of these four mop-headed British youths.... The Beatles follow a line of glamorous figures who aroused passionate cries and deep swoons. Most prominent in the 1940's was Frank Sinatra and in the 1950's Elvis Presley. Their glory passed when they got too old to be teen-agers' idols or when teen-agers got too old to need them. The same, it is predicted, will happen to the Beatles. In the meantime, there are two ways to handle the situation: either grin and bear it or relax and enjoy it. For the Beatles are inevitable.

UPDATE: So much for predicting tastes. In February, 14 million people tuned in to a special celebrating the 50th anniversary of the Beatles' first appearance on *The Ed Sullivan Show*. About 73 million people tuned in to the 1964 broadcast.

A paradise tree snake draped over a branch can launch in an instant and glide to another branch or to the ground.

IT'S ALIVE

When snakes fly

A snake jumping out a window has at least a little bit in common with a paper airplane.

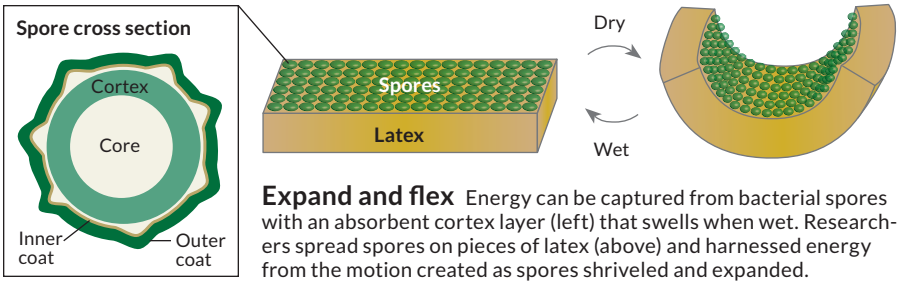
Few snakes do anything but fall, but the paradise tree snake widens and flattens its body as if trying to catch some lift. And instead of holding a straight Superman pose, it undulates and whips S-curves in the air in a 3-D motion that researchers don't have a word for. "Just watch the video," says biomechanist Jake Socha of Virginia Tech in Blacksburg.

Launching from a 10-meter height, *Chrysopelea paradisi* snakes regularly glide outward 10 meters, and Socha has witnessed a champion glide of 21 meters. The snake is an accomplished aerialist among the five *Chrysopelea* species of flying snakes, all from South and Southeast Asia.

INTRODUCING

Spore power

With mighty bursts of rehydration, bacterial spores offer a new source of renewable energy. *Bacillus* spores quickly shrivel in dry times and bloat with a blast of humidity. The transitions, which take about half a second, pack a powerful punch that biophysicist Ozgur Sahin at Columbia University realized could translate to usable energy. By smearing spores onto a flat piece of rubber about the length of a human hand, Sahin and his colleagues developed a spore-powered generator. In arid conditions, parched spores pull the rubber into a curve, while wafts of wet air plump up spores and spring it flat again. The team linked the rubber to an electromagnetic generator, so that every flex produced an electric current. By weight, spore power rivaled the juice in a car battery, Sahin and colleagues report January 26 in *Nature Nanotechnology*. Since the spores tote such a high energy potential — more than 1,000 times that of mammalian muscle — Sahin and colleagues say energy-harvesting devices based on the dormant dynamos could be linked into municipal grids to contribute a power boost to homes and cities. — *Beth Mole*



Expand and flex Energy can be captured from bacterial spores with an absorbent cortex layer (left) that swells when wet. Researchers spread spores on pieces of latex (above) and harnessed energy from the motion created as spores shriveled and expanded.

IT'S ALIVE: J. SOCHA; INTRODUCING: X. CHEN *ET AL/NATURE NANOTECH*, 2014

Watch a video of gliding snakes at **bit.ly/SNsnakesfly**

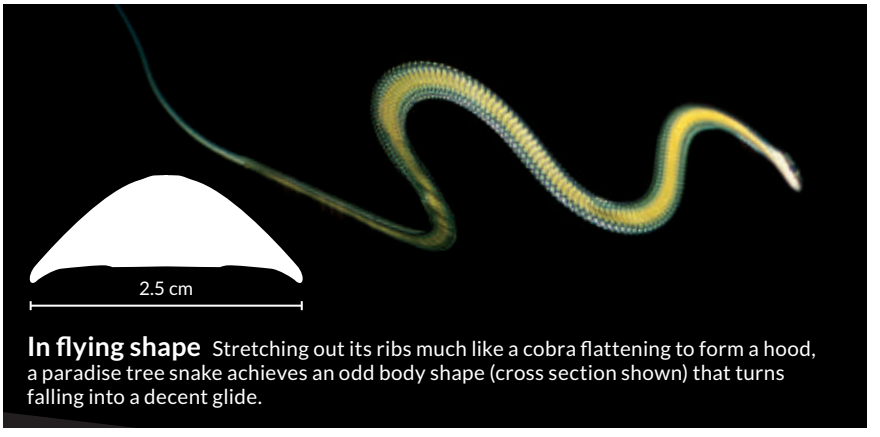
The paradise glider lives in trees, climbing in easy slithers and jumping off branches to escape both predators and scientists. It really does jump, Socha says. The snake anchors its tail on a branch, and the front of the body first drops down and then shoots back up and out headfirst. It has some power to aim its glides, and Socha suspects it has unusually good vision for a snake. He has seen gliders he was studying snap heads-up alert and follow the motion of an airplane across the sky.

Yet a resting paradise glider looped over a branch "just looks like a normal snake," he says. "That's part of the fascination."

Most of the time the paradise tree snake is as sausage-round as any other snake. But during a glide, the flyer splays out its ribs and sucks in its belly. Its round cross section turns into more of a dome, like a sliced mushroom cap — an odd shape for an airfoil.

Socha and his colleagues used 3-D printing to create a snake stand-in with the same cross section and tested fluid flowing around it at various speeds and angles. At many angles the chubby shape could generate much of the lift a gliding snake needs, the team reports in the Feb. 1 *Journal of Experimental Biology*.

But the domed shape doesn't account for all the lift the snake actually achieves. Socha is now curious about the contributions of the snake's aerial motions. A bicycle racer can catch a boost by drafting behind another racer, so Socha wonders if a long snake whipping its curves might basically be drafting itself. — *Susan Milius*



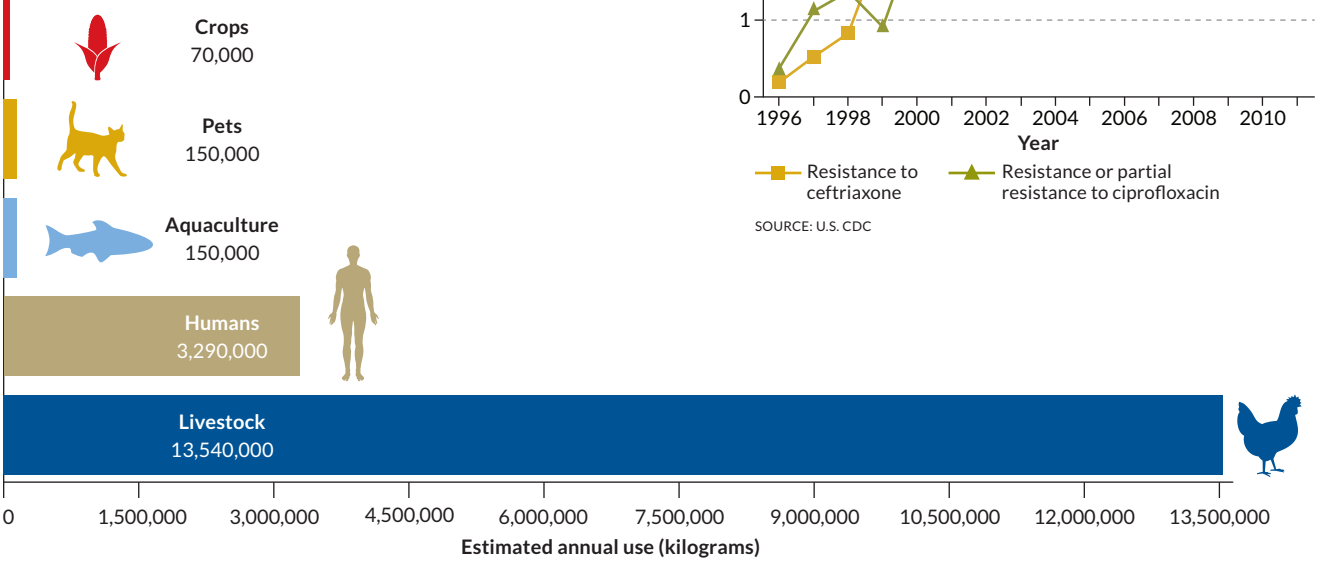
In flying shape Stretching out its ribs much like a cobra flattening to form a hood, a paradise tree snake achieves an odd body shape (cross section shown) that turns falling into a decent glide.

SCIENCE STATS

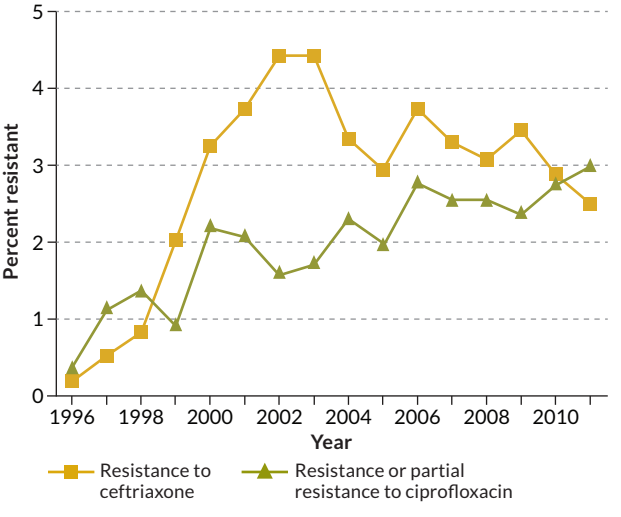
Where antibiotics go

Of the 51 tons of antibiotics consumed every day in the United States, about 80 percent goes into animal production (below). The widespread use of antibiotics in livestock may be contributing to growing resistance to the drugs by bacteria such as *Salmonella* (right). In December, the U.S. Food and Drug Administration enacted a voluntary program phasing out antibiotics used to make livestock grow bigger. SOURCE: A. HOLLIS AND Z. AHMED/*NEJM* 2013

U.S. antibiotic use



Antibiotic resistance of *Salmonella* infections in humans



SOURCE: U.S. CDC

CHICKEN: PINARE/SHUTTERSTOCK; OTHER ICONS: E. OTWELL

MATTER & ENERGY

Step taken toward ignition

Fusion energy output hits modest milestone

BY ANDREW GRANT

The 192 laser beams at the $3.5 billion National Ignition Facility have now triggered fusion reactions that briefly sustain themselves. The reactions, reported February 12 in *Nature*, produced nearly 10 times as much energy as the previous record for laser fusion. But they still fall well short of recouping the energy supplied by the world's most powerful laser.

"It's a very important milestone," says Steven Rose, a plasma physicist at Imperial College London. "However, there are many other milestones to pass."

In 2009, NIF officials at Lawrence Livermore National Laboratory in California were far more confident. Computer simulations had suggested that a NIF laser pulse could compress a layer of frozen hydrogen within a peppercorn-sized plastic capsule to one thirty-fifth its original size. The extreme pressure would drive up the temperature to 50 million degrees Celsius, causing pairs of hydrogen nuclei to fuse and cumulatively release more energy than the lasers supplied.

Had NIF achieved that milestone, known as ignition, it would have marked the first time a controlled fusion reaction generated more energy than it took to get started. "A lot of people thought this would be a walk in the park," says Robert McCrory, director of the University of Rochester's Laboratory for Laser Energetics and a frequent NIF collaborator.

But NIF hasn't come close. For reasons unknown, the fuel resists compression, often warping into bulbous shapes and tearing apart before much fusion takes place (*SN: 4/20/13, p. 26*). "Mother Nature doesn't like putting a lot of energy into small volumes," says Livermore physicist Omar Hurricane.

In early 2013, physicists tried changing the timing of the laser pulse. Instead of ramping up the laser energy gradually, the researchers tried delivering an initial surge of high energy to swiftly drive the fuel inward symmetrically before it could tear apart. Initial experiments showed promise that this "high-foot" laser pulse could overcome some of NIF's problems.

Excitement peaked on September 27, when researchers fired a high-foot laser pulse with 1.8 million joules of energy at a small gold cylinder that held the plastic capsule. More than 99 percent of that energy was lost as it cascaded from the laser to the gold cylinder to the fuel inside the capsule. Nonetheless, an 11,000-joule infusion was enough to implode the fuel and spark a flurry of fusion reactions, transforming pairs of hydrogen nuclei into energetic neutrons and fast-moving helium nuclei. The newly formed helium then crashed into more hydrogen nuclei, transferring heat and spurring more fusion reactions.

During the 160 trillionths of a second of sufficient pressure and temperature, about 5,100 trillion fusion reactions took place. The reactions produced 14,000 joules — more energy than the fuel absorbed. That's a first for any laser fusion experiment. However, it's well short of compensating for the laser's energy. It's analogous to making a solid return in the stock market, but only after a broker has taken a big commission of more than 99 percent of the initial investment. "It sounds very modest and it is, but it's closer than anyone has gotten before," Hurricane says.

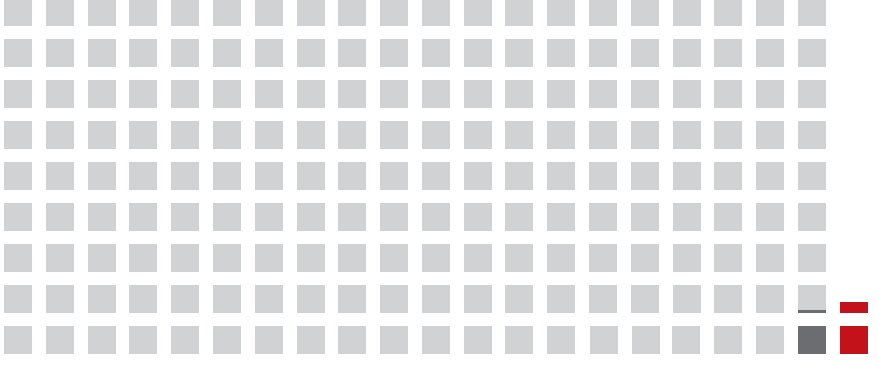
Much of Hurricane's optimism stems from the fact that about half the 14,000 joules produced resulted from helium heating the fuel from within. NIF won't achieve ignition, McCrory says, unless helium fosters a chain reaction that exponentially increases the fusion rate.

To make progress, physicists have to make the fuel absorb more of the laser energy, as well as coax more self-heating. Researchers have many ideas to test in simulations and experiments, including replacing plastic capsules with ones made from diamond and further tweaking the timing of the laser pulse.

McCrory warns that ignition is still distant. But Hurricane and his colleagues finally feel on their way. "A lot of people are jazzed," he says. ■

Energy budget For the first time, laser fusion reactions released more energy (red squares) than the fuel absorbed (dark gray). But to become a useful source of power, the reactions need to release more energy than is produced by the laser (gray).

National Ignition Facility experiment, September 27, 2013



Each square = 10,000 joules of energy

Energy used:
- Laser energy absorbed by fuel
- Laser energy not absorbed

Energy produced:
- Energy released by fusion reactions

M. ATAROD

GENES & CELLS

Monkeys born with edited genes

DNA-snipping technique shows therapeutic promise

BY TINA HESMAN SAEY

The birth of two monkeys provides hope that a new type of gene therapy may help correct genetic defects in people. The cynomolgus monkeys are the first primates to have their genes precisely edited using a gene-snipping tool borrowed from bacteria, a team of Chinese scientists reports January 30 in *Cell*. The work is part of an effort to genetically engineer monkeys with mutations like those seen in human diseases.

Other researchers have inserted foreign genes into primates (*SN: 6/20/09, p. 13*), but until now no one has succeeded in altering the animals' own genes, says Guoping Feng, a neurobiologist at MIT.

To alter the monkeys' genes, Jiahao Sha of Nanjing Medical University and his colleagues wielded molecular scissors discovered in bacteria. The scissors are a DNA-cutting enzyme called Cas9. In bacteria, Cas9 is part of a primitive "immune system" — known as CRISPRs — that chops up viruses that the bacteria recognize as threats.

Sha's team injected mRNA used to produce Cas9 into single-celled monkey embryos. At the same time, the researchers inserted other RNA molecules that would precisely guide the enzyme to its DNA targets.

For this study, the researchers chose three genes to disrupt and found that two of the three targeted genes had been simultaneously altered in eight of 15 injected embryos. Embryos with the edits were transferred into surrogate mothers. Two babies delivered by one of the surrogate moms on November 11, 2013 carry the disrupted genes. Two of the other surrogates miscarried, and the researchers say that they are awaiting the birth of the remaining monkeys.

Only the targeted genes were disrupted, the researchers reported. That fact is encouraging, says Jennifer Doudna, a biochemist at the University of California, Berkeley who is a pioneer of CRISPR techniques. It suggests that CRISPRs could be used to repair some human genes without inadvertently damaging others. ■

Two female cynomolgus monkeys named Mingming and Ningning are the first primates with precisely placed cuts in their genes.

BODY & BRAIN

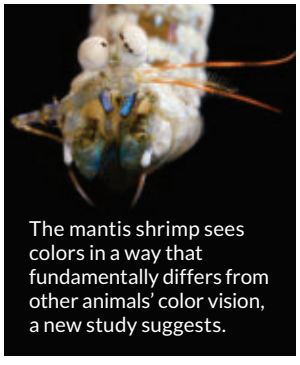
Bizarre vision may save brainpower

Mantis shrimp perceive color in a way unlike any other animal

BY LAURA SANDERS

The mantis shrimp looks like a Mardi Gras parade and hammers its enemies so fast that water boils. Now scientists have added another distinction: The mantis shrimp has a really strange way of seeing colors.

People and other animals perceive colors by blending and comparing signals from a few types of eye cells called photoreceptors. In contrast, the mantis shrimp sees each color separately with one of a dozen kinds of specialized cells, scientists suggest in the Jan. 24 *Science*.



The mantis shrimp sees colors in a way that fundamentally differs from other animals' color vision, a new study suggests.

FROM TOP: Y. NIU *ET AL*/*CELL* 2014; COURTESY OF M. BOK

The vision system might be a way for the mantis shrimp to quickly see colors without a lot of brainpower. Because mantis shrimp don't have big brains, their dazzlingly complex eye might do the bulk of their color processing, says vision scientist Michael Bok of Lund University in Sweden.

Instead of working together, each of the 12 types of photoreceptor in the mantis shrimp seems to work alone, rendering the animal surprisingly bad at distinguishing colors (*SN: 9/22/12, p. 11*), says study coauthor Justin Marshall, a vision neuroscientist at the University of Queensland in Brisbane, Australia.

Marshall and his colleagues studied mantis shrimp (*Haptosquilla trispinosa*) that had learned to swipe at a particular hue of optical fiber to get food. Then the team added an optical fiber of a different color and watched as mantis shrimp chose between the two. As the two hues grew closer and closer, mantis shrimps' performance worsened.

When the wavelengths of the two colors grew closer than 25 nanometers (to people, that represents the difference between pure yellow and orange), the animals started to have trouble identifying the food-linked fiber.

Marshall and colleagues think that mantis shrimp detect colors by shunting each wavelength of light into one of 12 narrowly defined bins, creating an almost pixelated representation of color. If this color discrimination happens largely in the eye without much brain processing, the system might save time, allowing for fast decisions necessary in the violent life of a mantis shrimp, Marshall says. ■

ATOM & COSMOS

Old stars glean neighbors' gas

Snatching matter helps blue stragglers stay youthful

BY ASHLEY YEAGER

Stealing keeps some stars looking young. The thieves, called blue stragglers, swipe material from a neighbor, leaving behind a dead stellar companion as a calling card, data from the Hubble Space Telescope show.

Natalie Gosnell, an astronomer at the University of Wisconsin–Madison, and colleagues discovered three blue stragglers that share orbits with white dwarfs, the remnants of dead stars. The findings, posted January 29 at arXiv.org, match astronomers' ideas about what would be left if a blue straggler took gas from a now-defunct companion star. The stolen goods allow the blue stragglers to burn hotter and look bluer, as much younger stars would.

"These blue stragglers absolutely did form from taking matter from another star. It is the first time we have been able to say that for a specific population of blue stragglers," Gosnell says.

Determining how blue stragglers pilfer matter and what happens to them may help astronomers better understand the physics of the dozens of other cosmic phenomena that involve mass transfer, such as exchanges between two stars that ultimately cause explosions.

Astronomers first identified blue stragglers in 1953. The stars were puzzling because they were as old as the cooler, redder stars around them. Over the years, astronomers have come up with three explanations for how blue stragglers cover their age: Each straggler could have collided with another star and absorbed matter from it; it could have existed in a star trio and merged with a companion; or it could have stolen mass from another star. These hypotheses have been difficult to test.

Some of the blue stragglers (circled) in the open star cluster NGC 188 have white dwarf companions, confirming that the hot, blue stars have stayed young-looking by stealing material from their now-dead neighbors.

Gosnell and colleagues used the Hubble telescope to study ultraviolet light coming from blue stragglers in NGC 188, a 7-billion-year-old cluster of stars 5,800 light-years away in the constellation Cepheus. The researchers knew how much UV light should come independently from a blue straggler and from a white dwarf. Finding blue stragglers that have extra UV light, equivalent to the amount a white dwarf gives off, is a signal that a straggler and a white dwarf orbit each other and once exchanged material. Three blue stragglers in NGC 188 fit the profile, the team reports.

The results do not rule out that collisions and mergers also form blue stragglers, but the findings do provide "waterproof evidence" that mass stealing occurs, says astronomer Michał Różyczka of the Nicolaus Copernicus Astronomical Center in Warsaw. In 2013, his team reported what appeared to be a blue straggler in the act of stealing from its companion.

The new data make an even stronger case for mass transfer among these stars by showing that it happened multiple times in a population of blue stragglers. ■

MATTER & ENERGY

Monopole mimic emerges in frigid concoction

Physics experiment simulates long-sought magnetic particle

BY ANDREW GRANT

Lurking somewhere in the universe, most physicists agree, are minuscule magnets with just one pole — a north or a south, but not both. Scientists haven't spotted any yet, but a new experiment offers an unprecedented glimpse at what these elusive magnetic particles should look like.

"It provides a window into the physics of the particle without having the particle itself in front of you," says David Hall, a physicist at Amherst College in Massachusetts who led the research.

ATOM & COSMOS

Filament of cosmic web set aglow

Peek at massive, outstretched gas cloud could reveal hidden structure of the universe

BY GABRIEL POPKIN

All of the universe's matter, cosmologists believe, forms a web of dark matter and gas that was spun shortly after the Big Bang and has been stretching out ever since. Now astronomers say they have glimpsed a brightly lit strand of this web.

But the researchers found far more cold gas than they expected based on computer simulations of the cosmic web, suggesting that the web's structure could differ from theoretical predictions.

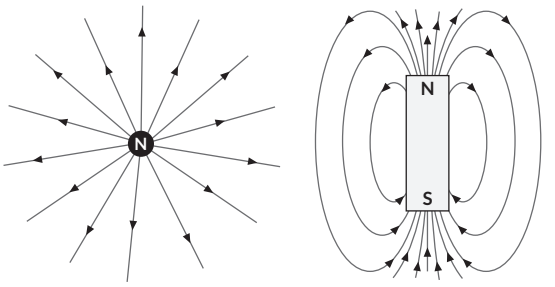
Most of the universe's mass seems to reside in slender interconnected filaments, which are primarily made of dark matter with smaller amounts of gas. Cosmologists' theories suggest that

K. GARMANY AND F. HAASE/NOAO/AURA

Magnets seem to come in only one variety, with two poles like a bar magnet's. But in 1931, Nobel Prize–winning physicist Paul Dirac demonstrated mathematically that single-pole magnets, known as monopoles, could exist. His mathematical reasoning was so strong that most physicists today have little doubt of monopoles' existence, despite decades of fruitless searches.

Hall had rarely thought about monopoles until 2009, when he read a paper that proposed a way to simulate one in the lab. The recipe called for a Bose-Einstein condensate, an exotic state of matter produced by cooling a gas to billionths of a degree above absolute zero. At that extreme temperature, hundreds of thousands of atoms can behave collectively like one particle, allowing scientists to simulate quantum processes on a larger scale.

In following the recipe for an artificial monopole, Hall and his team had to manipulate a condensate's rubidium atoms, each of which acts like a compass needle. The researchers exposed the atoms to a carefully crafted magnetic field, which caused the compass needles to orient themselves toward a single point in space — as if someone had placed an isolated magnetic north pole there. The researchers detail their findings in the Jan. 30 *Nature*. "It's a very nice paper," says MIT physicist Wolfgang Ketterle.



One pole An artificial monopole (left), whose magnetic field spreads away in all directions, came from researchers' manipulation of an ultracold gas. In a traditional bar magnet (right), the magnetic field juts out from the north pole and bends toward the south pole.

Hall emphasizes that his creation is a simulation of a monopole: There is no physical particle where the monopole appears to be.

But he says the experiment gives physicists a chance to explore a so-called quasiparticle that, at least mathematically, behaves just as Dirac predicted an actual monopole would 83 years ago. "We've realized Dirac's conception of what a magnetic monopole ought to be, and his conception is the gold standard," Hall says.

Hall expects other physicists to replicate his experiment and simulate how the artificial monopole interacts with other particles. Such experiments could yield clues as to how an actual magnetic monopole might reveal itself in nature. ■

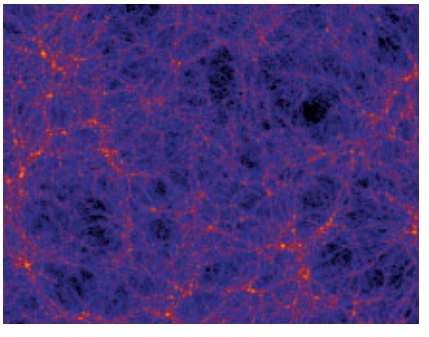
gas collects at filament intersections and becomes dense enough to form luminous galaxies. But because the filaments' dark matter is invisible and their sparse gas emits little light, the threads connecting galaxies have remained mostly hidden.

Astronomers have recently begun to spot filaments backlit from a distance by extremely bright galactic nuclei called quasars. But researchers could gain far more information about the web's structure from a quasar shining onto a nearby filament, which would then emit its own light, says astronomer Michael Rauch of the Carnegie Institution for Science in Pasadena, Calif. "To see the cosmic web in emission is the holy grail."

Seeking it, Sebastiano Cantalupo of the University of California, Santa Cruz and his colleagues tried a clever technique. They put a filter on the Keck I Telescope in Hawaii to block all wavelengths except the one at which illuminated hydrogen gas in filaments should glow. Through this filter, they took a 10-hour image of a distant quasar and its surroundings. They found a large, outstretched cloud of quasar-lit hydrogen well outside the radius of the halo of gas and dark matter that surrounds quasars. Because no other structures are known to exist so far from galaxies, the team concludes in the Feb. 6 *Nature* that the cloud is a cosmic web filament.

Making such a finding is difficult because quasars shine only in specific directions like a flashlight beam, says Cantalupo. He calls the discovery "a lucky cosmic coincidence." He and his colleagues say that the surprisingly large amount of gas they found — more than 10 times as much as simulations predict — could force cosmologists to revise their theories.

The cosmic web, shown in a computer simulation, consists of filaments of dark matter and gas. Galaxies reside where strands intersect.



"It's scientifically highly exciting to find an object like this," says Rauch. But he is not convinced that the structure is a cosmic filament. He notes that the imaged quasar and a second quasar the team found in the neighborhood could have merged halos in a way that resembles a web filament. Such a scenario could explain the cloud's high gas content.

But Cantalupo's team argues that the cloud's wispy, asymmetrical shape and the large distance between the quasars make such an explanation unlikely. Rather, the researchers suspect that current simulations are too imprecise to estimate filaments' gas content correctly.

The team's finding may require revisions to theories, says Volker Springel, a cosmologist at Heidelberg University in Germany. Other astronomers will probably emulate the researchers' technique. If they find similar results, Springel says, "then I think it would really convince all the skeptics." ■

FROM TOP: M. ATAROD, ADAPTED FROM M.W. RAY *ET AL*/*NATURE* 2014; ANATOLY KLYPIN/NEW MEXICO STATE UNIV., JOEL PRIMACK/UC SANTA CRUZ

BODY & BRAIN

Common diuretic could alleviate autism symptoms

Drug that lowers chloride levels in brain cells staves off abnormal behavior in rodents

BY LAURA SANDERS

Curbing chloride in nerve cells could combat symptoms of autism, a study of rats and mice suggests. The results may explain why a small group of children with autism seemed to improve after taking the common diuretic bumetanide in an earlier study.

The details of how bumetanide works, published in the Feb. 7 *Science*, provide important clues about how autism spectrum disorders arise in a developing brain, says Susan Connors of the Massachusetts General Hospital for Children's Lurie Center for Autism in Lexington, who was not involved in the study. If extended to people, the results would point to a concrete biological difference in the brains of people with autism, one that could be targeted with drugs. That would be "a great step forward," says Connors.

In the new study, bumetanide curbed autismlike behaviors in pups when given to pregnant mice and rats a day before delivery. But Connors and others caution that it's too soon to try the diuretic on infants or pregnant women.

In 2012, Yehezkel Ben-Ari of INSERM, the French National Institute of Health and Medical Research, and colleagues published results of a small clinical trial that found bumetanide seemed to improve children's symptoms of autism or Asperger's syndrome. But the scientists didn't know how the drug worked. "We give a diuretic and the kids feel better, but you have no idea of the mechanism," Ben-Ari says.

So the team turned to two animal models: mice with a mutation that causes behaviors similar to those seen in people with the autism spectrum disorder fragile X syndrome and rats exposed during gestation to the chemical valproate, which results in autismlike behaviors.

In addition to behaviors such as abnormal vocalizations, these rodents had a pronounced brain abnormality, the researchers found: Their neurons had too much chloride, which interfered with a critical brain event that happens during birth.

During gestation, the neurotransmitter GABA makes brain cells very excitable and active. After birth, GABA does the opposite, calming nerve cells. That switch is an important rite of passage for the developing brain, and earlier work suggested that it goes awry in people with autism.

Too much chloride leaves the brain in an immature, excitable state, Ben-Ari and colleagues report. But giving pregnant mice and rats a dose of bumetanide a day before delivery prevented abnormal behavior by reducing the chloride levels in pups' nerve cells and allowing their brains to undergo the GABA reversal.

"It's a very simple way to flip a switch," says J. Jay Gargus, director of the University of California, Irvine Center for Autism Research and Translation.

The hormone oxytocin, known for its role in labor and promoting social bonding, also lowers chloride in brain cells. Too little oxytocin right before birth resulted in rat pups born with overly excitable brains, the researchers found.

Oxytocin's relationship to autism is contentious. Some researchers have found a link between labors induced with oxytocin and elevated rates of autism. But the new results suggest that too *little* oxytocin during delivery might increase autism risk.

It's not known when bumetanide, if it even works in humans, would be most effective. Researchers generally agree that the earlier treatment starts, the better the outcome. As scientists hone their ability to spot autism in very young babies (*SN Online: 11/6/13*), treatments such as bumetanide might become feasible even during pregnancy.

Many other questions remain before the drug can be used to treat or prevent autism in people. Bumetanide is a potent diuretic, which reduces fluid retention and treats disorders including heart failure and high blood pressure. While it and oxytocin may turn out to be powerful avenues for further research, it's unclear how the drugs might influence the growing brain and body.

"A lot of things are changing in the first and second year of life, and you have to be cautious that you don't cause more problems," says clinician Randi Hagerman of the University of California, Davis Health System in Sacramento, Calif., who was not involved in the study.

Other researchers also urge caution. Bumetanide is available to anyone with a prescription, but it hasn't been extensively studied in children. "These are powerful medications," Gargus says.

Ben-Ari and colleagues have started another clinical trial of bumetanide that includes 80 children with autism ages 2 to 18. The team hopes to conclude the trial by the end of the year. ■

JUST THE FACTS

Cat bites

29.5

percent

Fraction of patients seeking medical attention for a cat bite to the hand who needed to be hospitalized during a three-year study

SOURCE: N. BABOVIC, C. CAYCI AND B.T. CARLSEN/ *JOURNAL OF HAND SURGERY* 2014

CYNOCLUB/ISTOCKPHOTO

LIFE & ENVIRONMENT

Sloths, moths, algae may live in three-way benefit pact

Insects and green slime may explain why the slow mammals make risky trips to the ground

BY SUSAN MILIUS

A tree-dwelling sloth's climb down to ground level for its weekly bathroom break may not be pointless daintiness.

The trip is risky and (for a sloth) energetically expensive. Yet the effort could be the sloth's contribution to a mutually beneficial, three-way partnership. The sloth's trips seem to encourage moths that mate in the mammal's fur and algae that thrive on moth detritus, suggests Jonathan Pauli of the University of Wisconsin–Madison.

The payoff for the sloth, after a Rube Goldberg–like string of actions by the other partners, could be rich blooms of nutritious algae to eat off its own fur, Pauli and colleagues propose in the Mar. 7 *Proceedings of the Royal Society B*.

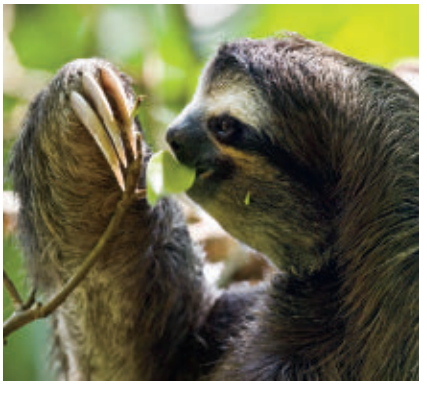
"Sloths are bizarre," Pauli says with enthusiasm. Why three-toed sloths go to the trouble to clamber down to the forest floor to scrape out a latrine depression about once every eight days has been just one of many questions about their lives.

To learn what might drive tree descent, Pauli and other researchers compared a tree-descending species with a less fastidious, two-toed sloth. At a site in Costa Rica, researchers vacuumed the fur of strict tree-descenders, the brown-throated three-toed sloths (*Bradypus variegatus*), and of Hoffmann's two-toed sloths (*Choloepus hoffmanni*), which sometimes climb down and sometimes don't bother. Compared with their tree-pooping cousins, three-toed sloths harbored more than four times as much moth mass in their fur. Their fur also had more nitrogen available to nourish algae — and more algae.

The scenario Pauli and colleagues put together starts with *Cryptoses* moths gathering in sloth fur to choose mates. When the sloth climbs to the ground, female moths rush to lay eggs in fresh sloth dung, the preferred baby food for the larvae.

The idea that the moths benefit from hanging around sloths is "not at all new," says Adriano Garcia Chiarello, a biologist at the University of São Paulo. What is novel, he says, is the suggestion that harboring abundant moths eventually provides a benefit for the sloths.

Moths may boost sources of nitrogen in the fur, Pauli and his colleagues say. Newly mature moths landing on sloth fur may bring with them nitrogen-spiked traces of their dung-rich childhoods. And when adult moths die after their mating frenzy, their decomposition may release nitrogen into the fur.



To make a living as one of the rare mammals that eats only tree leaves, a brown-throated three-toed sloth may be getting some help from moths and sloth-specialist algae.

Cryptoses moths, which hang out in sloth fur to find mates, may repay their hosts by providing nitrogen that fuels the growth of algae, a potential food source for the sloths.

Moths could thus fertilize growth of the *Trichophilus* green algae that favor sloth fur. Lab tests found that the algae should be highly digestible and up to five times richer in quick-energy lipids than sloths' usual diet of leaves. And the team found algal cells in samples from three-toed sloth stomachs. Just what percentage of the diet comes from the algae remains to be seen, Pauli says.

Chiarello, however, says that in the far more than 1,000 hours that he and his students have watched sloths in the wild, no one has seen the animals eating algae. "I don't remember ever seeing a sloth lick its fur," he says.

The paper may be overlooking some other players, speculate Jaanika Blomster and Milla Suutari of the University of Helsinki. They've described a wide range of tiny organisms that survive sloth grooming. It may be "more like a mini-ecosystem occurring in sloth fur, rather than just a two- or three-way symbiosis," Blomster says. ■

FROM TOP: PIOTR NASKRECKI/MINDEN PICTURES/NATIONAL GEOGRAPHIC CREATIVE; CHRISTIAN MEHLFÜHRER/WIKIMEDIA COMMONS

GENES & CELLS

Neandertal hot spots highlighted in modern humans' DNA

Stone Age people's mating with now-extinct species had both genetic pros and cons

BY BRUCE BOWER

Ancient interbreeding has left about 20 percent of the Neandertal genome (fossil of one shown) in the gene pool of modern Europeans and East Asians.

Humans appear to have inherited several traits related to skin, hair and some autoimmune diseases from Neandertal ancestors.

Two independent investigations identify for the first time the specific parts of the human genome that seem to have been most affected by Stone Age interbreeding with Neandertals. The research locates part of Neandertals' legacy in sections of present-day Europeans' and East Asians' DNA that are stocked with genes influencing the production of keratin, a key substance in skin, hair and nails.

By occasionally interbreeding with Neandertals after leaving Africa around 70,000 years ago, Stone Age humans inherited and retained keratin-related genes that must have aided survival outside of Africa, Sriram Sankararaman, a computational geneticist at Harvard Medical School, and his colleagues propose January 29 in *Nature*.

Neandertals' DNA contributions to modern humans also encompass genes related to several medical conditions, including lupus and Crohn's disease, Sankararaman's group says.

Neandertals lived in Europe and Asia between around 200,000 and 30,000 years ago. Previous studies estimated that 1 to 3 percent of non-Africans' DNA today comes from Neandertals, while present-day Africans have little or no Neandertal ancestry.

About 20 percent of the Neandertal genome shows up in various places in the DNA of living Europeans and East Asians, geneticists Benjamin Vernot and Joshua Akey of the University of Washington in Seattle conclude January 29 in *Science*.

These new reports represent "the first steps toward getting a genomic picture of the actual Neandertal individuals that mixed with modern humans," remarks paleogeneticist Mattias Jakobsson of Uppsala University in Sweden.

The genome of a Neandertal woman who lived about 50,000 years ago has already been sequenced (*SN: 1/25/14, p. 17*). The two research teams compared the ancient woman's genome with modern-day humans' DNA, using different statistical techniques. Future work will be able to use genomes from additional Neandertal fossils to home in on genes that modern humans inherited through particular instances of Stone Age interbreeding.

Sankararaman's team developed a method for calculating the probability that modern human gene variants and DNA segments containing multiple genes came from Neandertals. The researchers compared the Neandertal woman's genome with the DNA of 1,004 modern-day humans living in different parts of the world.

If, for instance, a European carried a gene variant found in the Neandertal but not in present-day West Africans, whose ancestors do not appear to have interbred with Neandertals, the researchers concluded that the gene variant probably originated in Neandertals.

In a genetic analysis of 379 Europeans and 286 East Asians, Vernot and Akey identified unusually long chains of gene variants that people probably inherited via Stone Age interbreeding, presumably from Neandertals. These Neandertal hot spots did not appear in the DNA of 13 West Africans.

Sankararaman's group found that far fewer signs of Neandertal ancestry appear on the X chromosome and along a stretch of DNA containing genes that affect the testicles than in other parts of modern humans' genomes. Genes that reduce male fertility tend to accumulate on the X chromosome when closely related species of modern animals interbreed, suggesting that such genes initially might have passed from Neandertals to humans before disappearing due to natural selection. Neandertal genes that compromised how the testicles work may have met the same fate.

The patterns of Neandertal DNA found in the human genome suggest that ancient populations interbred at least twice across Europe and Asia, Vernot and Akey say.

Still, large swaths of Europeans' and East Asians' genomes contain unexpectedly little Neandertal DNA, Akey says. "These regions potentially are a road map to finding genes that make us human." ■

AQUILAGIB/WIKIMEDIA COMMONS

BODY & BRAIN

DNA-built parcels carry cancer drug

Biodegradable system may be nontoxic way to target tumors

BY BETH MOLE

Eat your heart out Amazon. Packaging made of DNA-strapped nanoparticles could deliver cancer drugs directly to a tumor's doorstep, then quickly break down and see itself to the curb.

Researchers have used nanoparticle-based parcels to carry drugs to tumors before. But the new shipping system, which was tested in mice, is the first to include an exit strategy for the nanoparticles, which are often made of toxic metals that can accumulate in healthy tissues. The results appear January 26 in *Nature Nanotechnology*.

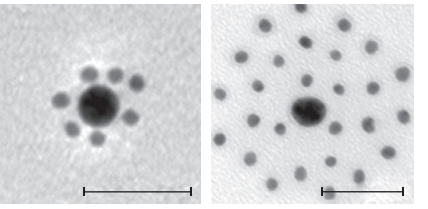
Biomedical engineer Warren Chan of the University of Toronto and colleagues created gold nanoparticles that can link together like Tinkertoys to build bigger, more complex structures. The particles' linkers are single strands of DNA chemically fused to each gold nanoparticle. The DNA connects with complementary DNA on other nanoparticles to create nearly endless particle combinations.

"This is a beautiful design," says biomedical engineer Zhen Gu of the University of North Carolina at Chapel Hill. The customizable system is simple and adjustable for different drugs and tumor types, he says.

By tweaking the size of the nanoformations, Chan and his team created structures that could bind cancer drugs such as doxorubicin and go directly to tumors in mice. The DNA connectors carried the drug. The size of the assemblies, about 100 nanometers across, allowed the structures to squeeze through tumors' unique pores without lingering in most healthy tissues.

What happens next is the real trick. Immune cells called macrophages, which gobble up foreign materials and remove them from the body, take up the nanostructures and degrade their DNA buttressing. The structures release their gold particles, which are small enough to float out of cells and leave the body via urine.

"It is a pretty unique approach," says Willem Mulder, a nanomedicine researcher at the Icahn School of Medicine at Mount Sinai in New York City. But, he adds, it will need more validation and tweaking before testing on people. ■



Tiny delivery Packaging made from different-sized nanoparticles (gray dots) linked by strands of DNA can transport cancer drugs directly to tumors and then safely biodegrade in the body. Researchers can easily alter the size and structure of the packages to accommodate different drugs. The scale bars represent 50 nanometers.

L.Y.T. CHOU ET AL/*NATURE NANOTECHNOLOGY* 2014

GENES & CELLS

Arctic melting may help parasites infect new hosts

Grey seals encounter killer microbe as their territories expand northward

BY TINA HESMAN SAEY

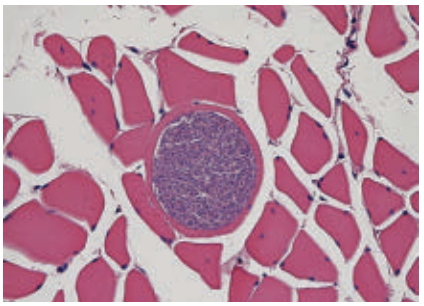
Along with melting Arctic ice comes an erosion of natural barriers that once separated parasites from potential hosts.

That erosion has allowed at least two pathogens to infect marine mammals they were previously unknown in, said Michael Grigg, a molecular parasitologist at the National Institutes of Health in Bethesda, Md. He reported the findings February 13.

A newly identified parasite was once frozen safely away from grey seals (*Halichoerus grypus*). It has now infected some with disastrous consequences. In 2012, about 20 percent of healthy-looking grey seal pups born on Canada's Hay Island off the coast of Nova Scotia mysteriously died. The cause turned out to be a parasite that destroyed the livers of 404 pups and two adults, Grigg said.

Grigg and his colleagues found that the parasite, a microscopic creature shaped like a crescent moon, also infects about 80 percent of ringed seals (*Pusa hispida*) but doesn't make them sick. The parasite, which Grigg and his colleagues dubbed *Sarcocystis pinnipedi*, invades cells and can cause inflammation that damages tissues. In ringed seals, the parasite gets into cells, but the animals protect themselves from inflammation by walling the microbes off in cysts.

Researchers had noticed parasite-filled cysts in ringed seals before but hadn't characterized the organism. It wasn't until the parasite started killing other species, including endangered Hawaiian monk seals and a Steller sea lion, that Grigg and other parasitologists were called in. Genetically, the organism resembles one that infects dogs, Grigg discovered.



As the Arctic emerges from a deep freeze, parasites including *Sarcocystis pinnipedi* (shown, purple) are able to infect animals that they have never encountered before.

Grey seals normally live only in sub-Arctic regions. Grigg thinks rising temperatures and melting ice may have encouraged grey seals to follow fish north into ringed seal territory. The researchers don't know how the parasite is transmitted, but they suspect grey seals may pick it up when encountering infected scat from a ringed seal.

Grey seals aren't the only marine mammals dealing with new parasites. Scientists have found some beluga whales in the Beaufort Sea north of Alaska infected with a parasite that lives in cats and can be transmitted to humans via kitty litter, Grigg and colleague Stephen Raverty, a veterinary pathologist at the University of British Columbia in Vancouver, reported. Freezing is one of the few things that can kill the parasite, called *Toxoplasma*, Grigg said. (In his lab, researchers store the organism in sulfuric acid.).

A warming Arctic means that the parasite can survive farther north than it could before. *Toxoplasma* had never before been found in the Arctic.

The researchers don't know how the parasite affects the whales, but they say it presents a danger to Inuit people who eat whale meat. *Toxoplasma* can cause pregnant women to miscarry, although the parasite is otherwise thought to be harmless to healthy humans.

The grey seal and beluga examples may portend other health threats stemming from Arctic melting, Raverty said.

But making direct connections between climate change and animal health is difficult, said Sue Moore, a biological oceanographer at the National Oceanic and Atmospheric Administration in Seattle. "We need to know better how [parasite spread] corresponds to warming, to changes in diet," she said. If a link exists, uncovering it will probably require biologists and climate scientists to team up. "Right now the people who know about how warm water moves up the coast aren't talking to the people who know what's going on with the animals," she said. ■

A newly identified parasite killed large numbers of grey seals in 2012.

FROM TOP: M. GRIGG; CHARLES CARAGUEL

EARTH & ENVIRONMENT

Sharks could serve as ocean watchdogs

Tagged with sensors, fish gather weather, climate data

BY BETH MOLE

The same gray triangles that peek above ocean waves to terrify beachgoers could prove a boon for climate scientists. By strapping sophisticated sensors to sharks' otherwise ominous fins, researchers can now collect temperature and other environmental data from the far reaches of the Pacific.

Maintaining devices that monitor conditions in the ocean is expensive, said marine scientist Kim Holland of the University of Hawaii at Manoa; a crucial network of buoys in the tropical Pacific

MATTER & ENERGY

X-rays uncover hidden faces in Rembrandt painting

Even the best artists hem and haw over their work, including Rembrandt. An intense X-ray beam has revealed that the artist painted the same face in four locations on one canvas before settling on one spot and covering up the rest.

The oil painting, Rembrandt's 1662 "Syndics of the Drapers' Guild," depicts five drapers — cloth experts — working while a servant behind them looks out at the viewer.

Chemist Joris Dik of the Delft University of Technology in the Netherlands examined the piece for cryptic features using a portable, high-powered tube that shoots a beam of X-rays into the painting's canvas. The technique identifies materials at the surface and in the subsurface of the painting.

Dik reported February 14 that just micrometers under the surface, buried layers of white lead paint outlined three additional iterations of the servant's face in various locations.

The find shows how chemistry and new technology can give insight into the thought processes of historical artists as they created their masterpieces, Dik said. — *Beth Mole*

REMBRANDT HARMENSZOON VAN RIJN/WIKIMEDIA COMMONS

is currently operating at reduced capacity due to budget problems. Using sharks as ocean surveyors could provide a new source of data for scientists developing weather and climate simulations. "Sending sharks to do the heavy lifting makes a lot of sense," Holland said.

Although other animals, including seals, have proven useful as data collectors (*SN: 11/6/10, p. 12*), sharks represent an untapped resource. Holland and his team recently discovered that sharks take nightly dives as deep as 800 meters. They also take 1,000-kilometer-long unexplained excursions to the center of the Pacific. The sharks' deep and long jaunts provide unprecedented access to ocean waters unplumbed by scientists, Holland said February 14.

Off the coast of Hawaii, Holland and his team have begun fitting the fins of tiger and hammerhead sharks with sensors about the size and shape of an ice cream cone. Holland began the project to study the behavior of the ferocious fish, but he realized the data could be more widely applied. Future shark-mounted gadgets will record water oxygen levels and conductivity, which researchers use to estimate saltiness and other chemical properties. The data from the sensors are beamed to a satellite system above the ocean when the sharks surface.

"It's a great idea," said oceanographer James Overland of the National Oceanic and Atmospheric Administration, who is based in Seattle. More data are always useful, he said, adding that some of the research ships used for ocean monitoring cost $10,000 to $20,000 a day to operate.

Budget problems have jeopardized the Tropical Atmosphere Ocean array, a set of buoys across the Pacific set up by federal researchers to collect data and monitor El Niño and La Niña events. Around half of the buoys are in need of repair and no longer collecting data.

Holland also notes that curious, chomping sharks often destroy robotic monitoring vehicles such as gliders.

Animals such as sharks are helpful in monitoring the ocean, said oceanographer Jennifer Francis of Rutgers University in New Brunswick, N.J. In addition to providing inexpensive oceanographic data, the method also tracks variations in the animals' behavior, habitat and feeding spots, she added.

The U.S. Integrated Ocean Observing System in Silver Spring, Md., is currently building a national network for collecting data from tagged animals. "All of this gives us clues as to how the ocean is changing," said Zdenka Willis, the program's director.

"It is hard to pinpoint a single data stream as being most important," Willis said. But given that the Pacific is large and undersampled, she said, data from tagged animals are poised to become more important. ■

LIFE & EVOLUTION

Sexually deceived flies not dumb

Male bee flies fooled into trying to copulate with a daisy may learn from the awkward incident. Certain orchids and several forms of South Africa's *Gorteria diffusa* daisy lure pollinators by mimicking female insects. The most effective daisy seducers grow a dark, somewhat fly-shaped bump on some of their otherwise yellow-to-orange petals. Males of dark *Megapalpus capensis* bee flies go wild. Males' success locating a female bee fly drops in the presence of deceitful daisies, researchers from South Africa's Stellenbosch University report in the March 22 *Proceedings of the Royal Society B*. But tests show the daisy's victims waste less time trying to mate with a second deceptive daisy than with the first. Evolutionary costs might push the bee fly to learn from mating mistakes. — *Susan Milius*

Orangutans take to the ground

Logging has orangutans on the run in Borneo. But an unappreciated tendency to go to the forest floor and scoot short distances gives red apes a chance to survive in patchy, partially destroyed forests, researchers report February 13 in *Scientific Reports*. More than 1,400 unobtrusive video cameras recorded 641 instances of orangutan ground travel between June 2006 and March 2013. The apes left the trees as frequently in dense forests as in areas hit hard by logging, indicating that this is Bornean orangutans' natural behavior, say researchers led by Marc Ancrenaz of HUTAN/Kinabatangan Orangutan Conservation Program in Sabah, Malaysia. Ground travel enables orangutans to forage for shoots, termites and other food, Ancrenaz says. Adult males engaged in the most ground travel. Females — alone, holding babies or accompanied by youngsters — accounted for just 115 cases of ground walking. Orangutans, listed as endangered, have been spotted walking upright across tree branches on the island of Sumatra (*SN: 8/4/07, p. 72*) but are rarely observed trekking on the ground. Human observers make the apes reluctant to descend from their leafy homes, the scientists suspect. — *Bruce Bower*

BODY & BRAIN

Prosthesis provides sense of touch

A new prosthetic hand allows its wearer to feel a firm orange, a fluffy cotton ball and a hard piece of wood. The device, described in the Feb. 5 *Science Translational Medicine*, restored a man's sense of touch by stimulating nerves in his arm. After Dennis Aabo Sørensen lost part of his left arm in a fireworks accident, researchers implanted electrodes onto two of his arm nerves. When his prosthetic hand touched an object, these electrodes zapped Sørensen's nerves, which then sent touch signals to his brain. With this prosthetic hand, a blindfolded Sørensen could feel the differences between a baseball, a bottle and a mandarin orange, European researchers report. The device joins other prostheses designed to convey the sensation of touch *(SN: 11/16/13, p. 12)*, an advance that researchers hope will help prostheses seamlessly integrate with the body. — *Laura Sanders*

EARTH & ENVIRONMENT

Rivers of volcanic rock and gas froze ancient animals in time

The Jehol fossil beds of northeastern China have yielded such treasures as the oldest beaked bird skeleton and impressions of soft tissues from prehistoric mammals and reptiles. Now, evidence suggests that pyroclastic flows — high-speed rivers of volcanic rock and gas — buried these ancient creatures and preserved them for 120 million years. How the creatures settled on ancient lake bottoms and became mixed with volcanic debris had been a mystery. Scientists had speculated that the animals' corpses were flushed into lakes by rivers and then covered with ash, or that a massive volcanic eruption suffocated birds midflight. But tiny mineral grains mixed among the fossils suggest pyroclastic flows, a team led by Baoyu Jiang of China's Nanjing University writes February 4 in *Nature Communications*. Many skeletons assume a bent-limb posture typical for creatures entombed by sudden volcanic outpourings. The bones also show cracks resembling those on skeletons at Pompeii, which were buried by the eruption of Mount Vesuvius. — *Gabriel Popkin*

MATTER & ENERGY

Strong, lightweight material mimics the design of bone

Stacks of tiny honeycomb structures that resemble the build of bone can form superstrong, lightweight matter unmatched by current construction materials. Strong but light materials could be used in everything from armor to insulation, but the substances are tricky to design. The strongest known materials, such as steel, can withstand thousands of megapascals of pressure but have densities well above 1,000 kilograms per cubic meter. To design a tough material without the bulk, scientists at Germany's Karlsruhe Institute of Technology swiped the microstructure of bone, which consists of hollow units stacked into sturdy structures. Using ceramic-polymer mixes and 3-D laser printing, the team created airy but brawny honeycomb structures that were each roughly 10 cubic micrometers or smaller. The stacked honeycomb formations could withstand up to 280 megapascals of pressure — similar to metal alloys — but had densities below 1,000 kilograms per cubic meter. The team reports the findings February 3 in the *Proceedings of the National Academy of Sciences*. — *Beth Mole*

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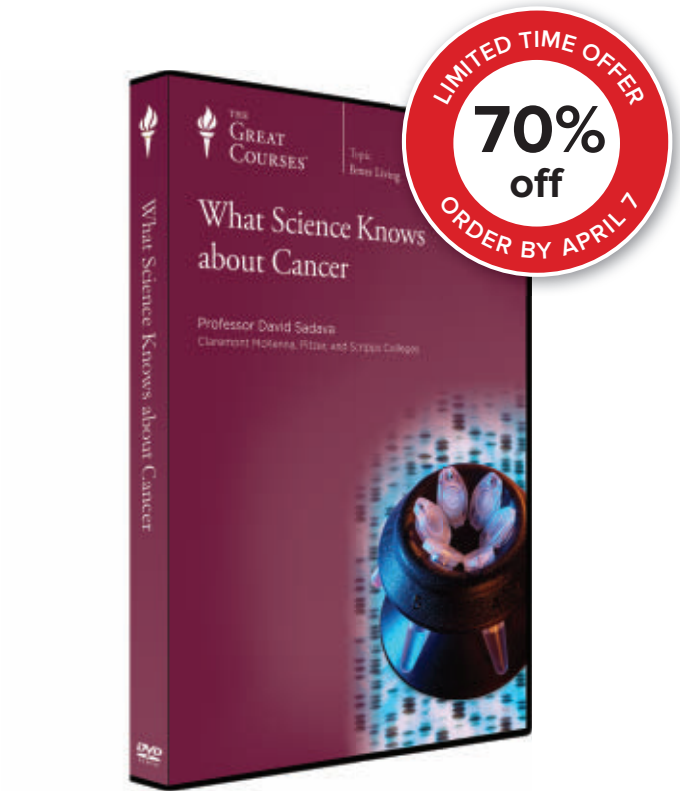

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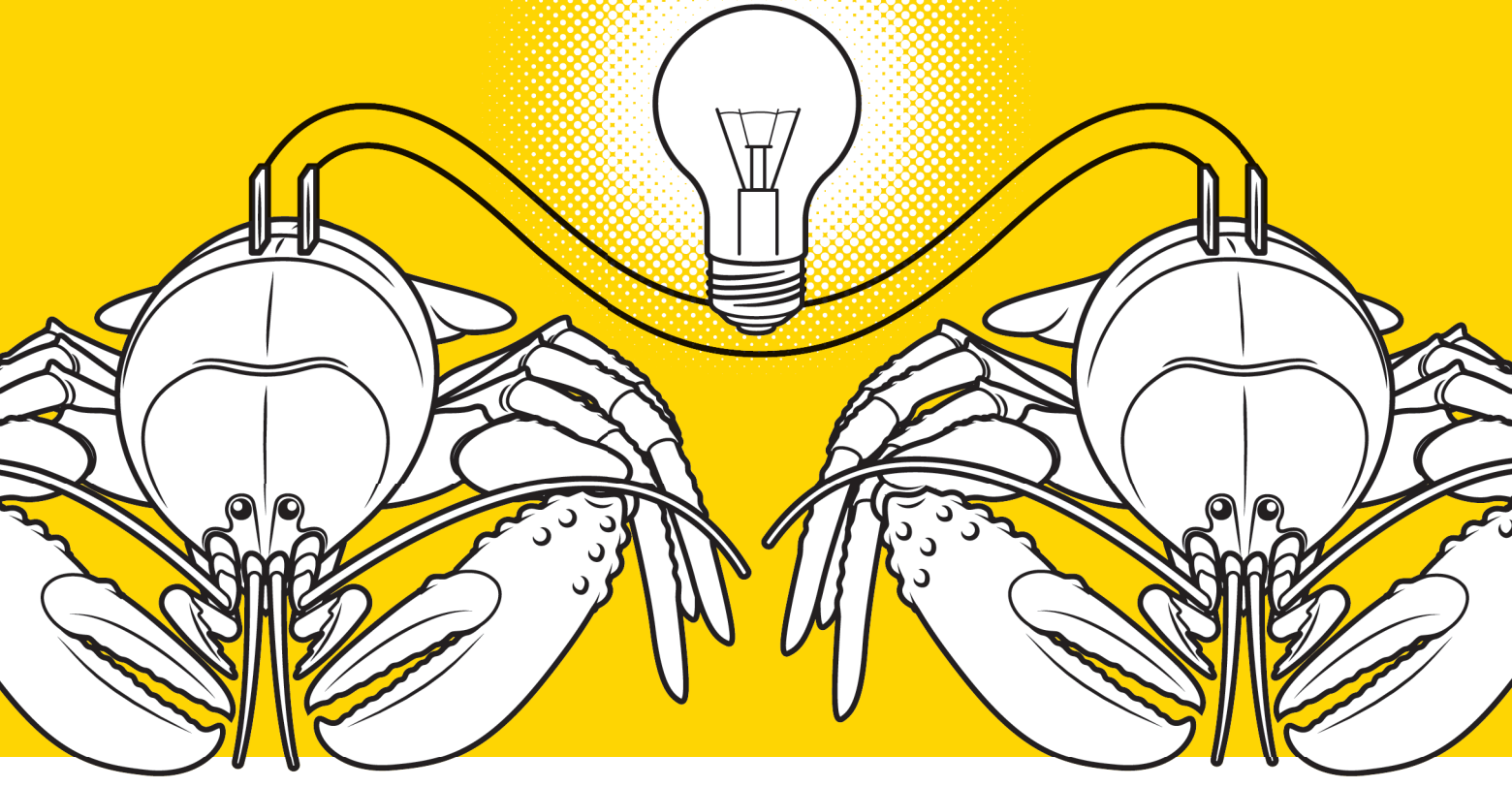


The body's chemistry may energize pacemakers or search-and-rescue roaches

By Sam Lemonick

Sometime in the future: A patient leaves the hospital with a new pacemaker implanted next to her heart to steady its beat. Her older brother, who went through the same procedure a few years earlier, will soon need another major surgery to replace his pacemaker's batteries. But she won't. Her device can generate its own electricity indefinitely with sugar and oxygen harvested from her bloodstream.

Scientists are racing to perfect the technology that could make this possible. If they succeed, these "biological fuel cells" could usher in a new wave of medical devices smaller and more versatile than today's batteries allow.

A pacemaker requires a lot of power, so it may not be the first medical device to go battery free. But what about a contact lens that monitors glucose levels in patients with diabetes? Powering it with the chemicals in tears is not so far-fetched. A patient-powered skin patch may one day measure temperature around a surgical wound to signal an infection.

Creative scientists have used snails, clams, rats and rabbits to power fuel cells for weeks at a time. A cluster of lobsters even managed to keep a wristwatch ticking. Someday, plants or half-robot insects wearing biological fuel cells could sniff out pollutants, search for earthquake survivors in collapsed buildings or eavesdrop on secret conversations.

To realize this sci-fi future, scientists first have to solve serious problems with the longevity of biological fuel cells and find ways to squeeze more power out of them. But they've shown startling progress in the decade since the first implanted biological fuel cell — in a grape — emitted power.

A constant supply of energy

Biological fuel cells run on some of the same fuels our bodies do, such as glucose. In general, a fuel cell uses chemical reactions to generate electricity. Batteries do the same, but all their fuel is stored inside. When it runs out, the battery dies. Fuel cells require constant input, like an engine.

Most biological fuel cells depend on enzymes, chemicals in our bodies that speed up reactions. These catalysts perform a range of complex and specific tasks inside cells. The enzyme glucose oxidase is a large molecule, hundreds of times bigger than the fuel that it breaks down, glucose. It is a long strand

JAMES PROVOST

twisted into a lumpy ball with an internal pocket shaped so that only glucose fits into it. In this protected nook, the reaction that splits glucose into molecules that cells can use happens without interference.

What an enzyme can accomplish in one action, a chemist would need dozens of steps to achieve, adding just the right amount of each ingredient at just the right time and carefully controlling temperature, pH and other factors to ensure that the desired transformations — and only those — take place.

At its most basic, a biological fuel cell is two enzyme-coated conductive wires implanted in tissue, a blood vessel or a nerve. Scientists have made these wires as thin as 5 micrometers, small enough to fit inside a nerve cell in the brain. The most common versions work like this: One wire, the anode, is coated with an enzyme, such as glucose oxidase or GOx, that reacts with glucose. The other wire, the cathode, is coated with an oxygen-reacting enzyme, for example, bilirubin oxidase or BOx. When GOx reacts with a glucose molecule, the enzyme takes two electrons from glucose. Meanwhile, BOx adds four electrons to an oxygen molecule. When the anode and cathode are connected, the electrons can flow from GOx to BOx, creating an electrical current. Add a light bulb to the connection and it would glow — at least in theory.

0.5
Voltage of a glucose-and-oxygen enzymatic reaction

1.5
Voltage of a AA battery

2.6
Minimum voltage recommended for a typical pacemaker

The enzymatic reaction cycle of glucose and oxygen produces about half a volt of electricity. Not much. By contrast, a AA battery carries about 1.5 volts. Medtronic, maker of one common pacemaker, recommends replacing the battery when it can produce no more than 2.6 volts.

In 2003, chemist Adam Heller revived an idea first put forth by artificial heart developers in the 1960s. They saw the potential of using enzymes as highly specific and effective catalysts in biological fuel cells. Heller, of the University of Texas at Austin, made the idea a reality. In a grape, a fruit high in glucose, he devised the first implanted enzyme-based biological fuel cell.

Heller's tiny power plant was groundbreaking, but it had practical drawbacks. Within 20 hours, its power output fell by half because side reactions with the enzyme caused buildup on the cathode, reducing its conductivity. Publishing his findings in *Physical Chemistry Chemical Physics*, Heller predicted the lifetime of glucose-oxygen biological fuel cells might eventually reach weeks, far short of the years-long lifetime necessary to compete with batteries.

So far, Heller has been right. No research group has done much better than weeks, but researchers continue to push for more, tweaking and adapting Heller's prototype.

Progress came in 2009, when Serge Cosnier and his team at Joseph Fourier University in Grenoble, France, demonstrated the first enzymatic biological fuel cell implanted in an animal.

Cosnier's fuel cell functioned for 40 days in a rat's abdomen. Although it produced only 0.13 volts, about one-quarter the voltage of Heller's grape, the experiment showed that animals can tolerate long-term implantation.

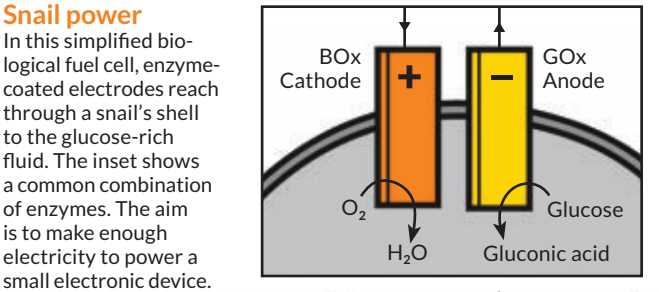
Like Heller's, Cosnier's biological fuel cell lost power quickly, as the cells consumed the available oxygen and glucose in their vicinity, his team reported in *PLOS ONE*. In animals with complex circulatory systems, it takes time to move blood around to replenish these fuels, and because oxygen is less plentiful than sugar, it usually runs out first. A Japanese group led by Matsuhiko Nishizawa solved this problem with a fuel cell open to the air. After demonstrating the principle in a grape, his group at Tohoku University is now adapting the idea into a power-generating patch. This flexible biological fuel cell would have the oxygen-fueled cathode on top, exposed to the air, while an array of tiny needles on the underside would reach sugars in the skin or tissue beneath.

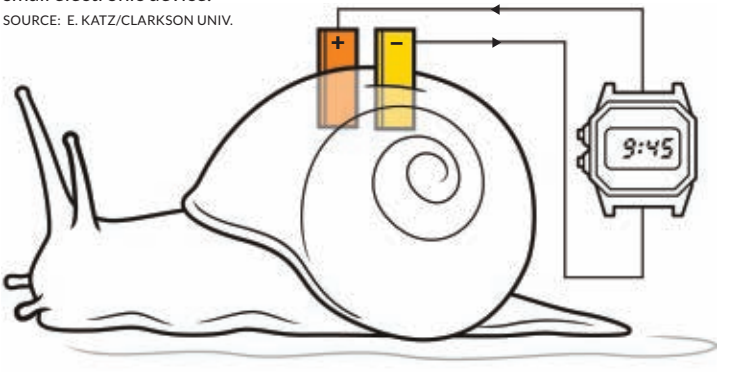
Bugs as spies

Clams, insects and lobsters offer a neat way around the fuel delivery problem. Invertebrates don't have the system of blood vessels most vertebrates do. The difference is like comparing a go-kart track to bumper cars. Rather than having to follow a closed course, the glucose and other molecules can travel more freely around invertebrates' bodies. This greater fuel availability makes organisms with open circulatory systems attractive targets for enzymatic biological fuel cells.

Chemist Daniel Scherson at Case Western Reserve University in Cleveland prefers to work with insects. "It's a nuisance to get permission to deal with animals," he says. "NIH doesn't

Snail power
In this simplified biological fuel cell, enzyme-coated electrodes reach through a snail's shell to the glucose-rich fluid. The inset shows a common combination of enzymes. The aim is to make enough electricity to power a small electronic device.
SOURCE: E. KATZ/CLARKSON UNIV.





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regard insects as animals, so you don't need an ethics review of insect trials." In a 2012 report in the *Journal of the American Chemical Society*, Scherson and colleagues explain how they devised an air-breathing enzymatic biological fuel cell using cockroaches.

He sees cockroaches as the next generation of first responders. "There is a real problem in creating a self-powered drone that can, for example, crawl under rubble," Scherson says. Better than a robot, he thinks, would be a roboticized insect. Biological fuel cells could power communications between the bug and a remote operator who controls its movements.

My little cyborg A Michigan company sells RoboRoaches, whose movements are controlled from a smartphone. Biological fuel cells might make roboticized insects more versatile for search-and-rescue or spy missions.

The idea's not that far out. Researchers at North Carolina State University, in Raleigh, have demonstrated that they can control some movements in both cockroaches and moths. Scherson envisions adding a biological fuel cell that would provide power for the electronics controlling a roboticized insect or for sensors that could tell first responders if an area is safe for humans. He has already demonstrated a basic version of this: a living, mobile cockroach that generates its own power to broadcast a signal to a receiver.

He also thinks the design could be adapted with microphones or cameras to recruit bugs as spies. "If a fly was flying in a room or stuck to a wall, nobody would think that was anything special," he says. "Unless the bug had a self-powered recording device." He says the CIA has already been in touch.

Three creatures better than one?

Two years ago, Evgeny Katz decided to push the boundaries further, looking for new approaches and collaborations to speed progress toward field-ready devices. With a thick Russian accent and a burst of white hair and mustache, Katz's optimism is infectious.

He began with a snail. Like others before him, Katz saw electrical output in his fuel cell drop off quickly, falling by three-quarters in the first half hour. However, his team at Clarkson University in Potsdam, N.Y., found that the original levels could be reached again and again if the snail was given food and allowed to rest.

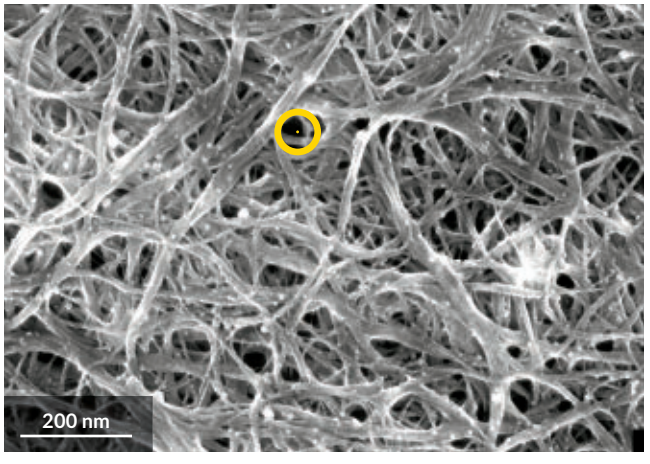
To get more power, Katz began wiring animals together. Three clams with biological fuel cells turned a small electric motor in an experiment reported in the September 2012 *Energy & Environmental Science*. The following year, his team used two lobsters to power a digital watch. Katz then came as close as anyone to realizing one of the technology's longest-sought goals: Using laboratory equipment to mimic the conditions in a human circulatory system, Katz ran a pacemaker using five connected biological fuel cells.

It was a big achievement, but it doesn't translate well to live animals. When he tried implanting two biological fuel cells in a single lobster, he was surprised to find they made only slightly more power than one cell on its own. The lobster, with its conductive fluid and tissue, was short-circuiting. Instead of completing a circuit through all four electrodes, the current skipped from one cell's cathode to the other's anode, leaving half of the electrons — and their electrical energy — stranded.

Even worse, Katz realized, the enzymes were woefully inefficient. He calculated that during his snail experiment only 6 percent of the enzymes were generating electricity. The chemical reactions with glucose were happening, but the enzymes weren't making a good connection with the electrode. "Inside the pretty big enzyme there is a small protected piece responsible for reactions sitting somewhere in the middle," says Katz. Good for enzyme selectivity; bad for generating power when the electrical connection can't reach deep inside the enzyme.

One solution is to embed the enzymes within a conductive substance that coats the electrode and can offer a bridge to the electrode for electrons. It's worked for Heller, Cosnier and Scherson, but the conductive mediator adds bulk to the biological fuel cell. Katz experimented with buckypaper electrodes to offer more connecting surface area for the enzymes. Buckypaper is made of tangled carbon nanotubes compressed into a sheet. Unfortunately, some of the tangles leave big holes between fibers. Enzymes can float in these holes without touching the conductive carbon.

"The distances between the nanowires are approximately 100 or 200 nanometers," Katz says. "The size of the enzyme is



Flattened tangles of conductive carbon nanotubes, each thousands of times thinner than a human hair, make up buckypaper, a high-tech material being tested as body armor, or in this case, as a conductor on an electrode in a fuel cell. An enzyme (inside yellow circle) can float in the spaces between strands, missing the crucial electrical connection.

FROM TOP: COURTESY BACKYARD BRAINS; ALAN G. MACDIARMID/NANOTECH INSTITUTE

much smaller, about 5 nanometers." He thinks only better nanotechnology can solve that problem, by adding conductive gold nanoparticles to fill space in the buckypaper or finding a way to compress the nanotubes more tightly.

Better electronics

Limited by the energy in a glucose molecule, research groups have struggled to produce the kind of power needed for implantable medical devices. Heller's grape made a little more than half a volt. Lobsters and clams don't do much better.

To break through these fundamental limitations, Katz has partnered with Patrick Mercier, an electrical engineer at the University of California, San Diego, to improve the electronics of biological fuel cells. Mercier is building circuits and transmitters that could operate within the capabilities of enzymatic biological fuel cells.

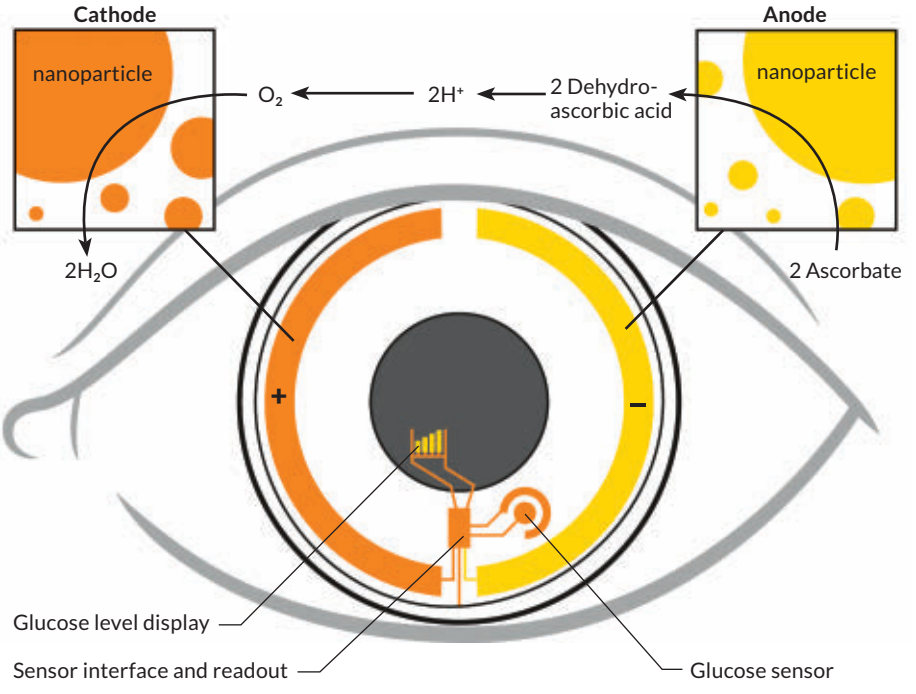
"I can design electronics that will try to optimize the amount of energy that we can extract from the biological fuel source," Mercier says. This could include regulating the enzyme reactions to limit fuel consumption so the cell doesn't run through all the available sugar or oxygen so quickly. He is designing converters that can step up the voltage that biological fuel cells produce to a level better suited for electronics. He and Katz have also tested capacitors, which store and quickly discharge small amounts of electricity. In a video available online, Katz's team uses a lobster to charge a capacitor, which he gleefully uses to power a small fan — briefly.

These advances may yet lead to battery-free pacemakers. But the advantages of air-breathing cathodes like Nishizawa's mean that biological fuel cells on patches or other external arrangements will probably appear before truly implantable fuel cells.

Contact lenses, for example, could carry sensors to monitor health, or come equipped with miniaturized displays, cameras and other electronics. Google announced in January a design for a contact lens that could help diabetics monitor their blood glucose levels. The company designed its lens to be powered wirelessly. Although it hasn't released the full details, almost all wireless power systems waste large amounts of energy in transit. Sergey Shleev of Malmö University in Sweden says biological fuel cell power may be a better option.

Shleev has designed a similar lens that runs on human tears, which contain many of the same compounds as blood and other fluids. In lab tests described last year in *Analytical Chemistry,* he demonstrated a biological fuel cell that runs on vitamin C, or ascorbate, from tears collected from volunteers. "I can provide a biological fuel cell making a small amount of power," Shleev says. "Can we incorporate useful electronics into the lens with those power requirements?" Google seems to have shown that it can, and Shleev says he is testing his own prototype for a competing human-powered lens.

Before your eyes Chemist Sergey Shleev is working on a prototype of a fuel cell–powered contact lens that could help diabetics monitor their glucose levels. In his design, the biological fuel cell's electrodes are adapted to curl around the outside of a contact lens, while a second cell monitors glucose and presents a simple reading on the edge of the user's view. SOURCE: S. SHLEEV/MALMÖ UNIV.



In 10 years, enzymatic biological fuel cell researchers have shown small but measurable progress. "The power density is there and if we can get these to work over a long period of time, absolutely we can use these to power pacemakers, possibly cochlear implants," Mercier says, optimistic that the limits that Heller ran up against may some day be surpassed.

Scherson recalls the moment he powered up his latest cockroach: "Now, we have constructed a cyborg." Reality seems more like science fiction every day. But any sentient computers out there, please note: It will probably be a few more years before you can wire us up as living batteries to power your *Matrix* dreams. ■

Explore more

- E. Katz & K. MacVittie. "Implanted biofuel cells operating in vivo – methods, applications and perspectives." *Energy & Environmental Science.* October 2013.
- M. Falk *et al.* "Biofuel cells for biomedical applications: colonizing the animal kingdom." *ChemPhysChem.* July 22, 2013.
- How to Harvest Electricity from Lobsters video: bit.ly/SNelectriclobster

Sam Lemonick is a freelance writer based in Washington, D.C.

JAMES PROVOST

QUANTUM TIMEKEEPING

Physicists are exploring the mind-blowing possibilities of linking a new generation of atomic clocks

By Andrew Grant

The best clock in the world has no hands, no pendulum, no face or digital display. It's a jumble of lasers, wires and strontium atoms in Jun Ye's lab at the National Institute of Standards and Technology (NIST) in Boulder, Colo. He keeps it cooled to about three millionths of a degree above absolute zero.

The clock, described by Ye in the Feb. 6 *Nature*, is so precise that had it begun ticking when Earth formed 4.5 billion years ago, it would not yet have gained or lost a second. Over that span, a Swiss quartz watch would stray at least a few thousand years.

Ye's atomic, or optical, clock is impressive, but it's just one step toward an ambitious timekeeping goal. He and his colleagues at JILA, a joint institute of NIST and the University of Colorado Boulder, envision 10 or more atomic clocks, installed in satellites and international labs, and intricately connected to form the equivalent of one global superclock. Whenever Ye checked the time with the atom-probing laser in his Colorado laboratory, his clock would be connected with every other clock on the network — instantaneously, regardless of distance — and deliver a reading hundreds of times as accurate as those produced by today's atomic clocks.

A network of clocks that accurate would have staggering capabilities. It would provide a level of worldwide synchronicity that is impossible with current technology. And synchronicity matters in an interconnected world in which electric utilities, Internet servers and financial companies coordinate their services to the nanosecond and want to do even better.

Remarkably, a global superclock would also be able to measure things that have no intuitive connection to time. Because time and gravity are innately linked according to Einstein's general theory of relativity, researchers would be able to use a clock as a sort of scale, correlating subtle fluctuations in a clock's ticking rate with the mass below it. Clocks flying above enemy territory could detect missing mass below the surface — perhaps the location of a secret underground tunnel or cave.

Building this clock network would be complicated but far from impossible. The key is coupling the steady advances of atomic timekeeping

S. EGTS

with quantum entanglement, the intricate connection of subatomic particles that is nearly as mysterious now as it was when Einstein deridingly called it "spooky" nearly 70 years ago. Exploiting this mind-bending phenomenon to create instantaneous quantum links across vast distances may yield the most complex timekeeping device in human history.

The ticket to greater certainty

Physics seemed to make a lot more sense before quantum mechanics, the theory that deals with the behavior of matter at atomic and subatomic scales, was proposed in the mid-1920s. In classical physics, objects large and small have definitive properties: An electron, for example, exists at a certain place at a certain time and possesses a certain spin. But the realm of quantum mechanics is ruled by randomness. An electron can be located in multiple places and spin in multiple directions at once — it can exist in what's called a superposition of states. Only when someone measures the electron does it settle on a specific set of characteristics.

The more scientists dug into the equations underlying quantum mechanics, the more counterintuitive the theory became. In 1935 Einstein, along with colleagues Boris Podolsky and Nathan Rosen, performed one of his famous thought experiments and realized that, in theory, multiple particles could interact and maintain a strange connection once separated. At first the particles would each remain in a superposition state, encompassing several properties simultaneously. Yet someone measuring one of the particles would immediately be able to determine the properties of the others. This instant connection held true regardless of the distance between particles: centimeters, kilometers, even light-years (*SN: 11/20/10, p. 22*).

Einstein seriously doubted that particles could maintain such an intimate long-distance relationship; he later called the illogical result "spooky action at a distance." Austrian physicist Erwin Schrödinger was far more open to the possibility. He coined the term quantum entanglement.

Atomic clocks are so precise that physicists can measure time to the quintillionth (10^{-18}) of a second with confidence. An entangled clock could do even better.

Today, physicists still aren't sure how multiple particles manage to coordinate their properties instantaneously. The phenomenon is most definitely real, however, and researchers are getting very good at demonstrating it in the lab.

In 2011, an Austrian team including Thomas Monz at the University of Innsbruck entangled 14 calcium atoms by squeezing them together with laser light (*SN Online: 4/10/11*). Before Monz's team made a measurement, each atom sat in a superposition of two possible electron configurations. But when the researchers measured the configuration of one of the atoms, the other 13 atoms instantly took on the same state. Due to entanglement, the 14 atoms behaved like one mega-atom.

Results like this are more than just a cool trick, says Harvard physicist Eric Kessler. In a realm ruled by randomness, entanglement is the ticket to greater certainty. A set of 14 atoms, each with two possible states, results in 16,384 possible combinations. But by entangling the atoms, Monz's team reduced the list of possibilities to two. In other words, instead of having to flip 14 coins, the researchers needed to flip only one megacoin.

A research team including Kessler and Ye proposes that scientists exploit this phenomenon to improve the accuracy of atomic clocks. Rather than flipping coins, however, they want to consolidate pendulums.

The key to a good clock is a pendulum that oscillates at a constant rate. Fortunately, nature offers the perfect pendulums: atoms. For a given atom, only discrete amounts of energy will coax one of its electrons to jump between energy levels. Over the last half-century, physicists have tuned lasers to shine with the exact energy

required to hasten those electron jumps. The frequency of the laser should be the same for every clock tuned to a particular type of atom, since that frequency is tied to the atom's intrinsic, immutable electron transition energy. (For cesium-133, the atom that calibrates the world's clocks, the frequency corresponds to microwave radiation oscillating 9.2 billion times a second.) In theory, the laser taps into a pendulum that never strays (*SN: 10/22/11, p. 22*).

But in practice, the pesky randomness of quantum mechanics fundamentally limits the fidelity of frequency measurements and thus the precision of cesium clocks. Ye's new strontium clock does better because it divides time into shorter pendulum swings, using visible-light lasers that oscillate 430 trillion times a second, and it probes several thousand atoms rather than just one. But even it is not immune to quantum randomness.

> "These atoms will act ... as one giant pendulum that can keep time much more accurately."
>
> **ERIC KESSLER**

Entanglement is the key to chipping away at that randomness, according to Ye, Kessler and their team. Their paper, posted online last October at arXiv.org, envisions a clock of entangled atoms that reduces noise by virtue of quantum connections between its components. Just as Monz's team consolidated 14 atoms into one mega-atom, Kessler says, "these atoms will act not as individual pendulums but as one giant pendulum that can keep time much more accurately."

While Ye hasn't yet entangled the atoms in his clock, he's comparing notes with a small group of quantum physicists that is already trying to devise entangled timepieces. James Thompson at JILA and Vladan Vuletić at MIT are working to squeeze clock atoms together with lasers, similar to Monz's technique. "It's really exciting talking to these guys and testing these ideas out," Ye says.

Creating individual entangled clocks is nice, but they serve no practical purpose sitting on a table in a laboratory. NIST broadcasts its cesium clock signal over the radio for use by consumers, businesses and scientists. Global positioning systems calculate a user's location by having multiple clocks compare the time it takes for microwave radiation to travel to various satellites. And the International Bureau of Weights and Measures near Paris receives time readings from clocks worldwide to set its Coordinated Universal Time, or UTC, standard. Clearly, Ye says, "linking clocks is absolutely necessary." The same goes for entangled clocks.

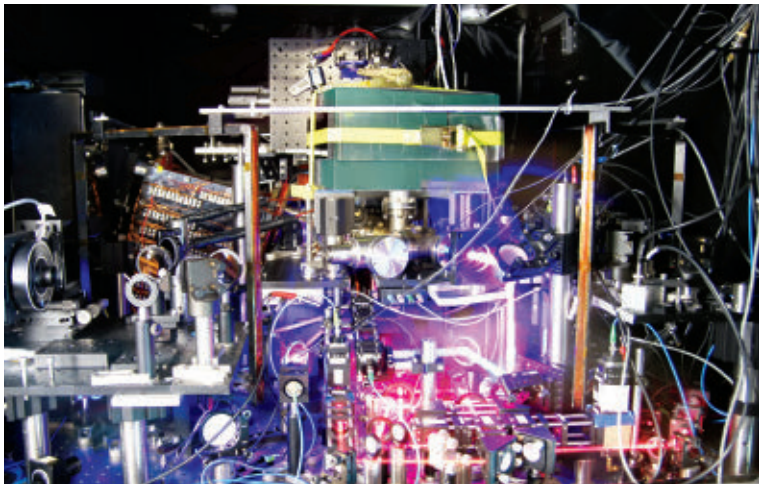
Transmitting time

The problem is that the faster an atomic clock pendulum swings, the more difficult it is to share that signal. Ye can't broadcast the visible-light signal from his strontium clock over the radio because it oscillates too quickly. That means scientists have to develop new technology that transmits visible-light timing signals from optical clocks. The trick is to pin down the sources of noise that skew the signal and counteract them, much like noise-canceling headphones.

Physicist Stefan Droste at the Max Planck Institute of Quantum Optics in Garching, Germany, is on the case. In September he and his team sent an optical timing signal through a 1,840-kilometer underground fiber-optic cable. He's now working with French researchers to link an optical clock in France with one in Germany. Meanwhile, in the mountains near Boulder, physicist Nathan Newbury recently reported success beaming optical signals through the air between his lab at NIST and a mesa about two kilometers away. It's a first step toward beaming signals from clocks like Ye's to and from satellites.

Droste's and Newbury's work is important because it could allow the world to share more precise time signals. But Ye and his colleagues argue that sharing isn't enough. They point out that there is no physical device that serves as a master world clock. UTC is actually a paper clock. Its "time" is derived by averaging the readings received from

The world's most precise and stable clock, located in Boulder, Colo., works by tuning lasers to the exact internal frequency of strontium atoms.



YE GROUP AND BRAD BAXLEY/JILA

some 200 cesium clocks around the world — a calculation that takes time to do. The result is that nobody — not even Ye, the man with the world's best clock — knows what time it is right now (see sidebar, this page).

This lag in determining the world's time is not an easy problem to fix. No matter the performance of individual clocks scattered around the world, scientists can't share that information with each other any faster than the speed of light. "It would be nice to be able to know what time it is at different places without having to make a phone call," says Chris Monroe, a physicist at the Joint Quantum Institute at the University of Maryland in College Park.

Which brings us back to Einstein's spooky action at a distance. In their October arXiv paper, Ye and his team propose constructing a network of entangled clocks that are also entangled with each other. That means that by measuring the frequency to excite one atom in one clock, a user would in a sense have access to every atom in every clock on the network. The result would be an unprecedented world clock made up of satellite clocks that each have immediate access to the exact time. "Any clock in the network could realize the [UTC] instantaneously," says Andrew Ludlow, a NIST physicist who did not contribute to the research.

To intricately link clocks thousands of kilometers apart, physicists would have to deliver entanglement from clock to clock through a process called quantum teleportation. The idea dates back only 20 years, but physicists have already exploited teleportation — the transfer of quantum information over long distances — with impressive success. In 2007, Anton Zeilinger of the Vienna Center for Quantum Science and Technology and colleagues teleported the polarization state of one photon to another photon about 143 kilometers away (*SN: 6/30/12, p. 10*).

In the Ye team's scheme, scientists would generate a pair of entangled photons and send them via satellite or fiber-optic connection to link two clocks. The photons pass through each clock and interact with the clock's atoms, passing on the entangled state. The same process can hook up the other clocks in the network. Once all the clocks are entangled, Kessler says, measuring one atom in one clock would derive information from every atom of every clock in the global network. In effect, all those atoms would combine forces to create an extraordinarily precise pendulum.

Put all the facets of the plan together — entangling multiple clocks each made up of entangled atoms — and the result is a master world clock that gives users instant access to a time measurement with as much as 10 times the precision of Ye's cutting-edge optical clock. For the first time, the world's standard-setting clocks could be perfectly synchronized.

Does anybody really know what time it is?

The international time standard — Coordinated Universal Time, or UTC — is a calculation, not a physical clock. That makes timekeeping a bit fuzzy. The International Bureau of Weights and Measures near Paris collects time readings from about 200 atomic clocks in more than 50 international labs and then, once a month, averages the results.

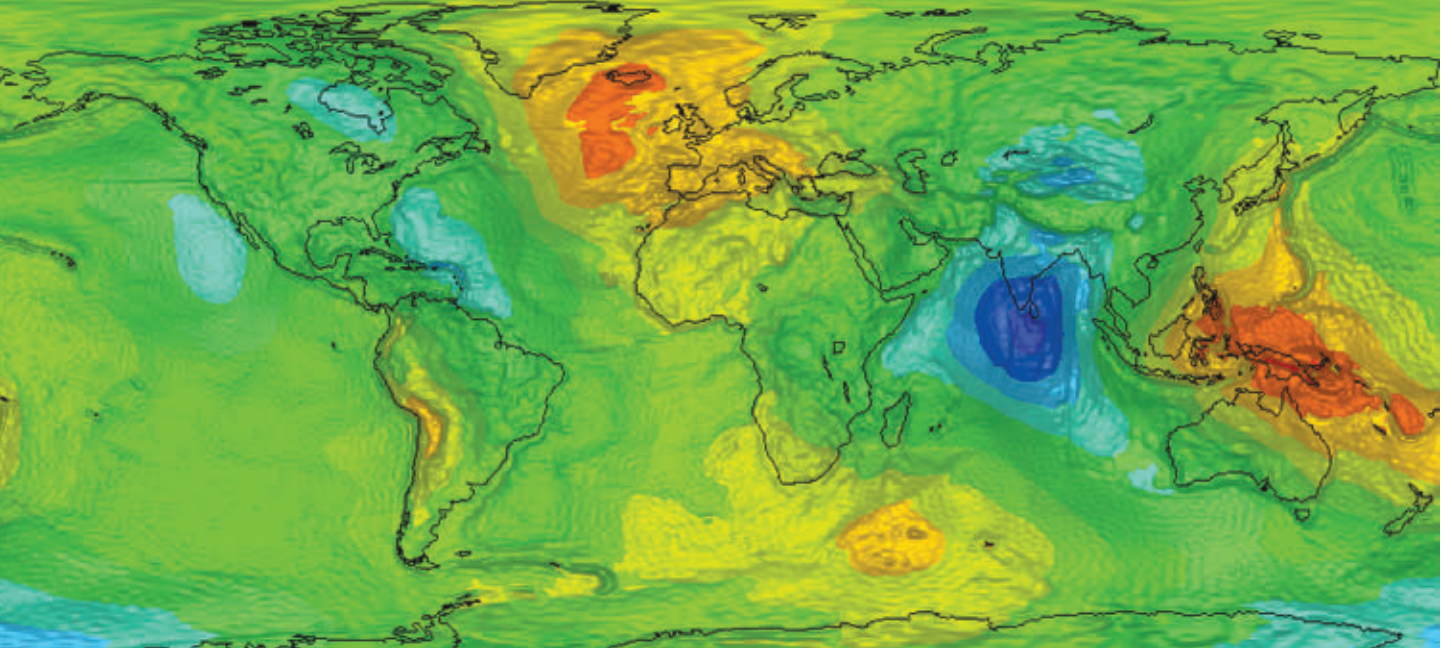
Judah Levine, the official U.S. timekeeper for more than 40 years, does his best to align U.S. clocks with UTC. Several times a day, he sends a file to the bureau with the time he thinks it is, based on the cesium clock at the National Institute of Standards and Technology in Boulder, Colo.

Around the 10th of each month, he gets an e-mail response telling him how wrong he is, based on the previous month's data. Levine then tweaks his clock's ticking rate — usually by a nanosecond per day. "I have to make an estimate of where I am today," he says, "because I won't know until a month from now." — *Andrew Grant*

Sky's the limit

A supercharged quantum clock network could do much more than tell time. According to general relativity, clocks tick at slightly different rates depending on the strength of the gravitational fields acting on them. For example, atomic clocks on GPS satellites gain about 45 microseconds on ground-based clocks each day because Earth's gravitational pull is weaker on objects at high altitude than it is on objects at the surface.

Put an ultraprecise clock inside a satellite and the time will fluctuate based on more than just altitude. Earth's gravitational pull varies ever so slightly at different points on the surface depending on the amount of underlying mass. Ye says that a pair of satellites fitted with superclocks could sweep over points on Earth to discover hidden geological features, such as magma migrating underground prior to a volcanic eruption.



Surveying Earth's gravity Maps from the GOCE satellite reveal variations in Earth's gravitational field. The colors represent the field's strength at various points on the surface: Red regions have stronger gravity than the average, blue shows zones of weaker pull. Satellites equipped with quantum-linked clocks would do far better at measuring these variations, potentially revealing secret caves and imminent volcanic eruptions.

Monroe suggests even grander, and perhaps unnerving, applications for security and defense. He estimates that these clocks would be able to carefully map the shape of Earth's terrain down to the millimeter. "You'd be able to see someone digging a tunnel under the U.S.-Mexico border from space," he says. The military could fly a pair of satellites over an enemy landscape and map every cave potentially inhabited by terrorists. "The satellite closer to the cave will experience less gravity, and thus will tick faster, than the satellite farther away," Ye explains.

It sounds great, but physicists still have a long way to go before they can implement these Earth-scanning satellites. Entangling 14 atoms in a carefully controlled lab setting is very different from entangling thousands of atoms in a dozen clocks scattered all over the world. And although teleporting a few photons over 140 kilometers is impressive, a quantum clock network would have to consistently transport individual photons from ground stations to satellites and back, all while preserving the particles' delicate superposition states.

"We're really quite far from doing this," says Jacob Taylor, a colleague of Monroe's at the Joint Quantum Institute. Monroe agrees, but says that he's still impressed by the idea because it combines several efforts that physicists are pursuing anyway. "It brings multiple aspects of quantum information science into one big cosmic unit," Monroe says.

For example, quantum computing researchers are exploring the same mechanism that enables entangled atoms to measure time (*SN: 3/10/12, p. 26*). Quantum computers would exploit the superposition states of atoms or photons — think Monz's 14 atoms before they were measured — to store and process enormous amounts of data. While 14 memory cells of a conventional computer can hold 14 bits of information, 14 quantum bits, or qubits, would hold 16,384 bits simultaneously.

Meanwhile, the teleportation required to link up clocks could help create secure quantum communication networks. Physicists envision building quantum channels in which users exchange information encoded in atoms or photons in superposition, just like atoms in the clock. Eavesdroppers trying to listen in on a conversation would disturb that fragile superposition state, exposing their presence.

The list of potential uses for quantum entanglement and teleportation goes on, and physicists will come up with new ideas as they toy with the amazing toolbox quantum mechanics provides. "This field has been waiting for a big killer application," Monroe says.

That quantum breakthrough just might come in the form of a superclock beyond compare. "It's a big challenge to build such a global device," Kessler says. "But all the building blocks are there." ■

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Explore more

- Peter Kómár *et al.* "A quantum network of clocks." arXiv:1310.6045. Posted Oct. 22, 2013.

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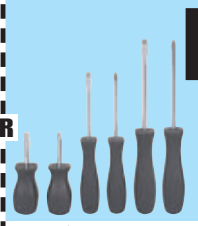

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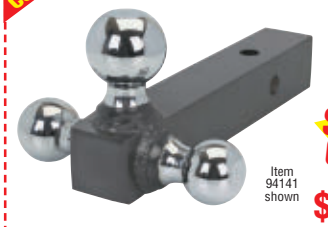

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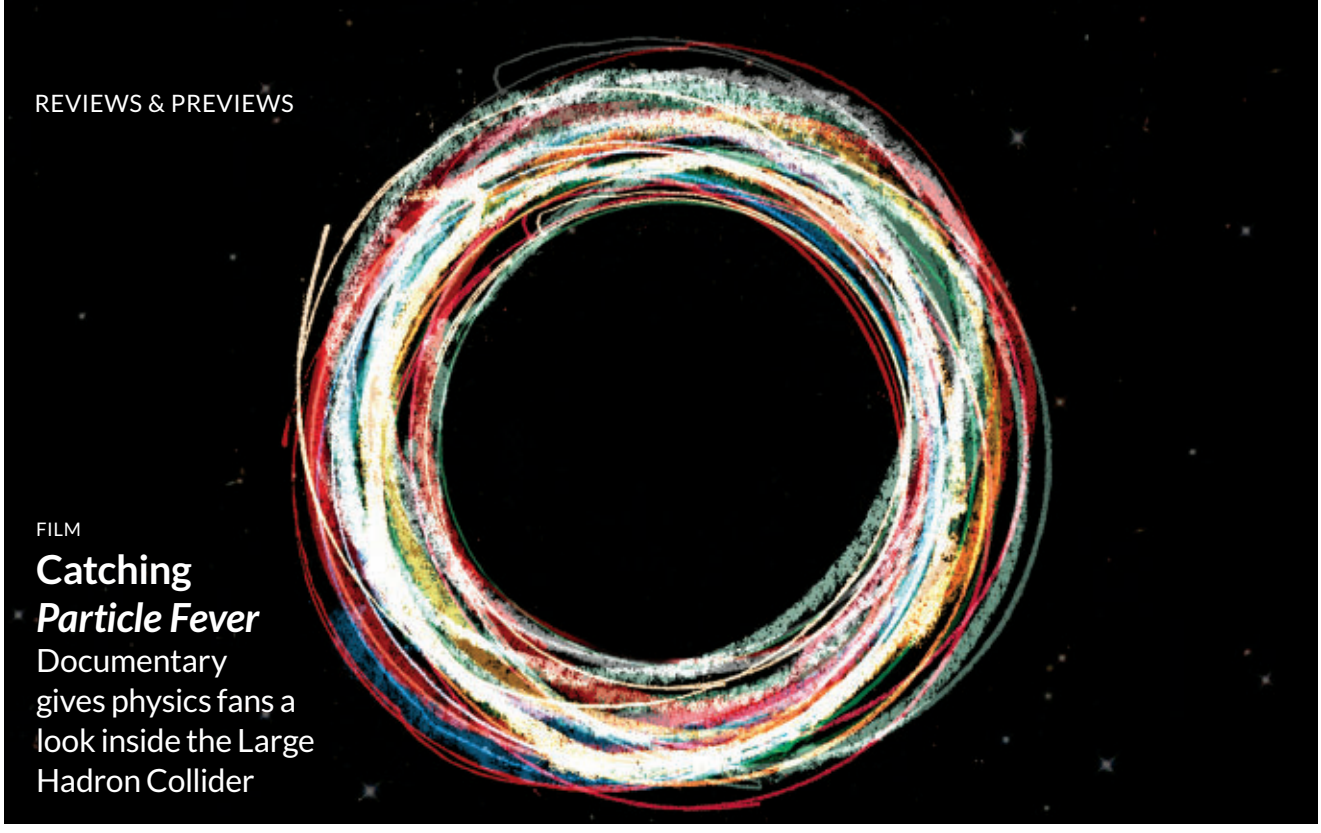


FILM

Catching *Particle Fever*

Documentary gives physics fans a look inside the Large Hadron Collider

There's a brilliant dreamlike sequence about halfway through the documentary *Particle Fever*, when theoretical physicist Nima Arkani-Hamed enters his building at the Institute of Advanced Studies in Princeton, N.J., looking troubled. Cartoon equations and figures swirl around his head. As he walks upstairs to his office and starts to work, the building's windows fall away. Shortly thereafter, the whole world disintegrates into a mess of alternate universes, almost none of which could support life. Could our existence be an accident, the film asks, and our attempts to understand nature a folly?

"This is the sort of thing that really keeps you up at night," Arkani-Hamed says. In the film, much of his life's work is riding on measurements emerging from the Large Hadron Collider, a giant ring-shaped particle accelerator under the Franco-Swiss border. The stakes are high too for David Kaplan, the Johns Hopkins physicist who conceived the film. But to do these theory-confirming or theory-busting measurements, thousands of experimentalists inhabiting the collider's tunnels and control rooms first have to get the machine to work — no small task.

These experimentalists, practical and hardheaded, are the yin to the theorists' yang. While Arkani-Hamed spins yarns with hair flying, LHC physicist Monica Dunford coolly dons a hard hat and plunges into the collider's electronic guts. Thanks to her and her colleagues' efforts, the machine eventually delivers data that confirm the proposition a handful of theorists dreamed up 50 years ago: An unseen particle called the Higgs boson explains why matter has mass (*SN: 7/28/12, p. 5*). The experimentalists cheer and pop champagne bottles; the theorists, tuning in from Princeton, clap too, but quickly get busy revising old theories and devising new ones.

Interspersed with the plot are artful explanatory animations and commentary by the six articulate physicists who carry the story. Through these characters, we learn that billions of dollars have been spent not just to find a particle; the discovery of the Higgs is a stepping stone toward a deeper understanding of the universe. Kaplan says the fate of his whole field hinges on making this clear to the politicians and public who will be needed to fund future accelerators.

The film, like the collider it chronicles, is not flawless. Viewers who haven't followed the LHC saga in the media may have trouble connecting the somewhat disjointed plot points. And physicists at work are not the most cinematic bunch: Much of the film consists of people staring at computer screens, writing equations on blackboards and drinking coffee. But this is a quirky and brilliant bunch of people, who in all earnestness say things like "Did you guys see our beautiful plot?" and "I really feel attached to this dataset." It's worth getting to know them a bit.

Kaplan began filming in 2007, when he realized he could potentially document "a unique event in scientific history," the discovery of the Higgs boson. He and his crew, which includes physicist-turned-producer and director Mark Levinson and editor Walter Murch (of *Apocalypse Now* fame), have done an admirable job with challenging material. The result is a beautiful and moving tribute to one of humankind's true triumphs. — *Gabriel Popkin*

To watch

Particle Fever
In select theaters March 5–April 18, or watch via online streaming or download. More information at www.particlefever.com

COURTESY OF PF PRODUCTIONS

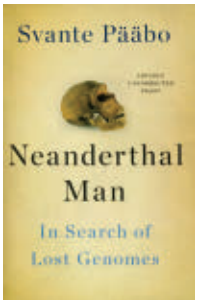
See the official trailer for *Particle Fever* at **bit.ly/SNpartfever**

BOOKSHELF

Neanderthal Man

In Search of Lost Genomes

Svante Pääbo



The hottest thing in human evolution studies right now is DNA extracted from fossils of Neandertals and other long-gone populations. Pääbo, the dean of ancient-gene research, explains in his book how it all began when he bought a piece of calf liver at a supermarket in 1981.

In those days, DNA had been successfully pulled only from living animals. Pääbo modified the methods to extract genetic material from the dead calf's liver, which had been heated to make it hard and dry like an Egyptian mummy. Pääbo then retrieved human DNA from an actual Egyptian mummy. A high-profile journal published his findings.

After that auspicious start, the Swedish scientist recounts how he came to run the world's first laboratory studying ancient DNA. A recurring theme in the book concerns Pääbo's obsessive push to eliminate sources of contamination in ancient DNA, especially modern human DNA transmitted by scientists who handle (and in one case, licked) fossils.

Pääbo describes professional tensions that flared in 2006 when his team chose a technique to sequence the Neandertal genome. Researchers who had developed an early method of extracting DNA from fossils lost out to developers of a simpler but more powerful procedure. Feelings were hurt. The leader of the snubbed research group became a competitor of Pääbo's for Neandertal bones and for bones from Neandertal relatives called Denisovans.

Aside from such behind-the-scenes dramas, Pääbo provides a fascinating look at how his personal life intersected with the founding of a scientific field that has revolutionized evolution.

—Bruce Bower

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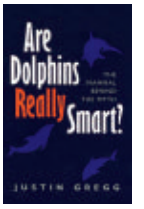
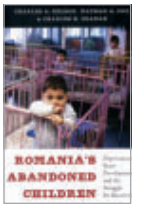


Are Dolphins Really Smart?

Justin Gregg

In a critique that is sure to spur debate, a dolphin behaviorist reviews the scientific literature and suggests that public enthusiasm for dolphin smarts has outpaced the evidence for their intelligence. *Oxford Univ., $24.95*



Romania's Abandoned Children

Charles A. Nelson, Nathan A. Fox and Charles H. Zeanah

The results of a long-term study lay out the heartbreaking cognitive and psychological effects on infants raised in orphanages without individual attention and affection. The authors' own project in Romania offers hope by showing the benefits of early intervention. *Harvard Univ., $29.95*

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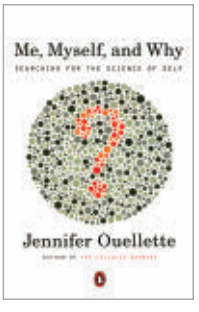

BOOKSHELF

Me, Myself, and Why

Searching for the Science of Self

Jennifer Ouellette

Near the end of Ouellette's new book — a personal journey exploring what shapes people's sense of self — she pops a candy tablet of LSD and settles in for her first psychedelic experience. Ouellette had heard that once the drug wore off and the acid-induced wonderland slipped away, the "self" came barreling back.

"I had to experience this firsthand," she writes. "After all, it was 'research.'" As the chemical toyed with her brain, Ouellette saw kaleidoscopes of swirling patterns and watched her husband transform into a dragon-man. She keeps the scene light, but her nonrecreational drug use adds a dogged, truth-seeking vibe to her latest project. It's an ambitious effort to dissect the hodgepodge of genetic and environmental factors that sculpt people's identities.

Ouellette submits herself to various scientific methods to figure out what makes her who she is, from a brain scan to personality tests to decoding her DNA. But the book isn't just a lighthearted romp in and out of research labs. It also delivers meaty dollops of biology and history.

As the author of *The Calculus Diaries* and the blog *Cocktail Party Physics*, Ouellette is a veteran at breaking tough scientific concepts into bite-sized pieces. She offers richly detailed backstories about genetics and personality science, from Gregor Mendel's pea plants to Franz Joseph Gall's early efforts to read people's traits by touching the bumps on their skulls.

Occasionally the book bites off chunks of science that could be too big to chew, but Ouellette tempers discussions of the latest research on gender identity and consciousness with her own journey of self-discovery. She steers tricky subjects away from textbook terrain by hopscotching through pop culture, dropping names from the X-Men to Harry Potter. Still, the book might appeal most to readers with a good grasp of the basics of biology and psychology.

The overall trip is as colorful as the one Ouellette took as "research" — and it's probably more illuminating.

—Meghan Rosen

Penguin, $16

JANUARY 25, 2014

1.3–4.0
billion
Revised estimate of U.S. birds killed annually by domesticated cats

6.3–22.3
billion
Revised estimate of U.S. small mammals killed annually by domesticated cats

Calculating vaccines' impact

*"Vaccine vindication" (*SN: 1/25/14, p. 5*) stated that vaccines have prevented 103 million cases of childhood diseases such as polio and rubella in the United States since 1924.*

"How can the study assume there were so many cases of illness that were prevented?" asked **Carolyn Bredenberg** in an e-mail. "Were the data extrapolated from old data, or inferred from models based on old data, or what?"

Researchers looked at disease rates during prevaccine times and the increase in the U.S. population since then to estimate the number of illnesses that vaccines have prevented, explains departments editor **Erika Engelhaupt**. "The number of prevented cases is the difference between expected cases and actual cases," she says. "Vaccines may actually have prevented even more illnesses than this calculation reveals, since the number of prevaccine cases may have been underreported."

Cat-induced death toll revised

*Last year, **Susan Milius** reported new estimates of the number of wild animals killed by domestic cats in the United States ("Cats claim billions of bird and small mammal victims annually,"* SN: 2/23/13, p. 14*).*

In December 2013, the authors of the original article in *Nature Communications* adjusted their estimates of the wildlife killed by cats each year. The first version of the paper included a narrower range of values than was appropriate for the statistical confidence level given. Fixing this error did not alter the basic conclusions of the paper, but the death tolls did change, with the originally published range of 1.4 billion to 3.7 billion cat-killed birds widening to 1.3 billion to 4.0 billion. The 6.9 billion to 20.7 billion range of small mammals killed by cats became 6.3 billion to 22.3 billion. The *Science News* article has been updated online.

Taming wildcat genetics

Feline domestication may have begun in the Far East with the small wildcat species Felis silvestris, *as **Susan Milius** reported in "Earliest farm cats found in China"* (SN: 1/25/14, p. 8*).*

Online commenter **Mark S.** wanted to know how similar the wildcats are to their domesticated cousins. "Cats go feral very easily," he wrote. "Can *F. silvestris* be socialized if you start with a young kitten, or is there a real genetic difference?"

Milius can't say whether wildcat kittens might act like domestic cats with the right training, but "the genetic differences are modest enough for plenty of researchers to treat domestic cats as just another subspecies of *F. silvestris*. Those slight differences may be important, though. Conservationists worry that any remnants of truly wild subspecies populations are losing distinctive adaptations through frequent crossbreeding with domestics, which include 'feral' cats."

New life for The Science Life

Science Visualized premiered on the back page of Science News *in October, taking the place previously occupied by The Science Life, which featured profiles of scientists and science enthusiasts.*

The Science Life "was a nice snapshot of a working scientist — something a younger person (and older!) could connect to," **Karey Kluesner** e-mailed. "I know you also have a student website, but I strongly feel that giving science a face on a regular basis is a very important thing versus simply having another page with pictures. The Science Life much better meets the goal of visualizing science — it makes it more real and gives credit to all the people working in the background to make everyone's life better and more meaningful."

Erika Engelhaupt responds: "Thank you to readers who have shown support for The Science Life. We have not abandoned the effort to cover the people and stories behind the science: The Science Life will be revived as an occasional feature in the Notebook section, partly in response to reader feedback."

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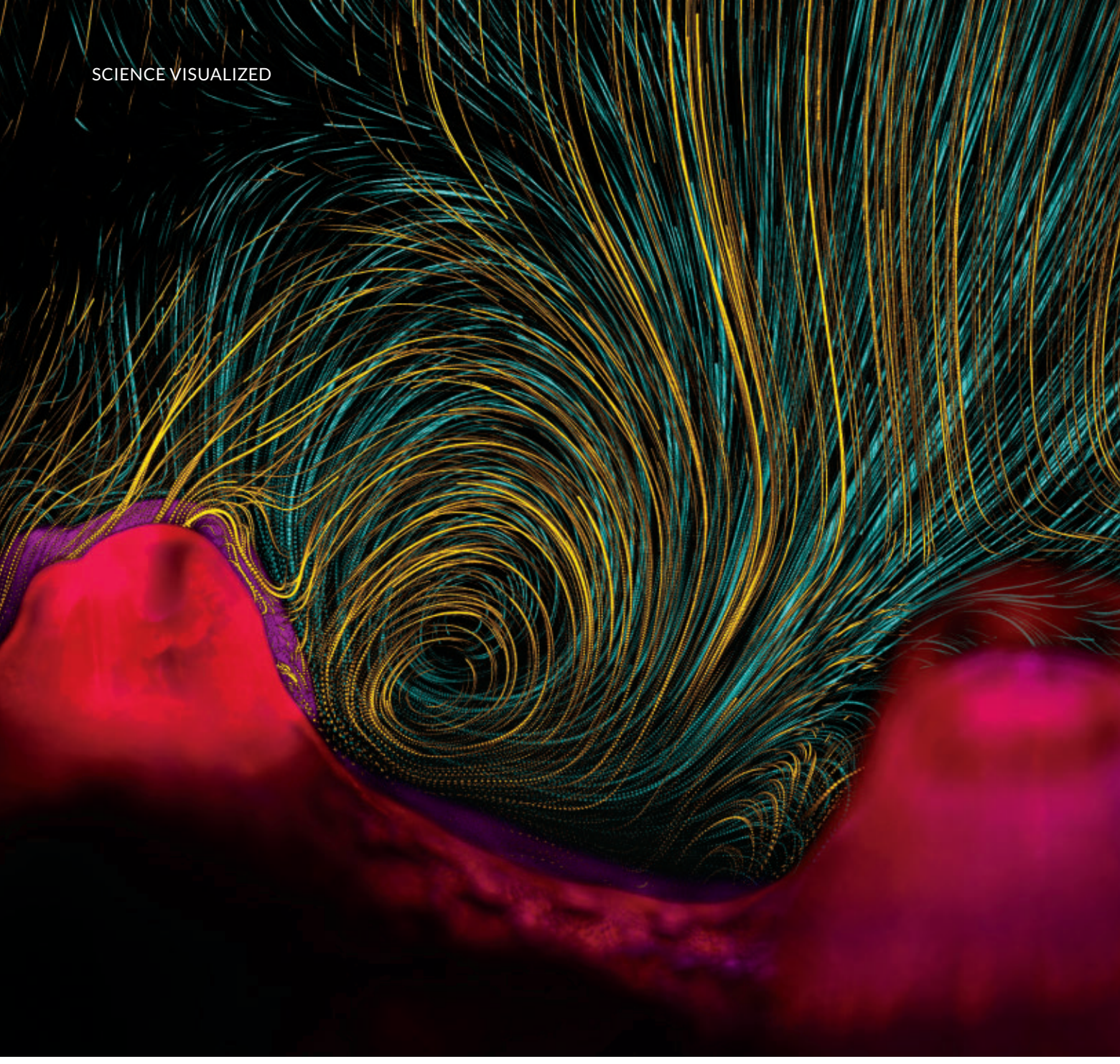

A tiny ocean vortex, with pop art pizzazz

Corals may whip up whirlpools to spin specks of food in and bits of waste out. Scientists had known that hairlike bristles, or cilia, on coral help sweep nutrients in, but the purpose of bristles lining the valleys between coral polyps had been more mysterious. Using video microscopy, MIT environmental engineer Vicente Fernandez and colleagues recorded two short clips of *Pocillopora damicornis* coral in seawater, taken 90 minutes apart. The researchers traced particle paths (gold) and coral polyp locations (pink) captured in the first video and the paths and polyps (aqua and purple) recorded in the second, then combined them. The resulting image, which won the 2013 International Science & Engineering Visualization Challenge in photography, shows that the corals shifted position over time, but the vortex swirling in the 3-millimeter gap between them endured. These steady whirlpools might keep corals healthy, Fernandez says, and the between-polyp bristles probably keep water twirling. — *Meghan Rosen*

V. FERNANDEZ, ORR H. SHAPIRO, MELISSA S. GARREN, ASSAF VARDI, ROMAN STOCKER/MIT

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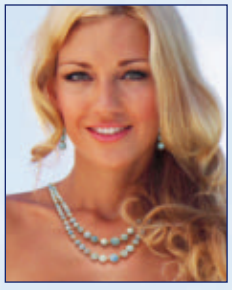

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