SN
SCIENCE NEWS MAGAZINE
SOCIETY FOR SCIENCE & THE PUBLIC
OCTOBER 29, 2016

Nobels 2016

Shocks in Baby Universe

Beyond Genomics

Zika's Long-Term Dangers

Coral Comeback

Scientists develop strategies for rescuing threatened reefs

Urgent: Special Driving Notice

To some, sunglasses are a fashion accessory…

But When Driving, These Sunglasses May Save Your Life!

Studies by the National Highway Traffic Safety Administration (NHTSA) show that most (74%) of the crashes occurred on clear, sunny days

Drivers' Alert: Driving in fall and winter can expose you to the most dangerous glare… do you know how to protect yourself?

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In the fall and winter, the sun is lower in the sky so it rises and sets at peak travel periods. During the early morning and afternoon rush hours many drivers find themselves temporarily blinded while driving directly into the glare of the sun. Deadly accidents are regularly caused by such blinding glare with danger arising from reflected light off another vehicle or snowy and icy pavement. Yet, motorists struggle on despite being blinded by the sun's glare that can cause countless accidents every year.

Not all sunglasses are created equal. Protecting your eyes is serious business. With all the fancy fashion frames out there it can be easy to overlook what really matters—the lenses. So we did our research and looked to the very best in optic innovation and technology.

Sometimes it does take a rocket scientist. A NASA rocket scientist. Some ordinary sunglasses can obscure your vision by exposing your eyes to harmful UV rays, blue light, and reflective glare. They can also darken useful vision-enhancing light. But now, independent research conducted by scientists from NASA's Jet Propulsion Laboratory has brought forth ground-breaking technology to help protect human eyesight from the harmful effects of solar radiation light. This superior lens technology was first discovered when NASA scientists looked to nature for a means to superior eye protection—specifically, by studying the eyes of eagles, known for their extreme visual acuity. This discovery resulted in what is now known as Eagle Eyes®.

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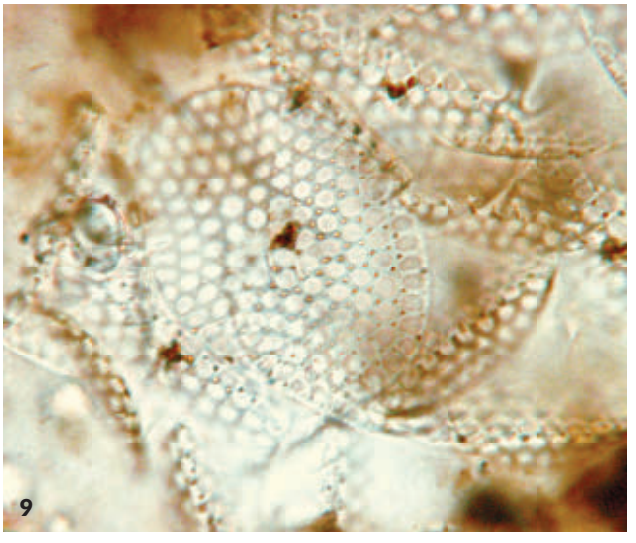
ScienceNews

Features

News



CLOCKWISE FROM TOP: JAMES PROVOST; ANTON PINCHUK/FLICKR (CC BY 2.0); P. COHEN

Departments

COVER The hard coral *Diploastrea heliopora* is common in Indonesia. Many corals are now under threat. *Reinhard Dirscherl/Alamy*

2016 Nobels: *Science News* fans read it here first

This year's Nobel Prizes (see Page 6) honored scientific achievements that dedicated *Science News* readers (with good memories) would have found familiar. A dive into our archives revealed some interesting results.

The physiology or medicine prize recognized autophagy, the cellular process by which living cells dispose of — or recycle — their biochemical garbage. Molecular biology writer Tina Hesman Saey identified the importance of this field years ago, writing an in-depth take in 2011 (*SN: 3/26/11, p. 18*).

The Nobel physics prize honored three researchers for their use of the math of shapes to describe matter in exotic states. Turns out that topology, which describes shifting shapes and spatial relationships (illustrated at the Nobel news conference by bagels and pretzels), helped elucidate some weird properties of matter at low temperatures, including superconductivity and various quantum phenomena. In 2010, contributing correspondent Alexandra Witze reported on one of the many fruits of such research in a feature on topological insulators (*SN: 5/22/10, p. 22*). These new materials could have applications in everything from detecting new basic particles to building quantum computers.

Chemistry's Nobel, for "molecular machines," cited work by researchers frequently mentioned in *Science News* over the years. News stories in 1996 and 1997 described Jean-Pierre Sauvage's work on molecules tied up like knots (pretzels again). J. Fraser Stoddart turns up often in our pages, including in a 1998 article on molecular pistons and cylinders. Bernard Feringa's key "molecular motor" advance was reported in 1999. More recently, former *SN* staff writer Rachel Ehrenberg described his nanometers-sized electric car (*SN: 12/17/11, p. 8*).

You can almost imagine Nobel committee members getting prize ideas by leafing through the pages of *Science News*. So, for you future committee members looking for noteworthy contributions, here's a few in this issue:

In medicine, we report on a potential new carrier of the Zika virus (Page 13) and recent efforts to understand Zika's impacts (Page 14). Then there's the emerging field of "multi-omics," research working to build a layered understanding of the cell's many different networks, from genes to RNA to proteins and chemical metabolites. By integrating data from multiple "omes" (the genome, proteome, transcriptome, metabolome and others), scientists expect to gain insights into how organisms work, as science writing intern Laurel Hamers reports on Page 24. The approach faces challenges due to the sheer amount of data. But by considering multiple layers of complexity in health and disease, it offers huge promise in the realm of personalized medicine.

In physics, writer Emily Conover describes calculations that imply shock waves could have swept through the universe immediately after the Big Bang (Page 7). Those shocks could help explain the preponderance of matter over antimatter, an enduring mystery in cosmology. Another hint about the missing antimatter has come from new observations at the Large Hadron Collider (Page 17).

For chemistry, we cover news (Page 15) of the first reported use in viable human embryos of the CRISPR/Cas9 gene-editing tool — a molecular marvel already getting Nobel buzz. — *Eva Emerson, Editor in Chief*

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SANDY SCHAFFER

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Excerpt from the October 29, 1966 issue of *Science News*

50 YEARS AGO

New hope for control of staph infections

Staphylococcal infections — especially rampant in hospitals and responsible for ... some fatal disorders — may be virtually stamped out. Researchers ... have extracted teichoic acid from the bacteria's cell wall and used it to protect groups of mice from subsequent massive doses of virulent staph organisms.

UPDATE: *Staphylococcus aureus* has not been conquered. As antibiotic resistance grows, the pressure is on to find ways to stop the deadly microbe. A vaccine that targets *S. aureus*' various routes of infection is being tested in patients having back surgery. Ideally, doctors would use the vaccine to protect hospital patients and people with weakened immune systems. This vaccine is the furthest along among several others in development. Meanwhile, a natural antibiotic recently found in human noses may lead to drugs that target antibiotic-resistant staph (*SN: 8/20/16, p. 7*).

A humming midshipman male (second from left) and a female are surrounded by two smaller sneaky males and a brood of wispy white larvae.

IT'S ALIVE

Melatonin makes the midshipman hum

For widemouthed, musical midshipman fish, melatonin is not a sleep hormone — it's a serenade starter.

In breeding season, male plainfin midshipman fish (*Porichthys notatus*) spend their nights singing — if that's the word for hours of sustained foghorn hums. Males dig trysting nests under rocks along much of North America's Pacific coast, then await females drawn in by the crooning.

New lab tests show that melatonin, familiar to humans as a possible sleep aid, is a serenade "go" signal, says behavioral neurobiologist Ni Feng of Yale University.

From fish to folks, nighttime release of melatonin helps coordinate bodily timekeeping and orchestrate after-dark biology. The fish courtship chorus, however, is the first example of the hormone prompting a launch into song, according to Andrew

FOR DAILY USE

Time to retire the 5-second rule

For some dropped foods, the five-second rule is about five seconds too long. Wet foods, such as watermelon, slurp up floor germs almost immediately, scientists report online September 2 in *Applied and Environmental Microbiology*.

Robyn Miranda and Donald Schaffner of Rutgers University in New Brunswick, N.J., tested gummy candy, watermelon and buttered and unbuttered bread by dropping morsels onto various surfaces coated with *Enterobacter aerogenes* bacteria.

Moist foods like PB&J pick up bacteria from the floor lickety-split.

Food was left on each surface — stainless steel, ceramic tile, wood and carpet — for periods ranging from less than a second to five minutes. Afterward, the researchers measured the amount of *E. aerogenes* on the food. *E. aerogenes* is a usually harmless bacterium that shares attachment characteristics with stomach-turning *Salmonella*.

As expected, longer contact times generally meant more bacteria on the food. But the transfer depended on other factors, too. Carpet, for instance, was less likely to transfer germs than the other surfaces. Gummy candies, particularly those on carpet, stayed relatively clean. But juicy watermelon quickly picked up lots of bacteria from all surfaces in less than a second. These complexities, the authors write, mean that the five-second rule is probably a rule worth dropping. — *Laura Sanders*

FROM TOP: MARGARET MARCHATERRE/CORNELL UNIV.; MARK DEIBERT/ISTOCKPHOTO

Bass of Cornell University. And what remarkable vocalizing it is.

The plainfin midshipman male creates a steady "mmm" by quick-twitching specialized muscles around its air-filled swim bladder up to 100 times per second in chilly water. A fish can extend a single hum for about two hours, Feng and Bass report October 10 in *Current Biology*. That same kind of super-fast muscle shakes rattlesnake tails and trills vocal structures in songbirds and bats.

Water abuzz with nighttime fish yearning is part of the California houseboat experience, Bass says. Sausalito festivals have included kazoo choruses in the midshipman's honor. The fish's common name comes from its luminescent spots, which reminded early biologists of buttons down the front of nautical uniforms.

Suited up and ahum, males await females cruising amid the chorus. A male sometimes half-gulps a passing female's head in his mouth and pulls her into his cave, Bass says. If she chooses to stay, she hovers upside down in the water, laying eggs in "a beautiful monolayer" across the ceiling. The resident male, or sometimes an interfering little sneak male, releases sperm into the water for external fertilization. Egg-papering a swath of rock can take her up to 24 hours, with the male occasionally repositioning her to cover different patches. Afterward, females swim off, leaving the dad to weeks of tending the mosaic of eggs from various females impressed by his humming marathons. — *Susan Milius*

The dots that line the underside of the midshipman fish are photophores, organs that produce light and are reminiscent of the rows of buttons on a sailor's uniform.

THE -EST

Extreme lightning sets records

Two electrifying light shows were much more than flashes in the pan. A 2007 thunderstorm over Oklahoma produced a lightning flash that stretched more than 321 kilometers horizontally — roughly the distance from Washington, D.C., to New York City. In southern France in 2012, a single lightning flash lit up the sky nonstop for 7.74 seconds, enough time for light to make about three round trips from Earth to the moon.

A World Meteorological Organization committee deemed these lightning flashes the world record holders for lightning distance and duration in a paper published online September 13 in the *Bulletin of the American Meteorological Society*. The new records emphasize the dangers posed by lightning flashes, even when a storm appears to be far away, the committee writes.

Lightning flashes used to be defined as lasting a second or less. With improved lightning-detection techniques, however, scientists can now accurately track much longer flashes (the Oklahoma flash clocked in at 5.7 seconds), so the committee recommended dropping the time limit.

As scientists get better looks at lightning, these records may be gone in a flash. Extreme lightning has also been spotted over Argentina, Africa's Congo Basin and the oceans. — *Thomas Sumner*

New techniques allow scientists to better monitor lightning flashes (shown), leading to extreme records.

TEASER

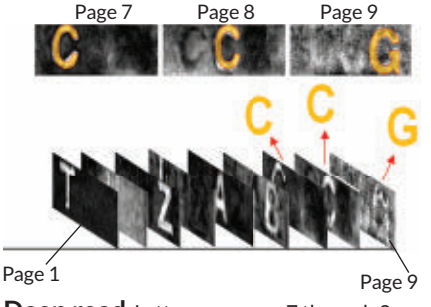
Peering between a book's covers

Book lovers: Scientists have devised a way to read without cracking a volume's spine or risking paper cuts (and no, we're not talking about e-books). The new method uses terahertz radiation — light with wavelengths that are between microwave and infrared waves — to view the text of a closed book. The technique is not meant for your average bookworm, but for reading rare books that are too fragile to open.

Barmak Heshmat of MIT and colleagues started small, with a nine-page book of thick paper that had one letter inked on each page. By hitting the book with terahertz radiation and looking at the reflected waves, the scientists could read the letters within.

Differences in the way the radiation interacts with ink and paper allowed the researchers to pick out shadowy outlines of the letters, and a letter-recognition algorithm automatically decoded the characters. The scientists could tell one page from another by using precise timing information: On the later pages, the waves penetrated deeper before reflecting and, therefore, took longer to return.

Historians also may be able to use the technique to find an artist's signature hidden beneath layers of a painting. Sneaking into your sister's locked diary is another story. — *Emily Conover*



Deep read Letters on pages 7 through 9 of a closed book are decoded using terahertz radiation. After isolating the reflected radiation from each page, the technique selects the frequency of radiation that provides the best contrast between ink and paper. An algorithm decodes the letters and then their locations inside the book.

CLOCKWISE FROM TOP: MARGARET MARCHATERRE/CORNELL UNIV.; B. HESHMAT/MIT; ANTON PINCHUK/FLICKR (CC BY 2.0)

SCIENCE & SOCIETY

Nobels honor the small and exotic

Prizes go to nanomachines, autophagy, topological phases

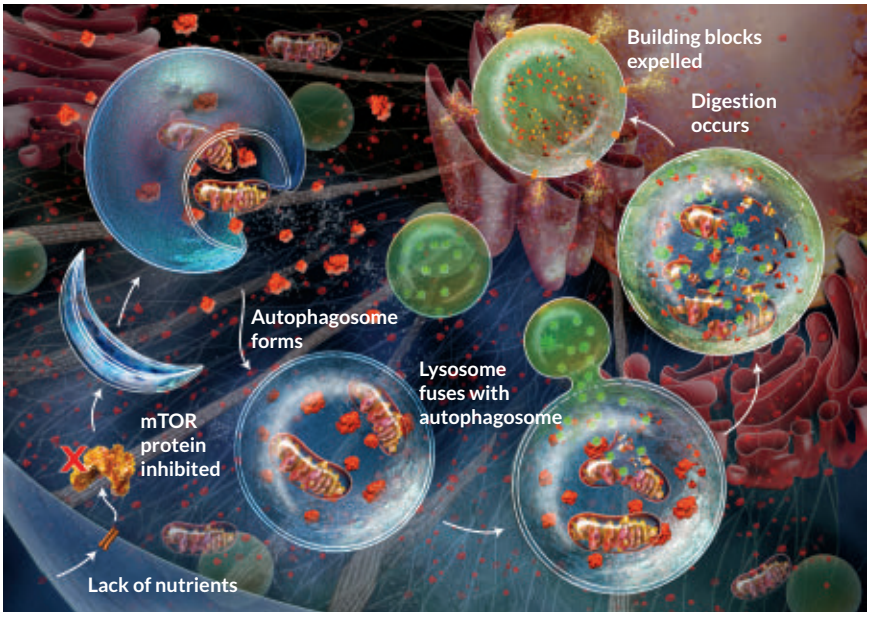
The Nobel science prizes for 2016 honored work exploring various microscopic realms, from cells digesting their innards to minuscule molecular motors and exotic phenomena best explained with bagels and pretzels.

Studies into how biological cells recycle their internal garbage earned cell biologist Yoshinori Ohsumi the physiology or medicine prize. David Thouless, J. Michael Kosterlitz and Duncan Haldane shared physics honors for using the math of shapes to explain the behavior of certain exotic states of matter. Chemistry honorees Jean-Pierre Sauvage, J. Fraser Stoddart and Bernard Feringa established the field of molecular motors, tiny devices with potential applications in medicine and computing.

Ohsumi, of the Tokyo Institute of Technology, received the prize of 8 million Swedish kronor (about $900,000) for his work on autophagy, a process that breaks down and recycles cellular junk, such as clusters of damaged proteins. Defective recycling may lead to neurological diseases; excessive recycling has been linked to cancer.

Ohsumi "set the framework for an entire new field in cell biology," says biologist Jennifer Lippincott-Schwartz of the Howard Hughes Medical Institute's Janelia Research Campus in Ashburn, Va.

The physics prize set bagels and pretzels trending on social media; the familiar foods illustrate the math that describes quantum phenomena in some exotic states of matter. Thouless, of the University of Washington in Seattle, was awarded half the physics prize with the other half split between Kosterlitz, of Brown University, and Haldane, of Princeton University.

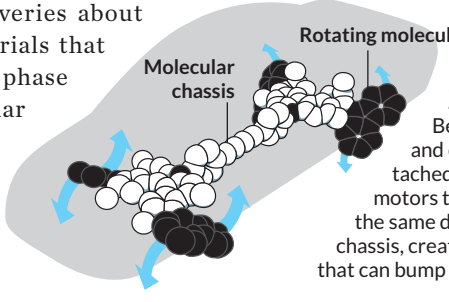


Recycle Starvation can force cells to digest themselves by a process called autophagy, cited in this year's Nobel Prize in physiology or medicine. Membrane-bound sacs (autophagosomes) engulf broken-down cellular parts. Then the sacs fuse with lysosomes, recycling old parts for reuse.

Their work involved topology, a branch of mathematics that deals with the study of shapes distinguished by abrupt transitions. A bagel, for example, is distinct from a cinnamon bun, because the bagel has a single hole, explained Thors Hans Hansson, a physicist at Stockholm University and a Nobel committee member. And the Swedish style of pretzel, with two holes, likewise differs from a bagel. But a bagel and a coffee cup, which each have a single hole, are topological twins — one shape can be gradually morphed into the other without cutting or pasting.

Using concepts from topology, the physicists explored unusual states of matter that occur under extreme conditions, including temperatures near absolute zero, where quantum mechanics becomes relevant. Thouless and Kosterlitz made discoveries about two-dimensional materials that exhibit more complex phase transitions than familiar examples such as ice melting into water. The pair discovered a new phase change called the Kosterlitz-Thouless transition. At low temperatures, vortices of swirling electrons are locked together. As the temperature is raised, these vortices suddenly separate and travel independently.

In 1983, Thouless explained the mysterious quantum Hall effect. It occurs in a thin layer of electrically conductive material under extreme cold and a high magnetic field; the conductivity of the layer, rather than varying gradually, can take on only certain values that are integer multiples of each other. In the bagel-pretzel analogy, each object can have only a precise number of holes; the number can change only in steps — just as conductivity changes in discrete jumps in the quantum Hall effect. In 1988, Haldane showed that a similar effect can occur even in the absence of a magnetic field.



Zoom zoom Bernard Feringa and colleagues attached four molecular motors that all spin in the same direction to a tiny chassis, creating a "nanocar" that can bump along a surface.

FROM TOP: NICOLLE RAGER FULLER; © JOHAN JARNESTAD/THE ROYAL SWEDISH ACADEMY OF SCIENCES

Pretzels also help to illustrate the knotlike molecules involved in making tiny molecular motors, which earned equal shares of the chemistry Nobel for Sauvage, Stoddart and Feringa. "If you had to choose three people at the top of the field, that's it. These are the men," says James Tour, a nanomachines chemist at Rice University in Houston.

In 1983, Sauvage, of the University of Strasbourg in France, devised a way to make interlocking molecular rings, or catenanes. That set the stage for more intricate molecular knots and motors.

Stoddart, of Northwestern University in Evanston, Ill., showed how to produce large quantities of molecular machines, starting with rings clipped around a central axle, a structure known as a rotaxane. He and colleagues later devised molecular elevators and pumps.

Feringa, of the University of Groningen in the Netherlands, built the first molecular motor in 1999 by devising molecules that would spin in one direction when hit with a pulse of light. Later, he and colleagues bolted four molecular motors to a tiny chassis, creating a "nanocar." Nanomachines may someday seek and destroy tumor cells or deliver drugs, Feringa speculates. — *Emily Conover, Christopher Crockett, Laurel Hamers, Meghan Rosen, Tina Hesman Saey and Thomas Sumner*

2016 Nobel Laureates

PHYSIOLOGY OR MEDICINE

Yoshinori Ohsumi
Tokyo Institute of Technology

PHYSICS

David J. Thouless
University of Washington

F. Duncan M. Haldane
Princeton University

J. Michael Kosterlitz
Brown University

CHEMISTRY

Jean-Pierre Sauvage
University of Strasbourg

J. Fraser Stoddart
Northwestern University

Bernard Feringa
University of Groningen

ATOM & COSMOS

Shock waves rocked baby universe

Study sheds light on magnetic fields' birth, antimatter mystery

BY EMILY CONOVER

Shock waves may have jolted the infant cosmos. Clumpiness in the density of the early universe piled up into traveling waves of abrupt density spikes, or shocks, like those that create a sonic boom, scientists say.

Although a subtle effect, the shock waves could help scientists explain how matter came to dominate antimatter in the universe. They also could reveal the origins of the magnetic fields that pervade the cosmos. One day, traces of these shocks, in the form of gravitational waves, may even be detectable.

> Shocks would have formed less than one ten-thousandth of a second after the Big Bang.

Scientists believe that the early universe was lumpy — with some parts denser than others. These density ripples, known as perturbations, serve as the seeds of stars and galaxies. Now, scientists have added a new wrinkle to this picture. As the ripples rapidly evolved, they became steeper, like waves swelling near the shore, until eventually creating shocks analogous to a breaking wave. As a shock passes through a region of the universe, the density changes abruptly, before settling back down to a more typical, slowly varying density. "Under the simplest and most conservative assumptions about the nature of the universe coming out of the Big Bang, these shocks would inevitably form," says Neil Turok, a cosmologist at the Perimeter Institute for Theoretical Physics in Waterloo, Canada.

In a paper published September 21 in *Physical Review Letters*, Turok and Ue-Li Pen of the Canadian Institute for Theoretical Astrophysics in Toronto performed calculations and simulations that indicate shocks would have formed less than one ten-thousandth of a second after the Big Bang.

"It's interesting that nobody's actually noticed that before," says Kevork Abazajian, a cosmologist at the University of California, Irvine. "It's an important effect if it actually happened."

These shocks, Turok and Pen found, could produce magnetic fields, potentially pointing to an answer to a cosmological puzzle. Magnetic fields permeate the Milky Way and other parts of the cosmos, but scientists don't know whether they sprang up just after the birth of the universe or much later, after galaxies had formed. Shock waves could explain how fields might have formed early on. When two shocks collide, they create a swirling motion, sending electrically charged particles spiraling in a way that could generate magnetic fields.

Shocks could also play a role in explaining why the universe is made predominantly of matter. The Big Bang should have yielded equal amounts of matter and antimatter; how the cosmic scales were tipped in matter's favor is still unexplained. Certain theorized processes could favor the production of matter, but it's thought they could have happened only if temperatures in the universe were uneven. Shocks would create abrupt temperature jumps that would allow such processes to occur.

Scientists may be able to verify these calculations by detecting the gravitational waves that would have been produced when shocks collided. The gravitational ripples produced would probably be too small to detect with current technologies. But under certain theories, in which large density fluctuations create regions so dense that they would collapse into black holes, the gravitational waves from shocks would be detectable in the near future. "If there was anything peculiar in the early universe, you would actually be able to detect this with upcoming technology," Abazajian says. "I think that is remarkable." ■

See the early universe simulation at **bit.ly/SN_shockwave**

Shrinking sea ice matters to land dwellers too, as ice connections and transport options dwindle for seed-dispersing wildflowers and migrating Peary caribou (below).

LIFE & EVOLUTION

Shrinking sea ice threatens mobility

Both furry and flowery travelers face trouble in a warmer world

BY SUSAN MILIUS

As warming breaks up the sea ice that serves as great frozen highways for Arctic wildlife, caribou and even wildflowers face route shutdowns, long detours or outright strandings.

Already, ice bridges that Peary caribou need for seasonal migrations from island to island are becoming scarcer, with worse to come, an international research team reports in the September *Biology Letters*. In the same issue, other researchers suggest that some plants need the icy travel routes: Ancestors of dozens of wildflower and miniature tree species probably used sea ice to colonize the far north after the last ice age.

Both studies point to the possibility that terrestrial Arctic plants and animals will face increasing difficulties sustaining their populations as their territories become more fragmented. "We often hear about the loss of sea ice, but rarely about the biological consequences," says Deborah A. Jenkins of Trent University in Peterborough, Canada, who worked on the caribou project.

Ice bridges let some Arctic foxes, for instance, move such long distances that genetic studies have registered an interconnected population in northern archipelagos from North America to Svalbard, north of mainland Norway.

The new study is the first to report how sea ice affects migration among some of the Arctic's storied caribou, says coauthor Glenn Yannic of Université Savoie Mont Blanc in Chambéry, France.

Of the three subspecies of caribou, Peary caribou (*Rangifer tarandus pearyi*) depend the most heavily on sea ice highways. The animals live mostly on the more than 36,000 islands of the Canadian Arctic Archipelago, rarely coming south to the mainland to mingle with other subspecies. Caribou can swim, but in practice rarely paddle more than 10 kilometers, Yannic says. Instead, some take a springtime walk across sea ice to their local calving grounds; at the end of the season, they walk back.

Travel between those islands has already gotten tougher, the researchers report, possibly requiring more roundabout routes. By analyzing patterns of fluctuating sea ice throughout the islands, the team shows that these landscapes have become 15 percent more difficult to traverse since 1979. If carbon dioxide emissions remain moderate to high, the ice bridges will probably shrink enough to make finding paths another 20 to 77 percent more difficult by 2086, the researchers calculate.

Though plants don't walk, biologists have theorized that seeds too could travel sea ice highways by snagging on the feet or fur of a moving animal. Or the slow creep of ice itself could nudge an embedded seed from, say, northern Russia to Iceland in a few years. The second study provides the first empirical evidence for plant transit by ice, says study coauthor Inger Greve Alsos of the Arctic University of Norway in Tromsø.

She and colleagues reconstructed probable routes for plants recolonizing parts of the far north (Iceland, Svalbard, East Greenland and the Faroe Islands) since the end of the last ice age. The team studied pollen grains pulled from gunk in lake bottoms and other evidence to track the earliest known appearances of 102 species in the northern frontier.

The shortest sea routes between the plants' likely origins and destinations were unusually rich in sea ice around the time of colonization, the researchers say, suggesting that abundant ice could have been useful for plant dispersal.

The study didn't look at what impact sea ice changes are currently having on these plants. But the rate of sea ice loss since 1979 has been about equivalent to an area twice the size of New Jersey disappearing annually, says Eric Post of the University of California, Davis. "Its loss, in ecological terms, could be likened to the ongoing clear-cutting of old-growth forest, year after year after year."

Travel trouble is just the tip of the iceberg when it comes to the impact of sea ice changes (*SN Online: 9/19/16*). For instance, as ice dwindles, extra sunlight reaching into the Arctic Ocean has fueled more than a 30 percent surge in the growth of photosynthesizing plankton since 1998, says biological oceanographer Kevin Arrigo of Stanford University. That boost is a bonanza for tiny marine grazers that in turn other organisms feed on. Sea ice is so important to Arctic life that the changes it brings — both gains and losses — can be dramatic. ■

LIFE & EVOLUTION

Fossils contain earliest signs of shells

Microscopic eukaryotes made armor 809 million years ago

BY THOMAS SUMNER

Life on Earth got into the shell game more than 200 million years earlier than previously thought.

Fossilized eukaryotes — complex lifeforms that include animals and plants — discovered in Canada are decked out in armorlike layers of mineral plates, paleobiologist Phoebe Cohen said September 27. At 809 million years old, the find is the oldest evidence of organisms controlling the formation of minerals, a process called biomineralization.

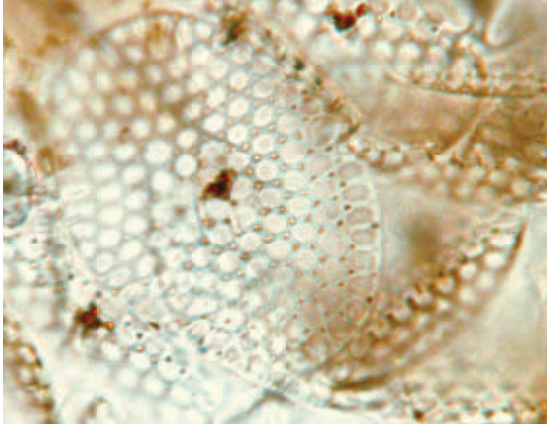
This earlier origin of biomineralization coincides with major changes that mark the end of a period known as the "boring billion" (*SN: 11/14/15, p. 18*), said Stanford University paleontologist Erik Sperling, who was not involved in the discovery. "There were big things going on with ocean chemistry," he said. "It's interesting to see the biological response."

These ancient microscopic eukaryotes built their exoskeletons using a very different process from most modern shell-making microbes. That uniqueness offers insights into how mineral-making abilities first evolved, said Cohen, of Williams College in Williamstown, Mass.

Donning an exoskeleton of minerals protects microbes from predators. Previous clear evidence of eukaryote biomineralization dates back to about 560 million years ago.

Odd fossils discovered in the late 1970s and covered in mineral plates shaped like circles, squares and "Honeycomb cereal" (as Cohen described them) hinted that the skill evolved much earlier. Dating techniques had put the age of the fossils somewhere between 811 million and 717 million years ago, but scientists couldn't rule out that the scalelike minerals had formed after these organisms died.

So Cohen and colleagues revisited the fossils. By dating organic-rich shale a few meters below the fossils in the rock record, the team pegged the fossils' age at 809 million years, give or take 5.7 million. An electron microscope revealed that each plate is a weave of elongated mineral fibers. This intricate, orderly design had to have been built by life manipulating mineral formation, Cohen said.



Fossilized microbes that date to 809 million years ago, such as this one found in Canada, may be the oldest evidence of organisms creating mineral plates for protection.

Most modern microbes make shells out of calcium carbonate, but the ancient shells are made of calcium phosphate. Today, phosphate is limited in the environment, and microbes avoid wasting it.

That may not have been an issue in the marine basin where the eukaryotes lived. Analysis of rocks surrounding the fossils indicate that the amount of oxygen in the waters was inconsistent. Fluctuating oxygen levels pulled phosphate from underlying sediment into the water, where it was available for mineral making. These conditions plus the need for protection from predation probably drove the evolution of biomineralization, Cohen said. ■

P. COHEN

EARTH & ENVIRONMENT

Evidence mounts for ancient comet

Impact 56 million years ago may have kicked off warming

BY THOMAS SUMNER

A period of skyrocketing global temperatures began with a bang, researchers say.

Impact debris and evidence of widespread wildfires around eastern North America suggest that a large space rock whacked Earth about 56 million years ago at the beginning of the Paleocene-Eocene Thermal Maximum, also known as the PETM, a period of rapid warming and rising carbon dioxide levels. The event is one of the closest analogs to modern global warming and is used to improve predictions of how Earth's climate and ecosystems will fare in the coming decades.

Too little is known about the newfound impact to guess its origin, size or effect on climate, said geochemist Morgan Schaller of Rensselaer Polytechnic Institute in Troy, N.Y. But it fits with the controversial proposal that a comet impact caused the PETM. "The timing is nothing short of remarkable," said Schaller, who presented the discovery September 27.

The impact may have contributed to the rapid rise of CO_2 in the atmosphere by stirring up carbon, but it was hardly the sole cause, said Sandra Kirtland Turner, a geochemist at the University of California, Riverside. She presented simulations that suggest the carbon influx probably occurred over at least 2,500 years, far too drawn out to be caused by a single event.

During the PETM, Earth warmed by 5 to 8 degrees Celsius. The rush of atmospheric carbon altered the relative abundance of different carbon isotopes in the atmosphere and oceans, leaving a signal in the sedimentary record.

While searching for that signal in 56-million-year-old sediments from sites along the U.S. East Coast, Schaller spotted microscopic glassy spheres. These specks resemble those from previously identified impact events, he and colleagues report in the Oct. 14 *Science*. Micropaleontologist Megan Fung, one of Schaller's Rensselaer colleagues, discovered charcoal pieces in the mix. That charcoal formed when wildfires sparked by the impact raged across the landscape, Fung proposed.

More evidence of the impact will help researchers to better constrain its location, scope and possible relationship to the start of the PETM, Schaller said. ■

ATOM & COSMOS

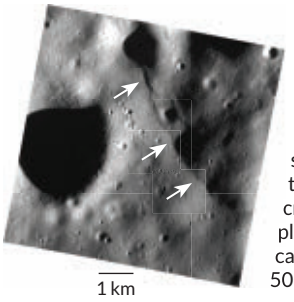
Mercury's surface still changing

MESSENGER's snapshot of cliffs hints at tectonic activity

BY CHRISTOPHER CROCKETT

Mercury has gotten some new wrinkles in its old age. The innermost planet shows signs of relatively recent tectonic activity, a new study suggests.

Tiny cliffs on the surface — just tens of meters high and a few kilometers long — resemble breaks in the planet's crust, researchers report September 26 in *Nature Geoscience*. The diminutive sizes of the cliffs, their sharp edges and lack of large overlapping craters imply that the faults are geologically young — less than 50 million years old. That's much younger than Mercury's larger, eroded scarps seen elsewhere, which probably arose over 3.5 billion years ago. The scarps indicate that the surface still fractures as Mercury cools and contracts, the researchers suggest, though other explanations are possible.



A line of small scarps (arrows) on Mercury, seen in this image from the MESSENGER spacecraft, suggests that the planet has been tectonically active in the last 50 million years.

Thomas Watters, a geologist at the Smithsonian Institution in Washington, D.C., and colleagues discovered the young escarpments in images taken by NASA's MESSENGER spacecraft, which orbited Mercury from 2011 to 2015.

Mercury's continued contraction isn't surprising, says planetary scientist Sean Solomon of Columbia University. "It's demanded by physics." Mercury has gradually cooled over its 4.6-billion-year history. As it cools, it shrinks. Sometimes that shrinkage cracks the surface. All of the other rocky planets probably exhibit this type of tectonic activity over time as well, but their atmospheres have erased much of the evidence. Only on Mercury and the moon — both airless — is the history of contraction preserved because of limited erosion.

It's not clear, though, if these new faults are related to that shrinking. "In and of themselves, they don't tell us very much," says Paul Byrne, a planetary geologist at North Carolina State University in Raleigh. Without an analysis of how the small, young scarps relate to the large, old scarps, he says, it's hard to draw conclusions. The new arrivals could just as well be produced by shifting rubble or shock waves from run-ins with asteroids, and, if so, would not be a sign of continuing tectonic activity. ■

EARTH & ENVIRONMENT

Young, hot Earth kept gold in mantle

Sulfur later ushered precious metals into core, study argues

BY ALEXANDRA WITZE

There's a new twist to the story of how Earth's most precious metals got to where they are in the planet.

Some 4.6 billion years ago, space rocks pummeling the infant Earth kept it hot and molten. As the planet grew bigger, a new study suggests, the heat and pressure kept some precious metals trapped within its upper layers rather than allowing them to sink into the newly forming core. Later, chemical reactions involving sulfur pulled the metals down deep.

The work illuminates not only what happened during the Earth's early years, but also why gold, platinum and related metals are so scarce in its upper layers today (*SN: 8/6/16, p. 22*).

"It's giving us a lot of new insights into how the planets formed," says geochemist David Rubie of the University of Bayreuth in Germany, whose team reports the discovery in the Sept. 9 *Science*.

Gold and platinum belong to a class of chemical elements known as the highly siderophile, or "iron-loving," elements. When molten, they tend to form alloys with iron. Today, roughly 98 percent of Earth's highly siderophile elements are tucked away in its iron-rich core.

Most researchers think the highly siderophile elements joined with iron and sank into the core as it formed in the first tens of millions of years of Earth's history. Rubie and colleagues say the story is a bit more complex. They have been studying how Earth glommed together from fragments orbiting the newborn sun. Each time a space rock smashed into Earth, heating it up and increasing its size, the pressures inside the planet went up.

At these higher pressures and temperatures, the iron-loving elements become less iron-loving. Rubie's team calculated that in the first 100 million years or so of Earth's existence, these conditions kept iron-loving elements in the planet's middle layer, the mantle, rather than permitting them to drop into the core.

"This is an attractive idea, as it realistically paints a picture of a dynamic system where conditions are constantly changing," says geochemist Raúl Fonseca of the University of Bonn in Germany.

But then the question becomes how the iron-loving elements eventually made it into the core. The answer, Rubie says, is sulfur. High-pressure experiments involving molten iron and sulfur showed that sulfur could have triggered the highly siderophile elements to eventually separate out, closer to the core.

To account for the traces of gold and platinum that remain sprinkled throughout the mantle and crust, Rubie's team invokes a final step popular with other scientists: Meteorites ferried a fresh dusting of these elements to Earth's surface.

Geochemist Richard Walker of the University of Maryland in College Park says the study is interesting and agrees that higher pressures made the iron-loving elements less iron-loving. But he thinks they could have still separated out into the core without the extra steps proposed by Rubie's team. ■

NASA, JHUAPL, CARNEGIE INSTITUTION OF WASHINGTON

MATTER & ENERGY

Rarest nucleus reluctant to decay

Tantalum-180m's half-life is at least 45 million billion years

BY EMILY CONOVER

Nature's rarest type of atomic nucleus is not giving up its secrets easily.

Scientists looking for the decay of an unusual form of the element tantalum, known as tantalum-180m, have come up empty-handed. Tantalum-180m's hesitance to decay indicates that it has a half-life of at least 45 million billion years, Bjoern Lehnert and colleagues report online September 13 at arXiv.org. "The half-life is longer than a million times the age of the universe," says Lehnert, a nuclear physicist at Carleton University in Ottawa. (Scientists estimate the universe's age at 13.8 billion years.)

The metal tantalum is uncommon, making up less than two ten-thousandths of a percent of the mass of Earth's crust. Tantalum-180m is even harder to find. Only 0.01 percent of tantalum is found in this state; it is the rarest known long-lived nuclide, or variety of atomic nucleus.

Tantalum-180m is an isomer — its nucleus exists in an "excited," or high-energy, configuration. Normally, an excited nucleus quickly drops to a lower energy state, emitting a photon — a particle of light — in the process. But tantalum-180m is "metastable" (hence the "m" in its name), meaning that it gets stuck in its high-energy state.

> "The half-life is longer than a million times the age of the universe."
>
> **BJOERN LEHNERT**

Tantalum-180m is thought to decay by emitting or capturing an electron, morphing into another element — either tungsten or hafnium — in the process. But this decay has never been observed. Other unusual nuclides can have even longer half-lives than tantalum-180m. But tantalum-180m is the longest-lived isomer found in nature.

"It's a very interesting nucleus," says Eric Norman, a nuclear physicist at the University of California, Berkeley. Scientists don't have a good understanding of such unusual decays; measuring the half-life would help pin down the details of the process and the nucleus' structure.

Lehnert and colleagues observed tantalum with a detector designed to catch photons emitted in the decay process. After running the experiment for 176 days and adding in data from previous incarnations of the test, the team saw no evidence of decay. If the half-life is shorter than 45 million billion years, the probability is high that the scientists would have seen some hint of the process. "They did a state-of-the-art measurement," Norman says.

The presence of tantalum-180m in nature is itself a bit of a mystery. The element-forging processes that occur in stars and supernovas seem to bypass the nuclide. "People don't really understand how it is created at all," Lehnert says. ■

LIFE & EVOLUTION

Bumblebees exhibit signs of emotions

After a treat, insects made more optimistic decisions, study finds

BY EMILY UNDERWOOD

To human observers, bumblebees sipping nectar from flowers appear cheerful. It turns out that the insects may actually enjoy their work. A new study suggests that bees experience a "happy" buzz after receiving a sugary snack, although it's probably not the same joy that humans experience chomping on a candy bar.

Scientists can't ask animals how they feel. Instead, researchers must look for signs of positive or negative emotions in an animal's behavior, says Clint Perry, a neuroethologist at Queen Mary University of London. In one such study, for example, scientists shook bees vigorously in a machine for 60 seconds — hard enough to annoy but not to injure — and found that stressed bees made more pessimistic decisions while foraging.

The new study, published in the Sept. 30 *Science*, is the first to look for signs of positive bias in bee decision making, Perry says. His team trained 24 bumblebees to navigate an arena connected to a tunnel. When the tunnel was marked with a blue "flower" (a placard), the bees learned that sugar water awaited them at its end. When a green "flower" was present, there was no reward. Once the bees learned the difference, the scientists threw a curveball: Rather than being blue or green, the "flower" had a confusing blue-green hue.

Faced with the ambiguous hue, the bees appeared to dither, meandering for about 100 seconds before deciding to enter the tunnel. Some didn't enter at all. But when the scientists gave half the bees a treat — sugar water — that group spent just 50 seconds circling the entrance before deciding to check it out. Overall, the two groups flew roughly the same distances at the same speeds, suggesting that the bees that had gotten a treat first had not simply experienced an energy boost from the sugar but were in a more positive, optimistic state, Perry says.

In a separate experiment, Perry and colleagues simulated a spider attack. Sugar-free bees took about 40 seconds longer than sugar-fed bees to resume foraging after the harrowing encounter.

The team then applied a solution to the bees that blocked the action of dopamine, a molecule that transmits rewarding signals in the insect brain. With dopamine blocked, the effects of the sugar disappeared, further suggesting that a change in mood, not just increased energy, was responsible for the bees' behavior.

The results are the first evidence for positive, emotion-like states in bees, says neuroscientist Ralph Adolphs of Caltech. Yet he suspects that the sugar's metabolic effects played some role in bee behavior.

Neuroethologist Geraldine Wright of Newcastle University in England shares that concern: "I would be very cautious in interpreting the responses of bees in this assay as a positive emotional state." ■

GENES & CELLS

DNA variants tied to dog sociability

Genes may shape propensity to look to people for help

BY TINA HESMAN SAEY

Dogs may look to humans for help in solving impossible tasks thanks to some genes previously linked to social disorders in people.

Beagles with certain variants in a gene that is associated with autism were more likely to sidle up to and make physical contact with a human stranger, researchers report September 29 in *Scientific Reports*.

That gene, *SEZ6L*, is one of five genes in a particular stretch of beagle DNA associated with sociability in the dogs, animal behaviorist Per Jensen and colleagues at Linköping University in Sweden say. Versions of four of those five genes have been linked to human social disorders such as autism, schizophrenia and aggression.

Genetic variants that make dogs more sociable may have been selected during domestication, Jensen says.

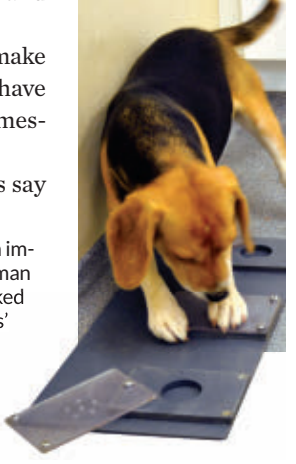
But other researchers say the results are preliminary and need to be confirmed by looking at other breeds. Previous genetic studies of dog domestication have not implicated these genes. But, says evolutionary geneticist Bridgett vonHoldt of Princeton University, genes that influence sociability are "not an unlikely target for domestication — as humans, we would be most interested in a protodog that was interested in spending time with humans."

Most dog studies take DNA from pets, village dogs and/or wolves. Jensen's team studied beagles that had been raised in a lab and not trained. The team put the dogs in a room with an unfamiliar woman and gave the dogs an unsolvable problem. The puzzle was a device with three treats that the dogs could see and smell under sliding lids. One lid was sealed shut.

After some futile attempts to open the sealed lid, many of the beagles looked to the human for help. Some tried to catch her eye, glancing back and forth between the woman and the stuck lid. Others made physical contact or tried to stay close to the woman.

The team then looked for places in the dogs' DNA where the most and least human-friendly dogs differed and found the five genes.

The finding is a statistical signal but doesn't establish what the genes might do to influence the dogs' behavior, says Harvard evolutionary geneticist Adam Freedman. ■



Beagles that tried to open an immovable lid often sought human help. Variations in a gene linked to autism may influence dogs' people-seeking behavior.

MIA PERSSON

LIFE & EVOLUTION

Bacterial DNA alters pill bug sex

Wolbachia gene transfers have shaped female chromosome

Wolbachia bacteria do some remarkable things to sex determination in pill bugs — even after the actual bacteria are long gone.

BY SUSAN MILIUS

When sex chromosomes among common pill bugs go bad from disuse, borrowed bacterial DNA comes to the rescue. Certain pill bugs grow up female because of sex chromosomes cobbled together with genes that jumped from the bacteria.

Genetic analysis traces this female-maker DNA to *Wolbachia* bacteria, Richard Cordaux, a CNRS investigator based at the University of Poitiers in France, announced September 29.

Wolbachia infects many arthropods, spreading from mother to offspring and often biasing the hosts' sex ratios toward females. In the common pill bug (a type of terrestrial crustacean), *Wolbachia* passed to eggs can make genetic males develop into functional females without any gene transfer. After generations of infections determining sex, these pill bugs' now-obsolete female-making genes have degenerated. Which makes it strange that some pill bug populations with no current *Wolbachia* infections still produce abundant females. That's where Cordaux and Poitiers colleague Clément Gilbert have demonstrated a second way that *Wolbachia* makes lady pill bugs — by donating DNA directly to the pill bug genomes.

The team has built a case that *Wolbachia* inserted feminizing genes into pill bug chromosomes. The bacterial genes thus created a new sex chromosome.

"Incredible," Steve Perlman said in wonder at the biology. He studies symbiosis and parasitism at the University of Victoria in Canada and says that far-flung gene transfers provide genetic variation that fuels evolutionary processes. ■

LIFE & EVOLUTION

Case builds for another Zika vector

Laboratory data suggest *Culex* mosquitoes can spread virus

BY SUSAN MILIUS

New evidence from separate labs supports the controversial idea that an overlooked and unexpected *Culex* mosquito might spread Zika virus.

The southern house mosquito (*Culex quinquefasciatus*) is common in the Americas. Constância Ayres of Brazil's Oswaldo Cruz Foundation previously surprised researchers with the proposal that this mosquito might spread Zika. But two U.S. research groups couldn't get the virus to infect the species.

Now, results from Ayres' and two other research groups have renewed the discussion. The data, reported September 26, suggest that Zika can build up in the house mosquito's salivary glands — a key step in being able to transmit disease. Basic insect physiology is only part of the puzzle, though. Even if the mosquitoes prove competent at passing along Zika, questions remain about whether their tastes, behavior and ecology will lead them to actually do so.

In the current outbreak, the World Health Organization has focused on mosquitoes in the *Aedes* genus, particularly *Ae. aegypti*, as the main disease vector. But Ayres had announced months ago the discovery of the virus in Brazil's free-flying house mosquitoes (*SN Online: 7/28/16*).

Duschinka Guedes, Ayres' foundation colleague, reported that captive house mosquitoes fed Zika-tainted blood had virus growing in their guts and salivary glands within days. To move from the mosquito to what it bites, viruses have to infect the insect midgut, then travel to the salivary glands and build up enough of a population for an infective dose. When Guedes offered the infected mosquitoes a special card to bite, they left telltale virus in the salivary traces, a sign of what they could do when biting a real animal.

Researchers from China and Canada also shared their results, some of which are unpublished.

At the Beijing Institute of Microbiology and Epidemiology, Tong-Yan Zhao found the virus peaking in the house mosquitoes eight days after their first contaminated drink. As a test of infectious powers, researchers let the Zika-carrying insects bite baby lab mice. Later, the virus showed up in the brains of eight out of nine mice. The results were reported September 7 in *Emerging Microbes & Infections*.

At Brock University in St. Catharines, Canada, Fiona Hunter has found signs that 11 out of 50 wild-caught *Culex pipiens pipiens* mosquitoes picked up the virus somewhere on their bodies. So far, she has analyzed one mosquito and reports that the virus was in its saliva.

These results contradict *Culex* tests at the University of Texas Medical Branch in Galveston. Those tests, with U.S. mosquitoes, found no evidence that *C. quinquefasciatus* can pick up and pass along a Zika infection, says study coauthor Scott Weaver. Stephen Higgs of Kansas State University in Manhattan and colleagues got similar results. Higgs muses over whether certain virus strains won't infect mosquitoes from particular places.

George Peck, who runs mosquito control for Clackamas County in Oregon, isn't convinced that the high virus concentrations dosing the test mosquitoes are realistic. Yet he's watching the issue because like much of northern North America, Clackamas doesn't have the *Ae. aegypti* vector to worry about. But there are plenty of *Culex* mosquitoes. ■

BODY & BRAIN

Concern grows over Zika birth defects

In utero infections may cause variety of long-term health issues

BY MEGHAN ROSEN

After a year caring for patients at the heart of Brazil's Zika epidemic, pediatric neurologist Vanessa van der Linden has seen some of the worst cases.

She was one of the first researchers to link Zika virus to microcephaly, a now well-known birth defect marked by a small, misshapen head and, sometimes, a forehead that slopes backward. Babies with the defect can have other symptoms, too: Van der Linden has seen 24-hour crying bouts, spasms, extreme irritability and difficulty swallowing.

Microcephaly is just the tip of the Zika iceberg, she said September 22 at a workshop in North Bethesda, Md., hosted by the National Institutes of Health. That's something public health officials have been warning about for months. Now, scientists have begun to describe a head-to-toe assortment of health problems linked to Zika virus infection in utero; they're calling it congenital Zika syndrome.

Still, the full scope of the problem, including the threat of more subtle neurological disorders such as learning disabilities or developmental delays, remains murky, says Peter Hotez, a pediatrician and microbiologist at Baylor College of Medicine in Houston.

"That's the big unknown: There's probably a spectrum of illness," similar to autism, he says. And it could take years for scientists to sort it all out.

It's a problem that Brazil is facing now, and one that Puerto Rico has just begun grappling with.

As of September 29, the U.S. territory had reported 24,127 confirmed cases of Zika infection. Of these, 1,977 are pregnant women. Carmen Zorrilla, an ob-gyn at the University of Puerto Rico's Maternal-Infant Studies Center who has examined some of these women and their babies, emphasizes the importance of following up on all babies exposed to Zika in the womb — even those without apparent birth defects.

"Even if they are born normal," she said, "it doesn't mean they'll be OK."

At the workshop, Zorrilla described the case of one of the first Puerto Rican babies born to a mother diagnosed with Zika. The baby didn't have microcephaly, but she did have another unusual problem: She couldn't open her eyes. A bad case of conjunctivitis (pinkeye) left her needing help opening her eyelids every morning — even 27 days after birth.

Zorrilla can't say for sure whether the problem was related to Zika, but "it really concerned me," she said. "This is the first baby I've seen with conjunctivitis that lasted for so long."

The case may be another clue that Zika's assaults on the body are widespread. And Zorrilla can expect to see more cases soon. Ultrasound examinations of 228 women in Puerto Rico with confirmed Zika infection have spotted brain abnormalities in 13 fetuses, including one with microcephaly.

Another observation could hint at problems to come: Most Zika-exposed fetuses have had slightly smaller heads than average, although "still within the normal limits," Zorrilla said. Measurements of leg bones and stomach size indicate the rest of the body is growing normally. Implications remain unclear, but the preliminary findings — from Alberto de la Vega, also an ob-gyn at the University of Puerto Rico — are the latest in a litany of anomalies linked to Zika.

Long-term problems aren't unusual in babies infected with another virus that causes microcephaly. Like Zika, cytomegalovirus can infect babies in the womb. Most CMV-infected babies don't have any obvious symptoms, but asymptomatic kids may have problems as they grow, including intellectual disabilities, hearing loss or cerebral palsy, researchers suggest in the October *Brain and Development*.

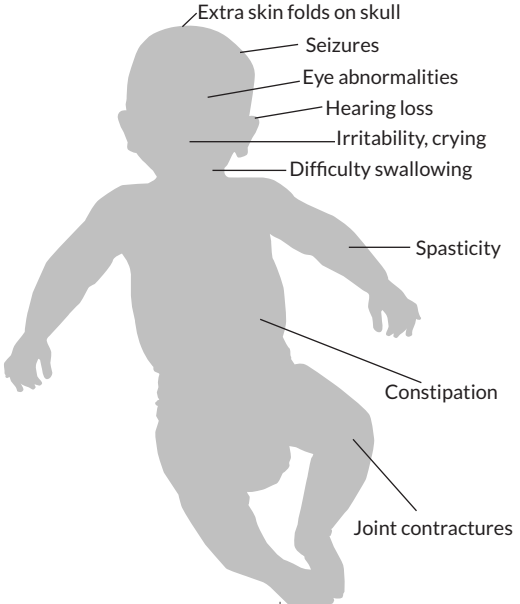
Beyond microcephaly, scientists have recently described other symptoms linked to Zika infection. In some babies, Zika seems to damage hearing. Of 70 Zika-exposed infants born with microcephaly, 10 percent had some hearing loss, researchers note in a U.S. Centers for Disease Control and Prevention report published September 2.

Zika can leave a mark on the eyes, too. More than a third of 29 babies with microcephaly had some sort of eye oddity, including mottled pigmenting and/or withered tissue, researchers reported in May in *JAMA Ophthalmology*.

Van der Linden has also observed a link between Zika and a deformity called arthrogryposis, where a child's joints can be stuck in contorted positions — even in babies without microcephaly. The condition might stem from problems with infected babies' motor neurons, the nerve cells that relay messages from the brain to the muscles, van der Linden and colleagues suggest August 9 in *BMJ*.

She has even seen babies born with normal head circumferences who later develop microcephaly or other brain defects. One mother, she says, came in five months after giving birth because she thought her baby wasn't developing normally. Like children with congenital Zika syndrome, the baby's head scans revealed "the same pattern of brain

Beyond microcephaly A growing body of evidence shows that babies infected with Zika virus in the womb can suffer a wide range of symptoms, from abnormalities in the eyes to contracted joints in the legs.



T. TIBBITTS

damage," van der Linden says. This pattern includes a malformed cerebral cortex (the wrinkled outer layer of the brain) and calcifications, strange lumps of calcium deposited within the tissue.

Scientists don't know exactly how Zika damages the brain, but they have ideas.

One recent report notes that Zika can infiltrate and kill both neuroepithelial stem cells, which give rise to brain cells, and radial glial cells, which can generate newborn neurons and help guide them to their proper place in the brain.

Zika also hinders these cells' ability to split into new cells, Yale University neuroscientist Marco Onorati and colleagues report in the Sept. 6 *Cell Reports*.

The virus can also invade the cells that give rise to bone, cartilage and muscles in the head, researchers report September 29 in *Cell Host & Microbe*.

Stem cells at work in the fetal brain eventually give rise to structures responsible for thought, memory and learning, raising concerns of a cascade of problems down the road. "This is a virus that blocks the development of the fetal brain," Hotez says. "That's about the worst thing you can possibly imagine."

And fetuses might not be the only ones at risk. "Kids in the first years of life also have growing, developing brains," he says. "What if they get infected with Zika?"

It's not an easy question to answer. But another disease could offer clues.

Malaria can cause severe neurological problems in infected kids. A condition called cerebral malaria may be linked to disorders such as attention-deficit/hyperactivity disorder, antisocial behavior and depression, scientists reported in March in *Malaria Journal*.

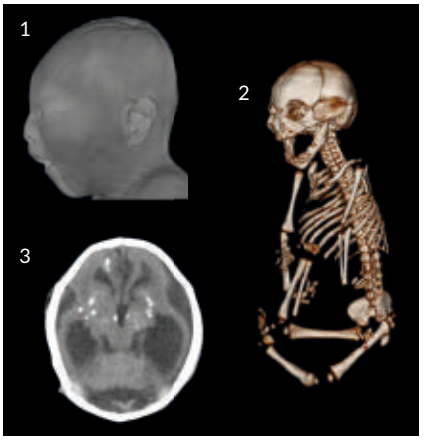
Researchers will need to watch out for long-term troubles in Zika-exposed babies born with no obvious symptoms, says the CDC's Sonja Rasmussen. "We don't want to make families too scared," she says. "But we do recognize the possibility of later-on seizures or developmental delay."

Since most people don't show signs of Zika infection, pinpointing the total number of pregnant women (and babies) exposed to the virus may be impossible.

In the Americas, at least tens of thousands of children may eventually suffer some sort of neurologic or psychiatric illness triggered by Zika, Hotez predicts in *JAMA Pediatrics* in August.

Van der Linden can't yet say whether the babies she has seen have learning disabilities or psychiatric illnesses, or more subtle cognitive problems. But she plans to follow these Zika-infected patients, including the babies who appeared normal at birth, for years. "We need time to better understand the disease," she says.

Hotez agrees: "It's going to take a generation of pediatric neurologists and infectious disease experts to figure this out." ■



A baby born to a woman infected with Zika in the first trimester of pregnancy had (1) an unusually small head, (2) joint contractures (reconstruction of the child's skeleton) and (3) calcifications in the brain (bright white spots).

P. SOARES DE OLIVEIRA-SZEJNFELD *ET AL/RADIOLOGY* 2016

GENES & CELLS

DNA editing in human embryos begins

Swedish lab is not alone in doing such experiments, scientists say

BY TINA HESMAN SAEY

A Swedish scientist is gene editing healthy human embryos, and he is probably not alone, researchers say.

Chinese researchers have reported editing genes in human embryos that are unable to develop into a baby. But developmental biologist Fredrik Lanner of the Karolinska Institute in Stockholm is the first researcher to publicly acknowledge editing genes in viable human embryos. Other researchers are almost certainly doing similar experiments out of the public eye, scientists say.

"My sense is that there are different groups out there doing this kind of work," says stem cell biologist Paul Knoepfler of the University of California, Davis.

Lanner allowed a National Public Radio reporter to watch as researchers in his lab injected a powerful new gene editor called CRISPR/Cas9 (*SN: 9/3/16, p. 22*) into early human embryos left over from in vitro fertilization. The editor is a two-part molecular scissors consisting of a DNA-cutting protein called Cas9 and a short piece of RNA that guides the protein to a gene that scientists want to snip.

CRISPR's ease and precision have made the prospect of editing human embryos nearly inevitable, says Chad Cowan, a stem cell biologist at Harvard University. Such experiments are probably going on privately in the United States, China and elsewhere, he says.

Sweden and other countries require proper justification and ethical oversight to do such research, Cowan adds, but researchers are often reluctant to talk to reporters before their work has been published. Lanner, however, told *Science News* that scientists should speak more freely about such research: "I'm doing my best to discuss these important experiments openly in scientific and general public forums."

Lanner is studying the development of early embryos in lab dishes to devise new infertility treatments, prevent miscarriages and learn more about stem cells. Studying human embryos is necessary, he says, because findings from lab animals and cell cultures don't always extend to human development. The altered embryos won't be allowed to develop for more than 14 days. ■

HUMANS & SOCIETY

Maya codex real, analysis claims

Grolier text could claim spot as oldest book from Americas

BY BRUCE BOWER

A bark-paper document with a weird backstory and a reputation as a possible forgery is the real deal, researchers say. If true, that increases the likelihood that the plaster-coated book is the earliest known manuscript from ancient America, dating back to the 13th century.

No forger could have known how to reproduce all the bookmaking techniques, colored inks and deities pictured in what's known as the Grolier Codex, concludes a team of researchers who specialize in the Maya and other ancient American societies. For instance, an illustration of a mountain god includes a flaring, cleft head or headdress. Other images of this god were first discovered at Maya sites several decades after the Grolier Codex turned up in the 1960s.

"Even a good faker would not have known about the mountain god's headdress," says David Freidel, a Maya expert at Washington University in St. Louis who was not involved in the study.

The new analysis comes from Michael Coe and Mary Miller of Yale University, Stephen Houston of Brown University and Karl Taube of the University of California, Riverside. Appearing in *Maya Archaeology 3*, an annual journal released September 7, the study is based on high-quality photographs of the book's 10 surviving pages. The original Grolier Codex most likely included 20 attached pages that folded like an accordion, the researchers say.

Drawn deities and written glyphs in the codex display influences from the Maya site of Chichén-Itzá on the Yucatán Peninsula and the Toltec site of Tula in central Mexico, the investigators say. Contact between the Maya and Toltec societies dates to between the end of Classic Maya civilization around 950 and the arrival of the Spanish in the 1500s.

A book called the Grolier Codex — long regarded as a fake by some scientists — may be the oldest known manuscript of ancient America. Deities depicted on the book's 10 surviving pages include a death god with a decapitated captive (left) and a bird/serpent god (right).

Two radiocarbon studies of fragments from the book, conducted in 1973 and 2014, suggest that it dates to the 1200s.

"The Grolier Codex was probably made by one scribe who did not distinguish between the Toltec and the Maya," Houston says. Fake Maya codices are ineptly done and easily spotted. "They are nothing like the Grolier Codex," Houston contends, which displays a sophisticated understanding of both Maya and Toltec artistic styles and glyphs.

Three other Maya bark-paper manuscripts, dubbed the Dresden, Madrid and Paris codices for where they're housed, were discovered and authenticated by the mid-1800s (*SN: 2/21/15, p. 14*). Those codices were made before Spanish contact but lack radiocarbon ages.

Since its reported discovery in a southern Mexico cave by looters in the mid-1960s, the codex has aroused suspicions of fakery. A wealthy collector allowed the document to be exhibited at New York City's Grolier Club in 1971, giving the codex its name. The collector claimed that two looters had taken him by plane to a remote spot where he was shown the book and other finds from the cave.

Another red flag was the codex's simple illustrations and glyphs. The authenticated Maya codices feature elaborate notations, calculations and illustrations.

These surviving Maya codices were probably spared by Spanish authorities as special examples of New World culture to show Europeans, Houston says. By contrast, the Grolier Codex is a "run-of-the-mill" ritual guide of a type that the Spanish destroyed en masse, he suspects.

A calendar predicting the movements of the planet Venus over 104 years, with an undetermined start date, appears in the Grolier Codex. The number of days between Venus' appearances as the morning star was used to time ritual events. Gods depicted in the Grolier Codex carry out demands of Venus related to the sun, death and other basic concerns.

The new analysis also supports the codex's authenticity, based on examination of previous radiocarbon dates and colored inks that probably include Maya blue, which has a chemical signature that was unknown until the 1980s, archaeologists Harvey and Victoria Bricker, both of Tulane University in New Orleans, wrote in an e-mail. The Brickers agree that the Grolier Codex has a mix of Maya and central Mexican features.

Still, the document remains controversial. Archaeologist Susan Milbrath of the Florida Museum of Natural History in Gainesville, a Grolier Codex skeptic, declined to comment specifically on the paper. But she e-mailed a 2007 paper suggesting that stains and tears in some parts of the document were produced long after the 1200s, possibly to make the manuscript look older than it is. Plaster and ink erosion caused that damage, Houston says. ■

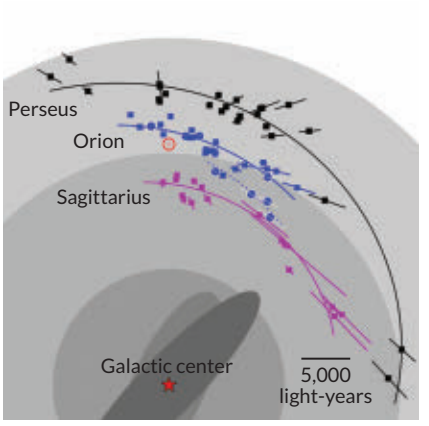
ENRICO FERORELLI, S. HOUSTON

ATOM & COSMOS

Solar system sits within major spiral arm of Milky Way

Our galactic neighborhood might be more expansive than thought. Rather than being stuck in a backwater galactic community, our solar system sits along a major spiral arm of the Milky Way, researchers say September 28 in *Science Advances*.

Astronomers suspected that our arm — the Orion Arm — was just a bridge connecting two bands of stars and gas: the Sagittarius and Perseus arms that wrap around the galaxy. Ye Xu of Purple Mountain Observatory in Nanjing, China, and colleagues measured distances to about two dozen stellar nurseries and found that they — and the sun — are scattered along an arm over 20,000 light-years long that parallels the two neighboring arms. This arc of a presumably larger spiral arm is comparable in length to the visible portions of the Sagittarius and Perseus arms.



Spiral arm Star-forming regions (blue) trace out the Orion Arm of the Milky Way, where the sun (red circle) is. This arm runs parallel to the Perseus (black) and Sagittarius (magenta) arms.

Our view of the Milky Way is blocked by interstellar gas and dust, so the galaxy's structure must be inferred through measurements like these and by comparisons with other galaxies. — *Christopher Crockett*

ATOM & COSMOS

Rosetta spacecraft ends mission

Rosetta is no more. On September 30, the orbiter touched down on the surface of comet 67P/Churyumov–Gerasimenko and immediately shut down, bringing an end to the mission.

The landing site has been dubbed Sais, the ancient Egyptian town believed to be the original home of the Rosetta stone, after which the mission is named.

Confirmation came from a planned loss of radio signal from the spacecraft. Onboard computers were programmed to shut down when Rosetta hit the comet. The spacecraft approached the comet at just a few kilometers per hour, but the probe wasn't designed for landings and was probably damaged.

Mission scientists will continue to keep busy analyzing all the data sent back before touchdown. — *Christopher Crockett*

MATTER & ENERGY

Evidence points to new form of matter-antimatter asymmetry

Like two siblings with divergent personalities, a type of particle and its antimatter partner have shown signs of behaving differently. It's the first time matter-antimatter differences have been detected in decays of a baryon — a category of particle that includes protons and neutrons. Such matter-antimatter discrepancies are key to explaining how the universe came to contain mostly matter, scientists believe.

Matter-antimatter differences in decays of baryons — made of three smaller particles known as quarks — were expected, but supporting evidence has eluded scientists until now. Previous work found differences between matter and antimatter for mesons, which consist of one quark and one antiquark.

For most processes, the laws of physics would be the same if matter were swapped with antimatter. But when this principle, known as charge parity, or CP, symmetry, is violated, matter and antimatter act differently.

Scientists with the LHCb experiment, located at the Large Hadron Collider near Geneva, have found hints of CP violation in the decays of a lambda-b baryon. When the lambda-b baryon decays, particles produced by the decay speed away at different angles and momenta for matter and antimatter versions of the baryon, the scientists report online September 16 at arXiv.org.

The well-tested theory of particle physics, the standard model, includes some CP violation, but not enough to explain why antimatter is now rare. So physicists are searching for additional sources of the discrepancy. — *Emily Conover*

EARTH & ENVIRONMENT

Methane didn't keep ancient Earth warm, new simulation suggests

Methane wasn't the cozy blanket that kept Earth warm hundreds of millions of years ago when the sun was dim, new research suggests.

By simulating the ancient environment, researchers found that abundant sulfate and scant oxygen created conditions that kept down levels of methane — a potent greenhouse gas — 1.8 billion to 800 million years ago (*SN: 11/14/15, p. 18*). So something other than methane kept Earth from becoming a snowball during this dim phase in the sun's life. Researchers report this new wrinkle in the so-called faint young sun paradox (*SN: 5/4/13, p. 30*) online September 26 in the *Proceedings of the National Academy of Sciences*.

Limited oxygen increases the production of microbe-made methane in the oceans. With low oxygen early in Earth's history, many scientists suspected that methane was abundant enough to keep temperatures toasty. Oxygen may have been too sparse, though. Recent work suggests that oxygen concentrations at the time were as low as a thousandth their present-day levels (*SN: 11/29/14, p. 14*).

Stephanie Olson of the University of California, Riverside and colleagues propose that such low oxygen concentrations thinned the ozone layer that blocks methane-destroying ultraviolet rays. They also estimate that high concentrations of sulfate in seawater at the time helped sustain methane-eating microbes. Together, these processes severely limited methane. — *Thomas Sumner*

Y. XU ET AL/SCIENCE ADVANCES 2016

REBUILDING reefs

With corals at risk, scientists attempt underwater rehab

By Amy McDermott

Coral reefs are bustling cities beneath tropical, sunlit waves. Thousands of colorful creatures click, dash and dart, as loud and fast-paced as citizens of any metropolis.

Built up in tissue-thin layers over millennia, corals are the high-rise apartments of underwater Gotham. Calcium carbonate skeletons represent generations of tiny invertebrate animals, covered in a living layer of colorful coral polyps. Their structures offer shelter, and for about 114 species of fish and 51 species of invertebrates, those coral skyscrapers are lunch.

Important as they are, corals are in jeopardy. Warming oceans are causing more and more corals to bleach white and become vulnerable to destruction. A prolonged spike in temperatures, just 1 to 2 degrees Celsius, is enough to kill the marine animals. Greenhouse gas emissions also acidify the water, dissolving the calcium skeletons. In some countries, fishermen use dynamite to catch fish, leaving behind coral rubble. Today, more than 60 percent of the world's reefs are at risk of disappearing.

A coral fluoresces purple (left), perhaps as a sunscreen defense for colorless polyps, in a photo taken September 12 of a bleached reef near Okinawa, Japan.

Threats to reefs have "dramatically escalated in the last few decades," says marine scientist Peter Harrison of Southern Cross University in Lismore, Australia. He has studied corals for three decades. "In my time as a reef researcher," Harrison says, "I've seen it get worse, firsthand."

Thirty years ago, massive coral bleachings were unheard of. Today, reefs are suffering through a third global bleaching event since 1998. With high ocean temperatures dragging on since

2014, this summer marked the longest and most widespread episode of worldwide coral bleaching on record (*SN: 7/23/16, p. 5*). Australia has been hit especially hard. More than 80 percent of the northern part of the Great Barrier Reef is bleached and close to half of those corals have died, according to a report in April from Australia's National Coral Bleaching Taskforce.

As reefs take a nose dive, scientists from Hawaii to the Philippines and the Caribbean are scrambling to save corals. Approaches that were once considered radical are "now seen as necessary in some places," says coral biologist Ruth Gates of the Hawaii Institute of Marine Biology on Oahu.

In Florida, researchers are restoring reefs with tiny coral fragments. In Hawaii, Gates is scouring the water for stress-tolerant corals and experimenting in the lab to breed the hardiest individuals. At the 13th International Coral Reef Symposium in Honolulu in June, Harrison's team reported early promising results of its effort to flood damaged reefs in the Philippines with tiny coral larvae.

What works on one reef won't necessarily save another. So researchers are testing an arsenal of options to rescue a diversity of underwater communities.

A different story

In the early 1980s, Harrison was a graduate student at James Cook University in Townsville, Australia, working on the Great Barrier Reef. At the time, textbooks taught that most corals reproduce by brooding: Fertilization occurred inside the body and larvae were released into the water to replenish reefs year-round. But Harrison witnessed something very different. For a few nights around a full moon in springtime, corals spawned, spewing eggs and sperm into the water to be externally fertilized. The sea was covered in a pink, oily slick.

"We found the corals hadn't read the textbooks," Harrison says. Eggs and sperm were meeting outside of the coral bodies, and larvae were developing while drifting in the currents.

That discovery spurred a cascade of studies on coral reproduction that led to the modern understanding that many corals reproduce only once or twice a year, in coordinated mass releases of eggs and sperm. Most of the resulting larvae die or drift out to sea, Harrison says. Only a small fraction survive to adulthood. Even so, mass spawns are "how reefs replenish themselves over time," he says.

Just after Harrison's discovery, the Great Barrier Reef, and then reefs around the globe, experienced bleaching on a massive scale. Normally, tiny algae live inside coral polyps. The algae make sugar and other nutrients for the coral, and can give polyps their characteristic bright colors. But when temperatures spike, algae become toxic. Corals spit out their partners, bleach white and can die if temperatures don't cool enough for the algae to return (*SN Online: 10/8/15*).

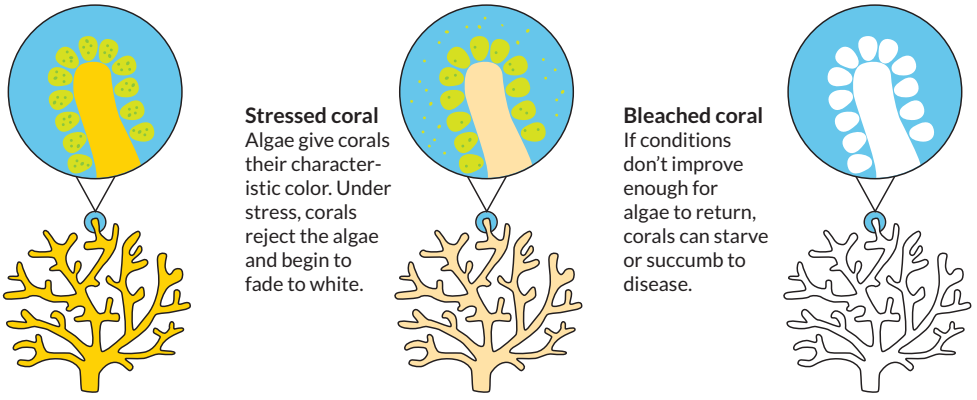
Corals worldwide were bleaching more often and more severely than had been recorded in the past. Scientists began to worry that reefs were in trouble. Some researchers, like Dave Vaughan, who manages the Coral Reef Restoration program at the Mote Tropical Research Laboratory in Summerland Key, Fla., took action.

This summer marked the longest and most widespread episode of worldwide coral bleaching on record.

In those days, Vaughan was a fish farmer, raising saltwater fish species in captivity. He began growing corals for tropical aquarium tanks. At the time, all the corals in the aquarium trade were taken from the wild, Vaughan says. He started growing coral species in captivity as an environmentally friendly alternative.

One day, Philippe Cousteau, grandson of legendary aquanaut Jacques, toured the operation. When the young Cousteau saw that Vaughan was raising corals for aquariums, "he shook his head," Vaughan remembers, "and said 'Dave, if you could do this for the aquarium trade, you can do this for the reef.'"

Stressed out
Changing conditions, such as rising ocean temperatures and local pollution, can kill reefs by bleaching corals. Here's how tough times turn reefs white.
SOURCE: NOAA CORAL REEF CONSERVATION PROGRAM



In those earliest days, most scientists were tackling small-scale reef damage caused by dropped anchors or boat groundings, Vaughan says. To repair that kind of minor damage, scientists began breaking 3- to 5-centimeter fragments from healthy corals on a neighboring reef and transplanting the chunks in damaged spots.

Cousteau's visit convinced Vaughan that he should try restoring reefs. While doing so, 11 years ago, Vaughan made a game-changing discovery: Tinier fragments of coral, only 1 centimeter long, repair themselves 25 to 40 times as fast as scientists had ever recorded corals growing.

Today Vaughan's team is spreading many of these microfragments over the surface of dead coral skeletons in the Florida Keys. As those bits fuse back together, they create a fast-growing "skin" over an otherwise dead reef. Condemned buildings are refurbished rather than razed.

The hope is that thousands of microfragments will carpet a small reef in two to three years, says Chris Page, a biologist at Mote Marine Laboratory working with Vaughan. That's super fast. "There's no way that's happening in nature," Page says.

Vaughan's team is cultivating 17 species for microfragmentation in large troughs on land, with seawater running through them. He is focused on the top six slow-growing massive species that create the foundation of the reef. Some can live for centuries, mounded into boulders the size of a truck.

The Florida researchers plunged their first 200 microfragments into the ocean three years ago, at two sites in a nearshore coral reef off Big Pine Key, Fla. The colonies are now six to eight times as large as they were at planting and have begun to fuse together into areas about the size of a 5-gallon bucket lid. Since then, Vaughan and Page have planted close to 10,000 microfragments in the wild. "People were looking for some glimmer of light," Vaughan says. "And restoration is turning out to be that in a big way."

Seeds of reefs

Fragmentation and the newer microfragmentation are both time- and labor-intensive, and therefore very expensive. And, Harrison says, they rely on cloning.

When one coral is broken into fragments, to be fattened up and then planted around a reef, each chunk is genetically identical. All those pieces have the same DNA blueprint to fight infection and to deal with stress. Unlike natural reefs, where individuals are genetically distinct and have different vulnerabilities, cloned corals share the same weaknesses.

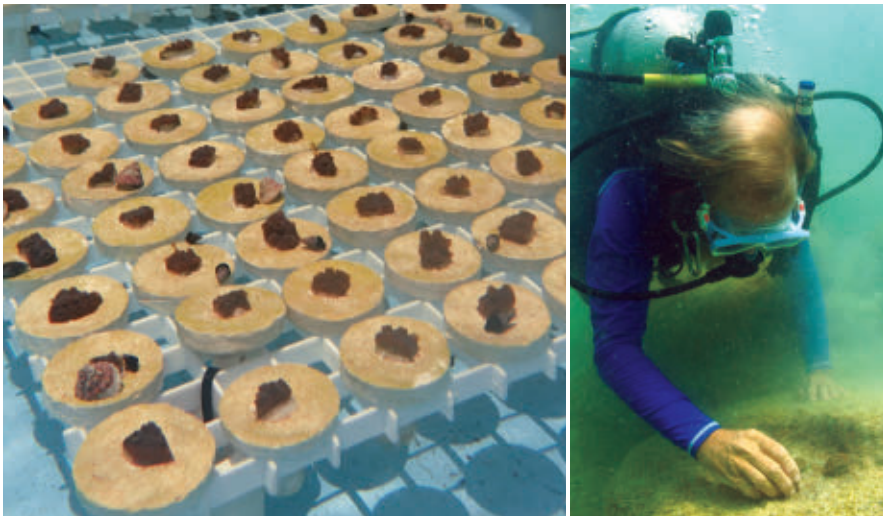
"People have spent years growing coral gardens only to have them wiped out by the next bleaching event," Harrison says. With more diversity, he adds, some of those corals might have survived. In a warmer world where bleaching and disease will probably become more common, "genetic diversity equals resilience."

To address the diversity issue, Vaughan and Page are raising 20 to 30 genetic variants of each coral species, to be planted around the reef. They are also collecting eggs and sperm from wild colonies of four coral species to grow on Summerland Key.

Harrison has been thinking about genetic diversity ever since the early 1980s, when he saw corals spewing sperm and eggs into the ocean. Few of the resulting larvae would survive. Many would drift away and most would die. All while Harrison saw reefs in decline.

What if, he wondered, scientists could take millions of those

Coral microfragments grow on round pucks in nursery troughs (left) on Florida's Summerland Key in 2016. Reef scientist Dave Vaughan (right) plants microfragments from the nursery to restore reef-building corals at the southern tip of Key West.



TOP: E. OTWELL; BOTTOM, FROM LEFT: C. PAGE; CONOR GOULDING/MOTE MARINE LABORATORY

diverse coral larvae and help them settle onto reefs to replenish ailing ecosystems?

Other researchers asked themselves the same question. In the late 1990s and from 2007 to 2009, two teams, in Australia and Palau, released coral larvae onto healthy reef areas in mesh tents pitched over the seabed. In both studies, thousands of larvae settled under the tents, many more than scientists would have seen naturally.

But those early results may have been misleading. Most of the early settlers in Palau died within 30 weeks. Flooding the reef with larvae didn't make a lasting difference in coral numbers. Maybe, the researchers speculated, settlers were too crowded, which meant swamping reefs with larvae made no sense.

Harrison wasn't ready to give up. Even though most of the new settlers had died, those studies were done on healthy reefs, he says. In battered areas, where some baby corals might naturally drift in, but not enough for the reef to self-heal, a flush of larvae could be a shot in the arm.

The idea was to find a badly damaged reef, where the worst problems, such as blast fishing, had stopped. Harrison would bring a few of the reef's mature, sexually active corals to the lab, persuade them to release sperm and eggs in aquarium tanks, and then take more than a million of their larvae back out to the reef. The plan was to saturate the environment with settling babies, as adult corals would have done in healthier days.

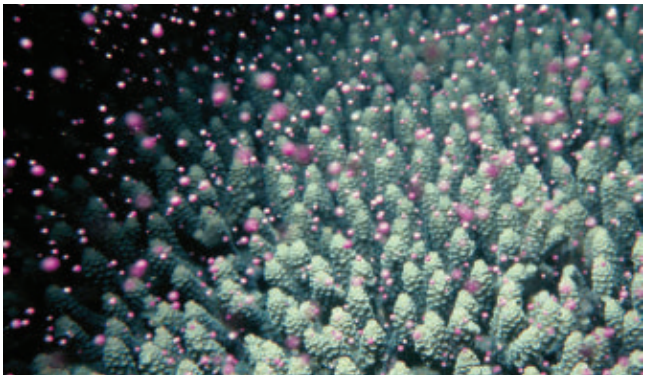
In 2013, Harrison's team, led by graduate student Dexter dela Cruz, began a small pilot experiment in the Philippines at a reef called Magsaysay, where nearly two decades of fishing with explosives had taken a toll. Blast fishing is "like hitting the reef with a sledgehammer," Harrison says. Magsaysay's large foundational corals were blown to bits. A once-vibrant city was now a wasteland.

By 2013, the blast fishing had stopped, but Magsaysay wasn't recovering on its own. So Harrison's team brought in larvae from a species of fast-growing, purple-tipped coral, called *Acropora tenuis*, collected from a nearby healthier reef. The scientists released more than a million larvae into floorless mesh tents pitched underwater over the reef. After five days, Harrison's team removed the mesh enclosures.

Over the next six months, most of the tiny coral settlers died. But, by the nine-month mark, the remaining populations had stabilized. Scientists expected more of the juvenile corals to die, but "incredibly and extraordinarily," Harrison says, none have. At 3 years old, the juvenile corals have reached sexual maturity and are now the size of dinner plates. In June, dela Cruz presented the findings in Honolulu.

For slower-growing corals, Harrison's approach will take extra patience. But for fast-growers like *A. tenuis*, reseeding larvae could be a quick and affordable way to help severely damaged reefs bounce back.

54 percent
Fraction of the reefs damaged in the Philippines



Peter Harrison (top, right) and Dexter dela Cruz (left) place millions of *Acropora tenuis* larvae into a mesh tent in April 2016 to rehabilitate Magsaysay, a degraded reef in the Philippines. When those larvae become adults, they spawn, like this *A. tenuis* on the Great Barrier Reef (bottom).

Winning corals

Getting more larvae onto damaged reefs is the first step, Harrison says. But some individuals are stronger and more stress-tolerant than others. As they grow up, these "winners" distinguish themselves by surviving.

Across the Pacific from Magsaysay, biologist Gates is studying winners. Rows of indoor and outdoor aquariums gurgle in her lab on Coconut Island, off Oahu's windward shore. Those tanks are full of *Montipora capitata*, a local and fast-growing coral collected from the patchy reefs surrounding the island.

In 2014 and 2015, unusually warm water hit Hawaii. Under stress, many corals rejected their symbiotic algae, then blanched from a healthy brown to white; some died.

Gates' team patrolled the reefs around the island during and after the bleaching, in search of hardy *M. capitata* individuals that stayed brown, even in hot water. The scientists are also interested in *M. capitata* that bleached, but then recovered. Gates equates the work to professional sports scouting, "out at high schools, looking for the best athletes."

When she finds top performers, Gates brings them to her lab to run them through their paces, exposing each

FROM TOP: KERRY CAMERON; P. HARRISON

pro-performer to different temperatures and pH levels in seawater tanks. Some conditions re-create today's oceans, while others mimic future warm and more acidic seas.

Today, Gates is breeding the strongest corals (her first batch of babies was born in June). She hopes that top performers will have "extremely talented kids" that inherit their parents' strengths. It's too soon to tell how the new corals will do once they're planted out on the reef.

"We're trying to give corals a leg up," she says. Reefs healthy enough to survive without human intervention are the ultimate aim. In the next five years, the researchers plan to branch out from *M. capitata* to look for super corals of all five species found in the bay surrounding Coconut Island.

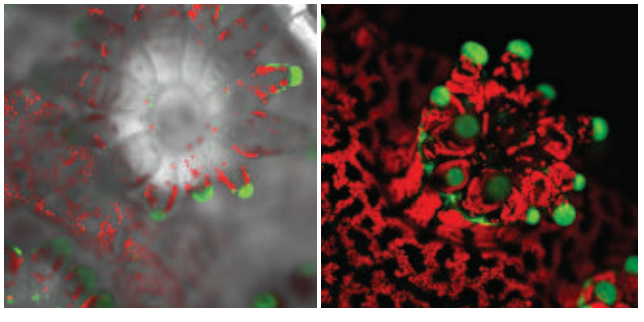
It would be ideal to find those super corals before the next big bleaching event. But for that, the researchers need another sign of resilience. That sign, Gates says, could be hidden in the way corals glow.

Some coral animals, and their symbiotic algae, are loaded with fluorescent proteins that absorb incoming light, then spit it back out by glowing. It's unclear what fluorescent proteins do for corals; they may be a kind of sun block, protecting corals from the intense light in shallow seas, or a form of camouflage or part of the immune system.

Stress affects corals' glowing proteins and changes their fluorescence patterns. In the Pacific and Indian Ocean species *Acropora yongei*, for instance, researchers reported in 2013 in *Scientific Reports* that the concentration of green fluorescent protein fell with temperature stress before bleaching and the coral glowed less intensely. In an earlier study, prolonged high temperatures changed the ratio of green to orange fluorescence in the endangered Caribbean coral *Orbicella faveolata*.

Gates expects that under stress, super corals will keep their healthy fluorescence patterns much longer than corals that are bleaching. One next step, Gates says, is to stress out tiny pieces of coral and watch what happens under a very powerful laser scanning confocal microscope. She'll expose nubbins of coral to acidifying water or increasing temperatures in a petri dish. The microscope will pick up the fluorescence of the nubbins and may indicate which corals will stay healthy the longest.

Once scientists can identify the hardiest corals, they can combine selective breeding with other rehab techniques.



Bleached corals (left) and healthy ones (right) fluoresce differently under a laser scanning confocal microscope. Glow patterns may help scientists identify super corals in the future.

Ruth Gates snorkels by bleached (left) and healthy *M. capitata* (right) on Oahu, Hawaii. She selectively breeds resilient corals.

Approaches like microfragmentation could help super colonies mature super fast. Then, Gates says, "we would have a strategy to get the reef producing its own offspring quite quickly."

No two approaches to saving reefs are the same, which is probably a good thing. Coral fragmentation, reseeding and selective breeding each have their pros and cons.

"The assumption that one size will fit all is completely flawed," Gates says. What might work on the Florida coast wouldn't necessarily work in the Pacific. Like far-flung cities, each reef has different needs and priorities. Their communities of coral vary as do the threats they face. Some problems, like warming oceans, are global in scope. Others, like pollution from roads and agricultural runoff, overfishing and dynamite fishing, are often more localized. Rehabilitation approaches will vary, depending on the type and severity of damage, and how the mosaic of coral species might respond.

Across the globe, "will the things that we do be different?" Gates asks. "Absolutely."

Rather than competing, Gates, Vaughan and Harrison are working toward a common goal: to find the right mix of approaches to support the reefs so they no longer need human help. ■

Explore more

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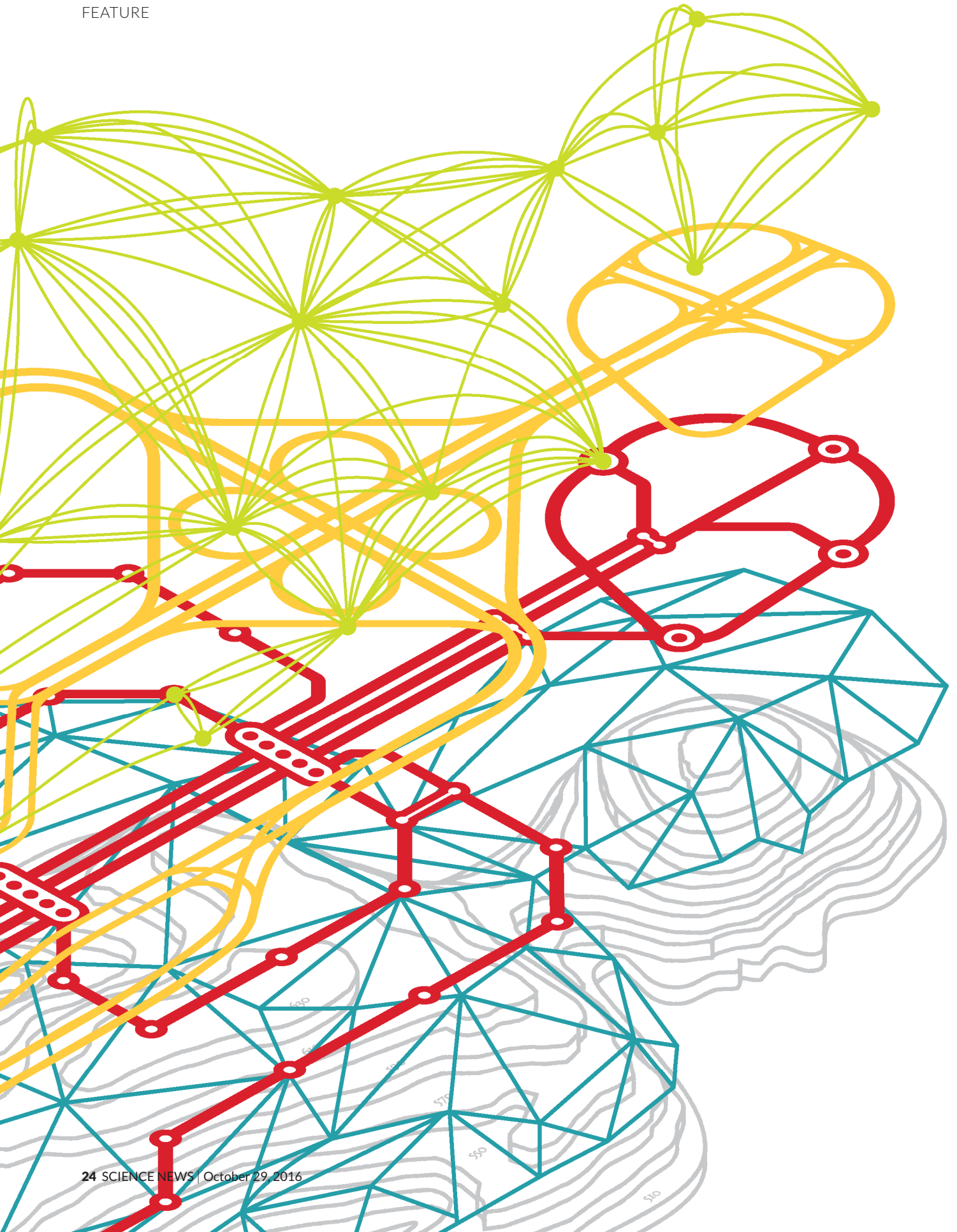
- Zac H. Forsman *et al*. "Growing coral larger and faster: micro-colony-fusion as a strategy for accelerating coral cover." *PeerJ*. October 20, 2015.
- Global Coral Bleaching: www.globalcoralbleaching.org

TOP: VULCAN INC.; BOTTOM, BOTH: KATIE BAROTT



Mapping Life's NETWORKS

Multi-omics offers a new way of doing biology

By Laurel Hamers

Michael Snyder's genes were telling him that he might be at increased risk for type 2 diabetes. The Stanford University geneticist wasn't worried: He felt healthy and didn't have a family history of the disease. But as he monitored other aspects of his own biological data over months and years, he saw that diabetes was indeed emerging, even though he showed no symptoms.

Snyder's story illustrates the power of looking beyond the genome, the complete catalog of an organism's genetic information. His tale turns the genome's one-dimensional view into a multidimensional one. In many ways, a genome is like a paper map of the world. That map shows where the cities are. But it doesn't say anything about which nations trade with each other, which towns have fierce football rivalries or which states will swing for a particular political candidate.

Open one of today's digital maps, though, and numerous superimposed data sources give a whole lot of detailed, real-time information. With a few taps, Google Maps can show how to get across Boston at rush hour, offer alternate routes around traffic snarls and tell you where to pick up a pizza on the way.

Now, scientists like Snyder are developing these same sorts of tools for biology, with far-reaching consequences. To figure out what's really happening within an organism — or within a particular organ or cell — researchers are linking the genome with large-scale data about the output of those genes at specific times, in specific places, in response to specific environmental pressures.

While the genome remains mostly stable over time, other "omes" change based on what genes are turned on and off at particular moments in particular places in the body. The proteome (all an organism's proteins) and the metabolome (all the metabolites, or small molecules that are the outputs of biological processes) are two of several powerful datasets that become more informative when used together in a multi-omic approach. They show how that genomic instruction manual is actually being applied.

"The genome tells you what can happen," says Oliver Fiehn, a biochemist at the University of California, Davis. The proteome and the metabolome can show what's actually going on.

And just as city planners use data about traffic patterns to figure out where to widen roads and how to time stoplights, biologists can use those entwined networks to predict at a molecular level how individual organisms will respond under specific conditions.

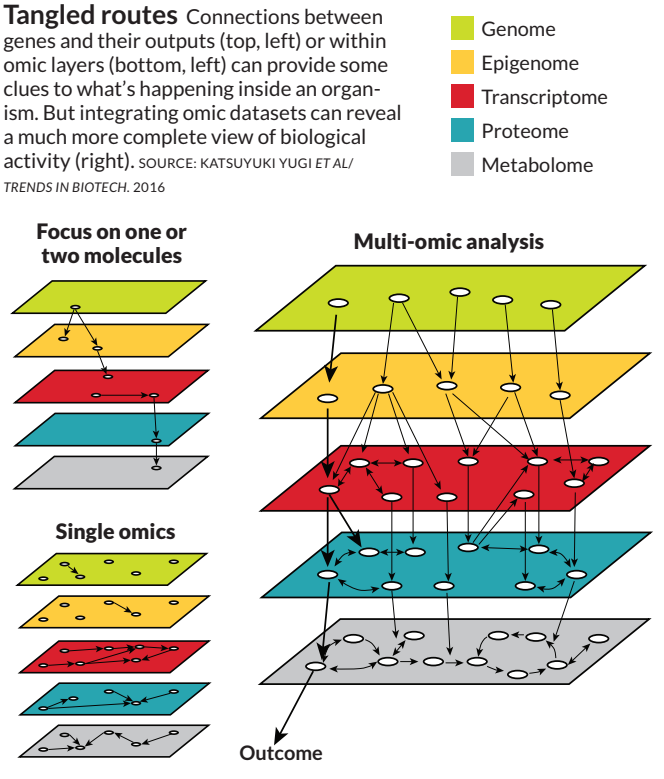
By linking these layers and others to expand from genomics to multi-omics, scientists might be able to meet the goals of personalized medicine: to figure out, for example, what treatment a particular cancer patient will best respond to, based on the network dynamics responsible for a tumor. Or predict whether an experimental vaccine will work before moving into expensive clinical tests. Or help crops grow better during a drought.

And while many of those applications are still in the future, researchers are laying the groundwork right now.

"Biology is being done in a way that's never been done before," says Nitin Baliga, director of the Institute for Systems Biology in Seattle.

Data dump

Scientists have long studied how genes influence traits. Researchers have figured out important connections between genes and the proteins they encode and have scoured the genome for associations between particular genetic mutations and diseases. But a gene-by-gene view of the body is like trying



Tangled routes Connections between genes and their outputs (top, left) or within omic layers (bottom, left) can provide some clues to what's happening inside an organism. But integrating omic datasets can reveal a much more complete view of biological activity (right). SOURCE: KATSUYUKI YUGI *ET AL/ TRENDS IN BIOTECH.* 2016

OPPOSITE: JAMES PROVOST; THIS PAGE: T. TIBBITTS

to diagnose a citywide traffic problem by looking at just one backed-up intersection.

"There are so many places that a system can go awry," Baliga says. When dozens of genes are working together, it's tricky to tease out which one is misfiring in a particular instance.

Baliga is among a growing group of scientists who want to study life through a systems lens, because sometimes that traffic jam at one intersection is being caused by an out-of-sight accident three blocks away.

Such an approach is particularly useful for unraveling the complexities of diseases like cancer and diabetes. These conditions involve a tangled web of genes, paired with lifestyle factors and environmental conditions — Is she a smoker? How much does she exercise? — that influence when those various genes are turned on and off.

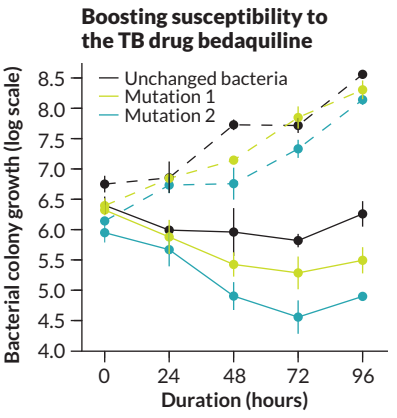
Reconstructing the tangled routes by which genes interact to influence the body is a slightly more complicated feat than mapping the best path from Tulsa to Tuscaloosa. For one thing, it requires serious computer power to gather, store and analyze all that data. The 3 billion chemical coding units that string together to form a person's inventory of DNA, if entered into an Excel spreadsheet line-by-line, would stretch about 7,900 miles. The human proteome contains more than 30,000 distinct proteins that have been identified so far. And researchers have cataloged more than 40,000 different human metabolites, such lactic acid, ethanol and glucose.

Working with such big datasets can be expensive, too. Compiling the first human genome took 10 years and cost almost $3 billion. Now, the costs of collecting and analyzing all these datasets have come down, so it's finally feasible to use them in tandem to answer big biological questions.

So many omes Piecing together the interactions of multiple biological networks can provide a fuller picture of what's going on in the body.

Ome	What is it made of?	What does it show?
Genome	DNA — the complete set of instructions for building an organism	Genes for building proteins and other molecules
Transcriptome	RNA — copies of protein-building instructions	Reflects which genes are turned on and off and their activity level
Proteome	Proteins	How the genetic instruction manual is actually being applied
Metabolome	Small molecules (metabolites)	Chemical reactions happening inside an organism
Epigenome	Molecules that modify the genome to change when genes are turned on and off	How environmental factors are influencing the activity of genes
Phenome	Outcomes determined by the other layers	Traits and diseases

Drug fix Researchers found two genes that were overactive in tuberculosis bacteria tolerant to the drug bedaquiline. The drug killed mutated strains with those genes knocked out faster than it killed the normal strain (solid lines), even though the three strains grew similarly without the drug (dashed lines). That confirms the network the scientists mapped.
SOURCE: E. PETERSON *ET AL*/ *NATURE MICROBIOL.* 2016



The important players

Scientists would like to understand the interplay between the genome and the proteome. Add in the metabolome. To make things more complex, there's the epigenome — the chemical modifications to DNA that help control which genes are turned on and off — and the transcriptome, the full range of RNAs that translate DNA's blueprints so they can be used to make proteins. It's no surprise that mapping such a comprehensive network for any organism is still a distant goal.

For now, scientists tend to focus their multi-omic studies on a particular disease or question. Baliga wants to learn how tuberculosis — which sickens nearly 10 million people per year and kills 1.5 million — evades drugs within the body. Many strains of the TB bacterium are resistant to existing treatments or can tolerate them long enough to establish a strong foothold.

To learn how *Mycobacterium tuberculosis* mounts a defense against a drug, Baliga is first looking within the bacterium, identifying the genes, proteins and other molecules that interact as the microbe infects a host.

He collects different types of omic data from *M. tuberculosis* alone and when it's in the presence of an antibiotic. His team recently focused on the microbe's response to bedaquiline, a drug used to treat multidrug-resistant TB. Baliga measured the microbe's transcriptome in the presence of different doses of bedaquiline and at different times after introducing the drug.

From this giant data dump, computer models helped narrow the focus to a smaller collection of genes, proteins and other molecules that changed under certain conditions. Visualization programs turned these mathematical outputs into maps that scientists could analyze.

About 1,100 genes behaved differently in the presence of bedaquiline, Baliga's team reported in August in *Nature Microbiology*. Measurements of the RNA indicated that most of those genes became less active, but a few shifted into overdrive. The researchers suspected those hyperactive genes might be behind the resistance — playing off each other to create a smaller network within the larger tuberculosis response network.

But statistical analysis alone wasn't enough to confirm the hunch. Correlation isn't cause, Fiehn points out. Scientists

T. TIBBITTS

need to figure out which of those changes actually matter.

That is, if you're scanning millions of data points looking for variation, you're going to find certain abnormalities that are due to chance and are unrelated to the disease or question at hand. But starting from that smaller dataset of outputs that change, scientists can then test which players are actually important in the network and which belong on the sidelines. In animal models or petri dishes, scientists disable one gene at a time to see how it affects the proposed network.

"Systems biology has been able to generate these amazing hypotheses about how genes interact," Baliga says. Testing them has historically been more challenging. But now, gene-editing technologies such as CRISPR/Cas9 (*SN: 9/3/16, p. 22*) allow scientists to more easily test these networks in living systems.

Baliga and his team edited the genome of *M. tuberculosis*, disabling the regulatory machinery responsible for some of the overactive genes. Sure enough, the drug worked better on the modified bacteria, the researchers reported.

Networking solutions

Once a network has been mapped, scientists can use it to predict (and maybe even prevent) illness.

Baliga's team identified a second drug that works with bedaquiline. The drug turns off some of the regulators for the overactive tuberculosis gene network that was fighting off the bedaquiline. Using the second drug with bedaquiline made tuberculosis bacteria more vulnerable, pointing to a potential strategy for dealing with persistent infections.

Baliga's group is also mapping networks in patients with glioblastoma, a particularly deadly type of brain tumor. In the August *Cell Systems*, the scientists described work designed to figure out why some patients respond to certain drugs while others don't. The aim is to personalize treatments, to choose a drug that targets the particular network glitch that gives rise to that patient's tumor, Baliga says. The drug might ramp up production of a protein that's currently in short supply, or turn off a gene that's mistakenly on. That same drug might be completely useless for another patient whose tumor developed through a different network error.

"Being able to do that systematically across all cancers, using networks — that has not happened yet," Baliga says. But scientists have devised drug treatments to address individual mutations. And expanding that to a greater range of cancers in the future is not farfetched, he says.

Other scientists are using multi-omic approaches for preventive medicine, for example, to be more effective and efficient in vaccine development. Despite years of trying, scientists still haven't created an HIV vaccine that can protect people against the virus, says Alan Aderem, a biologist at the Center for Infectious Disease Research in Seattle. Bringing a vaccine from test tube to market is costly and time-consuming. With a better understanding of how the networks of the body's immune system respond to the disease, researchers could be more selective in the vaccine candidates that they invest time and money in developing.

"The real value of systems biology is that it's predictive," Aderem says. "If you could predict upfront if a vaccine would work, you'd not only save a huge amount of energy, you'd also save a huge amount of lives."

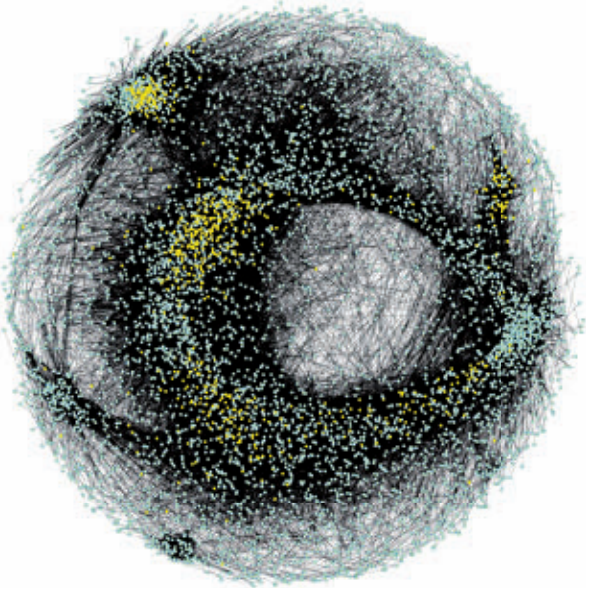
Plant power

Multi-omics has perhaps received the most attention in the context of human health — but that's also the realm where it's hardest to piece together the omic layers. Because simpler organisms can be manipulated genetically, it's easier to move from networks on a computer screen to real solutions.

For instance, some scientists are using multi-omic analysis to engineer networks that let crop plants thrive with less water. To turn carbon dioxide into sugar via photosynthesis, plants need a lot of water. But some desert plants make do with less. Most plants take in carbon dioxide through small pores in their leaves. Opening these pores can let water evaporate out. In the desert, where water is in short supply, some plants use a different network of chemical reactions to make energy: crassulacean acid metabolism, or CAM.

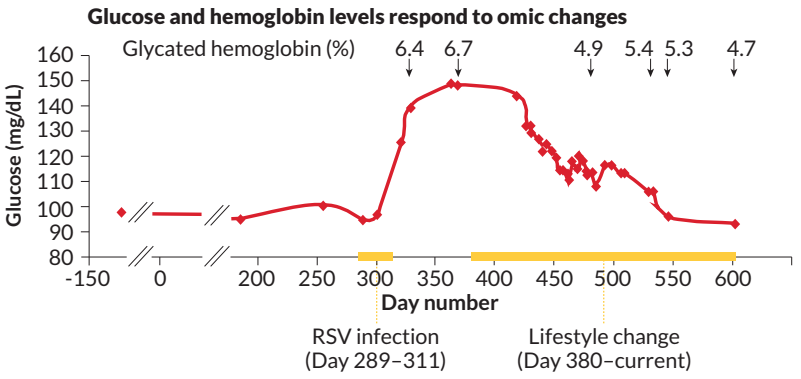
Plants that use CAM open pores in their leaves only during the cooler nighttime, when water is less likely to evaporate out. They store the CO_2 they take in until daytime, when they close the pores and convert the CO_2 into food.

"Our goal is to move this metabolic trick into crop plants," says John Cushman, a biochemist at the University of Nevada, Reno. "In order to do that, you have to understand the complexity of all the enzymes and regulatory components associated with the circadian clock of the plant."



This web shows interactions among genes in pineapple plant leaves, which use the drought-tolerant CAM pathway to make energy. Genes related to CAM are highlighted in yellow. Researchers want to insert this network into other crops to help them grow in arid conditions.

R. MING ET AL/NATURE GENETICS 2015



Sugar spike Michael Snyder's blood glucose levels jumped when he caught a cold (RSV infection) and stayed high after he recovered. When he changed his diet and exercise in response to a diabetes diagnosis, his blood sugar levels dropped to previous levels. He saw the same pattern in levels of glycated hemoglobin. SOURCE: R. CHEN *ET AL*/*CELL* 2012

Cushman's team has collected vast omic datasets from CAM plants. He estimates that several hundred genes coordinate the process, turning each other on and off and producing proteins that interact with each other and influence other genes.

His team is trying to engineer the plant *Arabidopsis* (a weed often used for genetic experiments) to use CAM by inserting the relevant genes into the plant. If they can get it to work in this small lab plant, the researchers want to do the same in poplar trees to help grow biofuel sources in harsh environments not usually suitable for agriculture. Someday, Cushman hopes, the technology will help food crops grow better in arid climates.

Better than a hunch

So far, collecting and integrating omic data is largely restricted to the lab — the work is still expensive and time-consuming. But scientists like Snyder, who diagnosed himself with type 2 diabetes, think that someday people could regularly collect these sorts of data to track changes in their health over time.

> "It becomes what I call data-driven medicine, instead of hunch-driven medicine."
>
> MICHAEL SNYDER

The Stanford geneticist began by analyzing his own genome. Then he started measuring his proteome, metabolome and other omic data at regular intervals to develop what he termed his "personal omics profile."

Certain mutations in his genome suggested that he was at risk for developing diabetes from the get-go. He was surprised, but didn't take action. Nearly a year into his experiment, though, changes in his other omic data suggested that his body was no longer using glucose properly. His blood sugar was elevated and so was a type of hemoglobin that increases with uncontrolled diabetes, according to a report in *Cell* by Snyder and three dozen colleagues in 2012. Those aren't new measures — they're exactly what a doctor would test in someone with diabetes symptoms.

But Snyder had no symptoms. He had just had a nasty cold, which he now thinks may have triggered the onset of diabetes because he was already genetically at risk.

Because he spotted the changes early and his doctor confirmed he had diabetes, Snyder was able to fend off symptoms by changing his diet and exercise habits — which was reflected in the follow-up data he collected.

He monitored how other biological measurements (molecules that standard medical diagnostic tests might not even look at) changed with the onset of his diabetes and the lifestyle changes he made in response. That information might be valuable for doctors hoping to detect the onset of diabetes in patients before symptoms appear. So now his lab is tracking omic data from 100 people, most of whom have elevated blood sugar levels, but have not yet been diagnosed with diabetes. Snyder wants to see whether viral infections trigger diabetes in other people, or whether his case is an isolated incident.

Snyder is still tracking fluctuations in his own data over time, too. He thinks it's a powerful tool for personalized medicine because it shows in real time how an individual responds to disease and other stressors.

"You'll be able to start linking disease to treatment to outcomes," Snyder says. "It becomes what I call data-driven medicine, instead of hunch-driven medicine."

Making sense of this sort of data isn't easy. "No story is the same," Snyder says. "We see a lot of strange stuff that we don't know how to interpret yet."

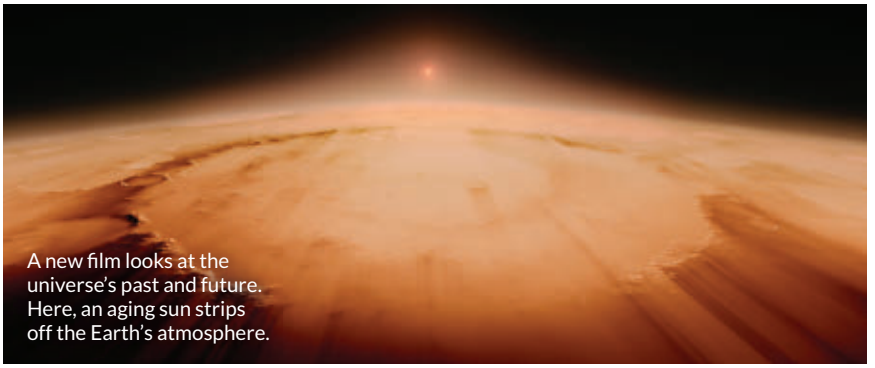
But collecting detailed omic-level data about individuals over time could still be useful, he says. By collecting more data from healthy people, doctors and scientists could get a better sense of what's normal. And tracking fluctuations in individual patients' data over time can show what's typical for that particular person. Snyder thinks that might be more valuable than knowing what's normal for people in general. Someone monitoring these biological signs might notice molecular changes — as he did — before they cause troublesome physical symptoms.

For the multi-omic future that Snyder and others envision, scientists will need a greater ability to store and wrangle massive amounts of data than they possess today. And they'll need ways to test the networks they uncover. But the potential payoff is enormous: A response map that can display the intertwining routes between genes and outcomes, as well as how distant red lights, speed bumps and construction zones play off each other to shift those paths. ■

Explore more

- "Integrated personalized omics profile." http://snyderome.stanford.edu
- The Metabolomics Innovation Centre. "Human metabolome database." www.hmdb.ca

E. OTWELL



A new film looks at the universe's past and future. Here, an aging sun strips off the Earth's atmosphere.

FILM

Voyage of Time more art film than documentary

Condensing billions and billions and billions of years into a 45-minute film is a tall order. But director Terrence Malick took on the challenge with *Voyage of Time: The IMAX Experience*. The film surveys the 13.8-billion-year history of the universe and even looks eons into the future as life on Earth, the planet and eventually the entire solar system fade away.

Voyage of Time
NOW PLAYING
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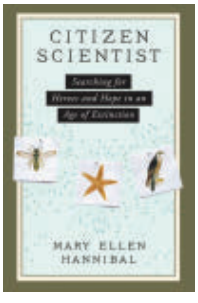
Starting with the Big Bang, the film progresses though highlights of the past, with a central focus on the evolution of life. Malick, best known for directing visually rich dramas such as *The Thin Red Line* and *The Tree of Life*, presents breathtaking cinematography, using locales such as Hawaii's lava-oozing Kilauea volcano as stand-ins for the past. Stunning visualizations and special effects bring to life the formation of the planets, the origin of the first cells, the demise of the sun and other events that scientists can only imagine.

The film is Malick's first documentary. If you can call it that. Viewers hoping for a David Attenborough–style treatment of the subject matter will be disappointed. The film is more evocative, with moody scenes that provide little explication. And the minimalist narration (by Brad Pitt) tends to be philosophical rather than informative.

Despite the unconventional style, Malick still sought to tell an accurate story, enlisting a group of scientists as advisers, including Lee Smolin of the Perimeter Institute for Theoretical Physics in Waterloo, Canada. Smolin says he was impressed with the result. "It's a very unusual film," he says, likening it to a visual poem or piece of art.

And that's probably the best mindset for watching *Voyage of Time*: Just sit back, soak in the dazzling visuals and contemplate the wonders of nature. — *Erin Wayman*



Citizen Scientist
Mary Ellen Hannibal
THE EXPERIMENT, $25.95

BOOKSHELF

Citizen scientists help planet in peril

You don't need a degree in science to monitor backyard owls or measure trees. And anyone with a computer can help scientists track seal populations in Antarctica. Citizen science projects like these — which depend on crowdsourced data — are booming. And when faced with a planet scarred by industrialization and climate change, these efforts might be exactly what we need, environmental journalist Mary Ellen Hannibal argues in *Citizen Scientist*.

What we call "citizen science" was once just "science." After all, many early conservationists and natural historians — people like John Muir — weren't academics. As species disappear faster and faster, scientists can't work alone. They need the eyes and ears of passionate people who are watching as flowers bloom earlier each year and butterflies become sparser.

Hannibal dips her toes into some of the citizen science projects happening within driving distance of her home in San Francisco. She chronicles efforts to count, track and save a variety of species, including sea otters and redwood trees.

Along the way, Hannibal discovers heroes both modern and historical: For instance, Rebecca Moore, who leads Google Earth Outreach, originally developed the mapping tool in the early 2000s to help stop logging in the Santa Cruz Mountains. And Alice Eastwood, botany curator at the California Academy of Sciences in the early 1900s, helped build the museum's plant collection. Lacking a college degree, she collected specimens for nearly 60 years — and even saved part of the collection from the 1906 San Francisco earthquake.

While Hannibal is contemplating extinction and habitat destruction, her father is dying from cancer. Her field expeditions become a lens through which she processes her dad's death. The parallels make *Citizen Scientist* part memoir, part science tale and part history book. Hannibal has a conversational writing style that moves quickly from topic to topic, punctuated with humorous and thoughtful asides.

Although centered in California, the book has a global message: Humans have much in common with the species we're trying to save. Grizzlies and wolves, for instance, "leave their natal home, light out for a huge territory, find a mate, and establish a new base of operations," Hannibal writes. The human heroes in our storybooks aren't so different. — *Laurel Hamers*

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Gene and tonic

Lab rats bred to drink a lot or hardly at all have revealed 930 genes linked to a preference for alcohol, a recent study shows. ***Tina Hesman Saey*** *reported the findings in "Rats offer DNA clues to alcoholism"* (SN: 9/3/16, p. 8).

John M. Wozniak Jr. wondered if the drinking rats were truly alcoholic, or if they gained nutritional or energy benefits from the alcohol.

The rats show the same clinical signs of alcohol withdrawal as humans, suggesting physical dependence, says study coauthor **William Muir** of Purdue University. "If the rats were just using the alcohol as an energy source and had no other effects, those withdrawal behaviors would be absent," he says.

Vision quest

Women who receive cornea transplants are more likely to reject them if the donors are male, freelance writer ***Amber Dance*** *reported in "A view to better cornea transplants"* (SN: 9/3/16, p. 4).

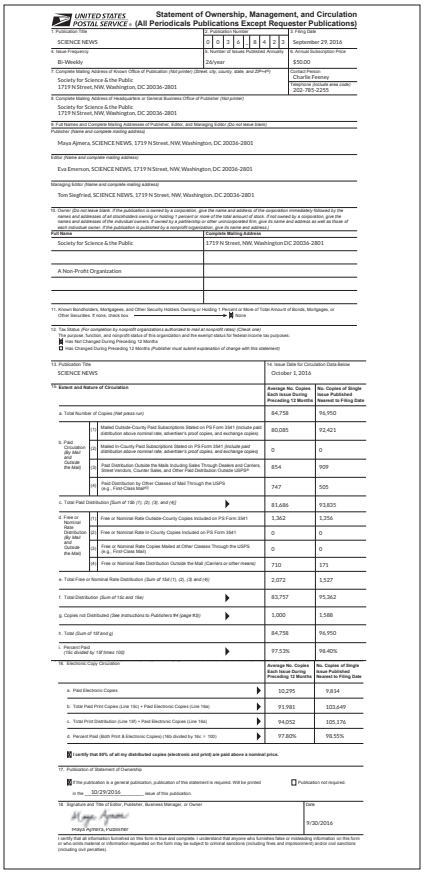
"Can tissue transplant[s] be modified somehow to cause less reactions?" asked online reader **WendyVerdades**.

Treatments that suppress the immune system's response to the foreign corneas, such as steroid eye drops, can help prevent or reverse rejection, **Dance** says.

However, scientists are working on a host of experimental treatments that don't require donor corneas to overcome the rejection problem. Approaches include growing new corneas from stem cells (*SN Online: 3/9/16*) and creating synthetic corneas using cornea cells and hydrogel.

Correction

The DNA helix illustrated on the September 3, 2016 cover of *Science News* twists left, a formation known as Z-DNA. What the illustration should have shown was B-DNA, which twists right. It is the form of DNA most abundant in living cells and the one researchers edit with CRISPR/Cas9.



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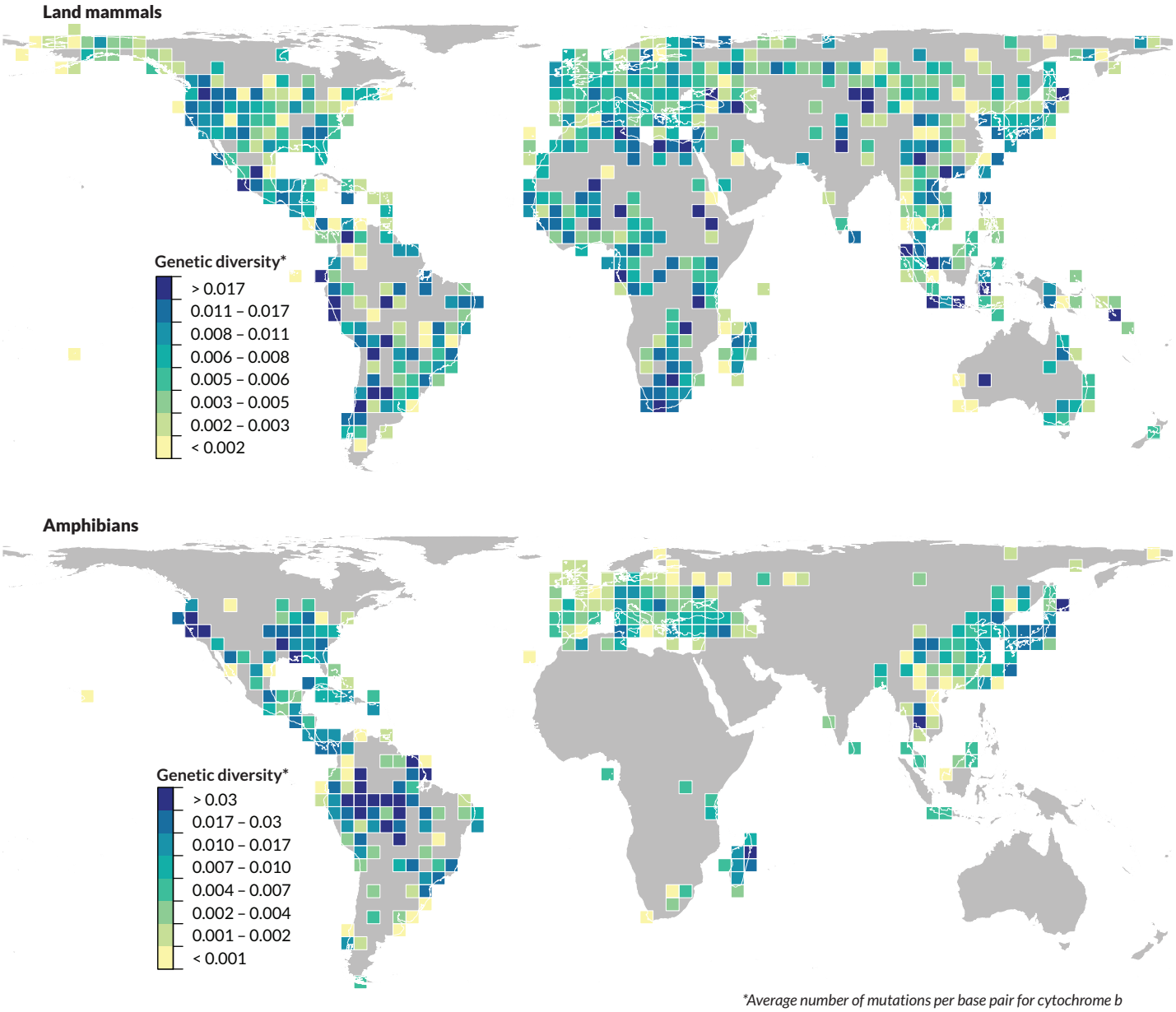

*Average number of mutations per base pair for cytochrome b

Charting genetic diversity around the world

Maps have long been used to show the animal kingdom's range, regional mix, populations at risk and more. Now a new set of maps reveals the global distribution of genetic diversity.

"Without genetic diversity, species can't evolve into new species," says Andreia Miraldo, a population geneticist at the Natural History Museum of Denmark in Copenhagen. "It also plays a fundamental role in allowing species populations to adapt to changes in their environment."

Miraldo and her colleagues gathered geographical coordinates for more than 92,000 records of mitochondrial DNA from 4,675 species of land mammals and amphibians. The researchers compared changes in cytochrome b, a gene often used to measure genetic diversity within a species, and then mapped the average genetic diversity for all species within roughly 150,000 square-kilometer areas.

For both mammals and amphibians, the tropical Andes and the Amazon have high genetic diversity, shown in dark blue. The same is true for mammal species in subtropical regions of South Africa and amphibian species in eastern North America, Miraldo and colleagues report in the Sept. 30 *Science*.

Areas affected by people, such as cities and croplands, show lower genetic diversity. The maps are a snapshot and so can't quantify humans' impact on this key marker, Miraldo notes. But she hopes the work provides a baseline to monitor how human activity and changes in climate affect the distribution of genetic diversity around the globe. — *Kate Travis*

BOTH: MICHAEL K. BORREGAARD, A. MIRALDO *ET AL*/*SCIENCE* 2016

See an interactive version of the genetic diversity map: **bit.ly/iMapGenes**

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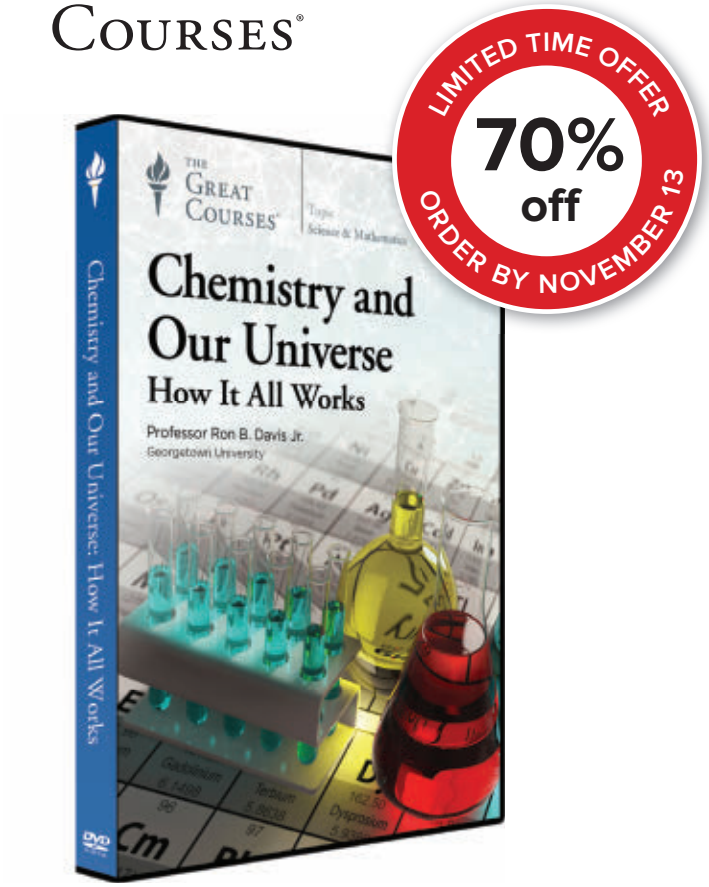

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