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SCIENCE NEWS MAGAZINE
SOCIETY FOR SCIENCE & THE PUBLIC
JUNE 22, 2019

Second Life for Seafood Shells

Nazi Uranium Mystery Solved

How Bacteria Outwit Antibiotics

Walk Like a Sauropod

Lyme Disease Limbo

After a tick bite, an infection is too easy to miss with current tests

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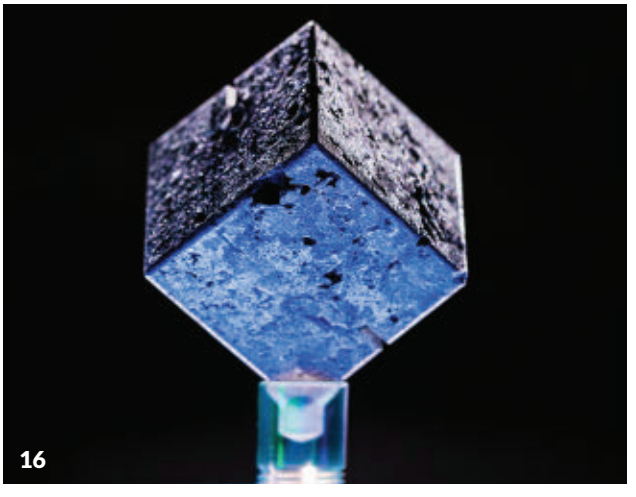
News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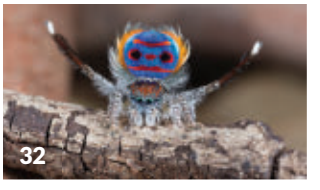
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Departments

SOCIETY UPDATE
Intel ISEF 2019 winners announced

COVER *Ixodes* ticks spread the bacteria that cause Lyme disease. *Phanie/Alamy Stock Photo*

FROM TOP: MARI SIGNUM; JÜRGEN C. OTTO; JOHN T. CONSOLI/UNIV. OF MARYLAND

Science hasn't managed to span the diagnosis gap

Star Trek's Dr. McCoy had no problem finding out what ailed his patients. He simply waved a handheld scanner over them, and the tricorder spat out a diagnosis — even if the patient was a Romulan.

Earthbound diagnostics haven't yet measured up to the extragalactic version, alas. Go to the doctor, and it's likely to take a variety of tests to come up with a diagnosis. And even then, the cause may still elude the experts.

The lack of precise, reliable tests takes a toll on patients and the physicians who care for them. Devising better screening and diagnostic tools remains a focus of research across multiple scientific disciplines. In this issue, contributing correspondent Laura Beil explains how the current standard test for Lyme disease comes up short, causing many people to miss out on early treatment as they go on a protracted search for the reasons for their symptoms (Page 22). Scientists are trying to solve that problem by devising more accurate tests for Lyme disease, Beil explains, including ones that would detect genetic changes in the body shortly after a bite from an infected tick.

When it comes to cancer, early detection is crucial. U.S. colorectal cancer rates have declined by more than 45 percent since the 1980s. Much of that success is thanks to early detection with stool-based tests or colonoscopy. Still, a worrisome rise in the cancer among younger people prompted the American Cancer Society to recommend last year that people start getting screened at age 45 (*SN: 6/23/18, p. 12*).

The inconvenience and ick factor of an invasive test like a colonoscopy can deter people from getting screened. Thus the allure of something that might be cheap, fast and painless: detecting chemical signals in the breath for diseases such as tuberculosis, heart failure and lung cancer (*SN: 11/16/13, p. 18*). It's not as farfetched as it may sound; a breath test for infection with *Helicobacter pylori*, the bacterium that causes stomach ulcers and increases the risk of gastric cancer, was approved by the U.S. Food and Drug Administration back in the 1990s.

But if you want farfetched, scientists are trying that, too. Last year *Science News* reported on a capsule stuffed with electronics, about the size of a hard candy. Researchers in Australia sent the capsule on a tour of the human gut, from whence the device transmitted reports on gas levels out to a smartphone (*SN Online: 1/8/18*). That advance reminded me a bit too much of the 1960s film *Fantastic Voyage*, in which actress Raquel Welch and colleagues hopped in a submarine and shrank down to the microscale so they could remove a blood clot from the brain of a famous scientist.

Clearly we're far from having detector-bots cruising our innards; the inventors of the gas-monitoring pill don't yet have a clear sense of how it would be used for diagnoses. And for too many people, the search for a diagnosis ultimately fails, even after big investments of time and money. So for now, we'll continue to wrestle with the ambiguities of diagnosis and the mysteries of the human condition, while scientists of all stripes strive to devise better means of divining what goes on within us. — *Nancy Shute, Editor in Chief*

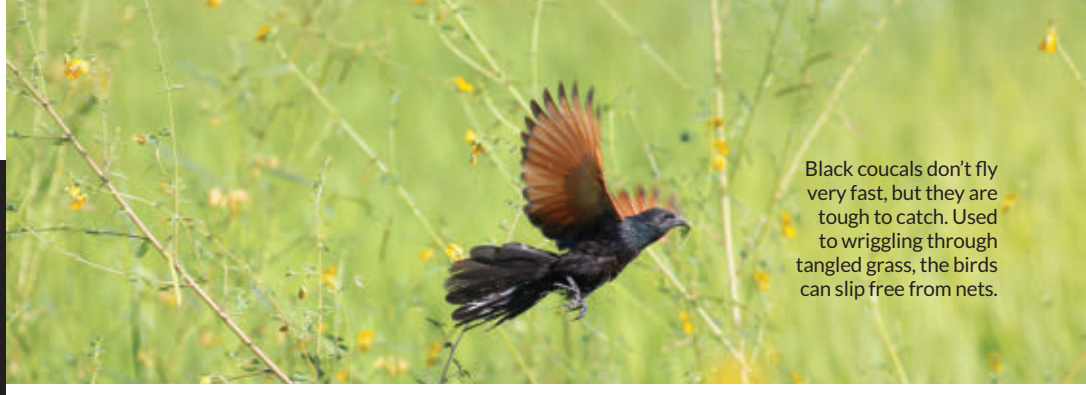
Excerpt from the June 21, 1969 issue of *Science News*

50 YEARS AGO

Lighter bulletproof vest

A new, lighter bulletproof armor ... composed of boron carbide fibers ... [is] capable of stopping a .30-caliber bullet.... The armor weighs about six pounds per square foot, compared to previous boron carbide armor of seven pounds per square foot.... Until now boron carbide armor has been used mainly to protect vital helicopter parts, but the lighter weight means it could be worn by ground troops.

UPDATE: Many boron carbide armor components have been replaced by Kevlar, which was developed around the same time (*SN Online: 4/8/15*). Made of woven synthetic polymer chains, Kevlar fast became essential wear for soldiers and law enforcement officers. More than eight times the tensile strength of steel, the textile distributes the energy of a bullet impact over a large area. Some modern body armor systems today weigh a tenth of their boron carbide counterparts. Scientists are testing engineered spider silk, another strong and flexible textile, for body armor (*SN: 5/11/19, p. 24*).



Black coucals don't fly very fast, but they are tough to catch. Used to wriggling through tangled grass, the birds can slip free from nets.

IT'S ALIVE

Black coucal dads have little time for philandering

The extreme dads of the bird world do all the work raising chicks while females fight intruders. The result: Male black coucals don't sleep around as much when they're busy parenting.

A male black coucal (*Centropus grillii*), on occasion, will slip over to another bird's nest to sire a chick. But when it's time to incubate eggs, the likelihood of such excursions drops by an average of about 17 percent, compared with male birds that don't have eggs or chicks, scientists reported online April 10 in the *Proceedings of the Royal Society B*.

And during the frantic first week of parenting after eggs have hatched, those philandering visits drop by almost 50 percent. That's when male coucals, native to sub-Saharan Africa, spend much of their days catching grasshoppers, frogs and other critters to feed chicks too frail to leave their woven grass nests. Even when chicks can wander from the nest, they still need at least two more weeks of dad's care.

In the unusual lives of black coucals, females defend territories while males (one shown) do the work of raising chicks. All that parenting cuts into males' time for infidelity.

Black coucals are among the few bird species in which females, rather than males, stake out and defend territories. Females are bigger than males and warn interlopers with "hoot, hoot" exchanges, which deepen in pitch if antagonists get closer. If hooting fails, a female will fly at the other bird to fight.

"You see just the grass moving, and you hear a grumbling," says study coauthor Wolfgang Goymann, a behavioral ecologist at the Max Planck Institute for Ornithology in Seewiesen, Germany. Goymann has seen females "with huge wounds on their heads."

A female's territory has up to five males nesting in it. She builds the basics of a nest and lays eggs with each male in her realm. Unlike other nestlings with dad-only care, these chicks hatch very early in development. They don't even have enough fluff for warmth, and dad needs to snuggle the chicks for about a week before they can venture beyond the nest.

Even when dads are busiest, they still slip off to other nests to meet up with females for mating both inside and outside their mate's territory. DNA tests revealed that about half of the male coucals that Goymann studied in southwest Tanzania's wetlands over 12 years were caring for at least one chick sired by another male.

Males have a strong urge to feed youngsters, even if they're from other nests, Goymann says. After he found bird trackers worn by three chicks and their dad in the innards of a venomous puff adder snake, Goymann assumed that the lone surviving chick was doomed. However, a neighboring male tending chicks of his own stepped in and fed the survivor.

Philandering aside, Goymann says, black coucals "are devoted dads."

— Susan Milius

BOTH: W. GOYMANN

RETHINK

Humboldt erred in his 1807 map

An iconic diagram of plants growing on Andean mountain slopes needs an update. Created 212 years ago by German explorer Alexander von Humboldt, the *Tableau Physique* is still used to assess how plant ranges have shifted with climate change. But errors, including that some plants described on one volcano were actually found on another, mean scientists using the diagram might not be using accurate data, researchers report online May 28 in the *Proceedings of the National Academy of Sciences*. This year marks the 250th anniversary of Humboldt's birth. The geologist, geographer and cartographer produced about 30 volumes from his travels of the Americas from 1799 to 1804 (*SN Online: 2/24/19*). He also continually revised the 1807 diagram, but those edits are less well-known, the researchers say. — *Carolyn Gramling*

The 1807 *Tableau Physique* marked a new kind of scientific visualization, combining plant and elevation data into one diagram.

MYSTERY SOLVED

Strange odors mingle in chocolate

Scientists have sniffed out the chemicals that give some dark chocolates their smell. Compounds that mingle in chocolate aromas include flowery linalool and soothing vanillin, which gives vanilla its smell. But other molecules produce vinegary or smoky odors, and one even smells like sweat, researchers report in the May 22 *Journal of Agricultural and Food Chemistry*.

"These single odorants usually never have the typical smell of the food itself," says food chemist Michael Granvogl of the University of Hohenheim in Stuttgart, Germany. Instead, in any given food, the scent depends on which molecules are present and at what level. Granvogl and colleague Carolin Seyfried of the Technical University of Munich bought two aromatic chocolate bars having at least 90 percent cocoa content. The pair crushed up each of the treats and extracted their volatile compounds, those that vaporize easily and can waft up to our noses to be smelled.

Of the roughly 70 aroma-producing volatile chemicals detected, 28 to 30 occurred in each bar at high enough levels for humans to smell. By combining these compounds at roughly the same concentrations as in the original chocolate bars, the scientists re-created each bar's aroma. A panel of more than 20 people with trained noses sniffed the concoctions and found that they smelled similar to the real deal. The study is the first to reconstruct dark chocolate's smell from odor compounds measured using state-of-the-art techniques, the researchers say. — *Carolyn Wilke*

TEASER

Space flames may hold secrets to soot-free fire

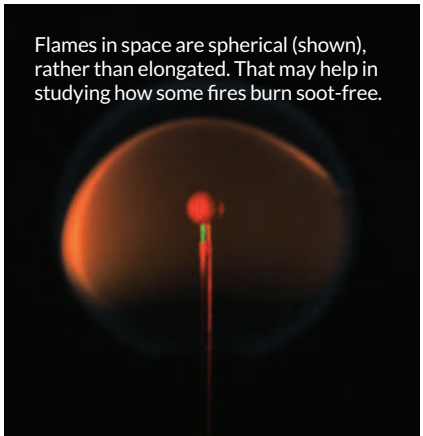
Solving this burning question requires starting fires in space.

Experiments being conducted on the International Space Station could help resolve a scientific debate about why some fires burn without producing soot. Made of carbon particles created when fuel fails to burn completely, soot is a pollutant. The particles are linked to health issues, such as cancer (*SN: 8/4/07, p. 69*), and contribute to global warming (*SN: 10/5/13, p. 26*).

One technique for eliminating soot is by fiddling with the composition of the fire's fuel and the surrounding air. Oxygen in the air is necessary for combustion, but air also contains nitrogen, which is inert. By removing air's nitrogen and mixing that nitrogen with fuel instead, scientists can produce soot-free flames.

But there are two views about why soot doesn't form. One theory says the flame burns clean due to an altered flow of gases. The other says that, as a result of the switch-up, the fire's temperature and makeup varies across the flame in a way that stops soot from forming.

Flames in space are spherical (shown), rather than elongated. That may help in studying how some fires burn soot-free.



Testing which idea is correct requires control over the flow of gases in a flame. That's tough to do on Earth, since hot gases inevitably flow upward, which gives candle flames their familiar elongated shape. In the microgravity of the space station, though, that upward flow doesn't happen; instead, gases form a ball of fire that can be tweaked to adjust flow.

"Having a nice spherical flame is just not possible on Earth," says engineer Richard Axelbaum of Washington University in St. Louis. He is working on the space station experiments, which are remotely controlled from the ground. "The space station allows us to carefully study the problem." Results from the trials should be published in several months. — *Emily Conover*

FROM TOP: CHARISSE KENION/UNSPLASH; ZENTRALBIBLIOTHEK ZÜRICH/WIKIMEDIA COMMONS; R. AXELBAUM, NASA

EARTH & ENVIRONMENT

China still emits ozone destroyer

Finding helps explain increase in emissions of banned CFC-11

BY MARIA TEMMING

China has continued producing an ozone-destroying chemical called CFC-11 in violation of an international agreement, researchers report.

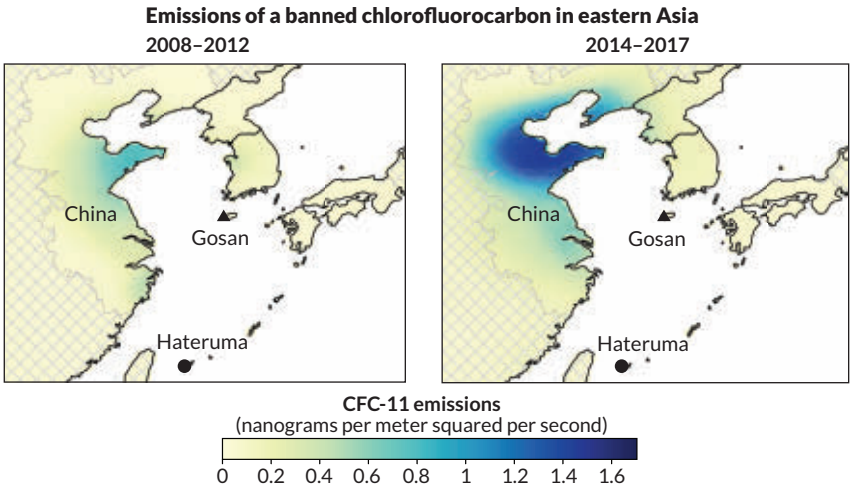
Air samples collected in South Korea and Japan suggest that eastern China emitted about 7,000 metric tons more trichlorofluoromethane a year from 2014 to 2017 than it did from 2008 to 2012. This boost explains a large fraction of the estimated global increase in CFC-11 emissions — between 11,000 and 17,000 tons annually — after 2012, researchers report in the May 23 *Nature*.

CFC-11 has been used to make foams for refrigeration and insulation. But each atom of chlorine from CFC-11 and similar molecules, collectively called chlorofluorocarbons, can destroy 100,000 atmospheric ozone molecules. Under the 1987 Montreal Protocol, an international treaty that phased out the production of CFCs by 2010, no one should be producing CFC-11 anymore.

"Now there is a very clear indication that some places are not adhering to the Montreal Protocol," says A.R. "Ravi" Ravishankara, an atmospheric scientist at Colorado State University in Fort Collins who wasn't involved in the work.

These results demonstrate "the need for verification and continued vigilance" in enforcing the treaty, he says. Continued production of the chemical may delay the recovery of the hole in the ozone layer (*SN: 12/24/16, p. 28*).

Hints of illegal CFC-11 production came in 2018. Observations revealed that the global decline of CFC-11 in the atmosphere slowed significantly after 2012, but the culprits responsible for ramping up emissions remained uncertain.



Going up Atmospheric data from Gosan station in South Korea and Hateruma station in Japan suggest that annual CFC-11 emissions in eastern China increased by about 7,000 metric tons between 2008–2012 (left) and 2014–2017 (right).

Sunyoung Park, a geochemist at Kyungpook National University in Daegu, South Korea, and colleagues homed in on the CFC-11 source by analyzing air samples collected from monitoring stations in North America, Europe, Australia and eastern Asia from 2008 to 2017.

"In the non-Asian stations, the signals are consistent with declining regional emissions, whereas at the eastern Asian stations, we saw signals that very strongly suggested that emissions increased," says Matthew Rigby, an atmospheric scientist at the University of Bristol in England. Stations in Japan and South Korea showed spikes in CFC-11 levels as plumes of pollution wafted overhead. The size of those spikes grew after 2012.

The team ran computer simulations to determine where the CFC-11 could have originated. From 2008 to 2012, eastern China emitted an average of about 6,400 tons of CFC-11 per year, the analysis indicated. That number increased to about 13,400 tons per year from 2014 to 2017. This pollution boost arose primarily around the northeastern Chinese provinces of Shandong and Hebei. The researchers found no evidence of significantly increasing emissions from any other eastern Asian country.

On-the-ground investigations by the Environmental Investigation Agency, an international nonprofit organization, and Chinese authorities have also turned up evidence of illegal CFC-11 use in manufacturing. "China will continue cracking down on illegal production and use of [ozone-depleting substances] and strengthen regulation over relevant industries," Zeng Rong, a spokesperson of the Chinese Embassy in England, wrote in a letter to the *Guardian* newspaper in August 2018 in response to a news article about China's production of CFC-11.

The annual 7,000-ton bump in CFC-11 emissions from eastern China accounts for only about 40 to 60 percent of the estimated global increase in CFC-11 emissions after 2012. That leaves scientists wondering where the rest is coming from, Ravishankara says. "It really would help if [we had] these measurements from other parts of the world." The monitoring network used in this study doesn't extend to other parts of Asia, Africa or South America.

Further investigations are also needed to tease out which industrial processes are responsible for the emissions, Rigby says. If CFC-11 is trapped inside newly manufactured materials like foams, that gas will eventually leak out, he says. "It's entirely possible that the total emissions that we've seen so far are actually a relatively small fraction of the total amount of CFC-11 that was produced." ■

M. RIGBY *ET AL*./*NATURE* 2019

BODY & BRAIN

Gut bacteria can alter many drugs

Findings may help doctors identify right medications for patients

BY MARIA TEMMING

Prescribing the best medication may require going with a patient's gut — or at least, the bacteria that live there.

Anecdotal reports have revealed that some gut-dwelling microbes chemically alter oral medications, affecting how well those drugs work. But the scope of this problem has remained unclear. Now, a survey of these interactions suggests that gut bacteria can modify many drugs and that the genetic makeup of a patient's microbiota may predict that person's response to medications, scientists report online June 3 in *Nature*.

The researchers tested the ability of 76 types of bacteria — selected to represent the microbial diversity of the human gut — to alter the molecular structure of 271 oral medications, from hormones to antiviral drugs. Bacteria were incubated with nutrients and drug solutions in test tubes for 12 hours. In that time, 176, or about two-thirds, of the drugs were modified by at least one bacterial strain; each strain modified 11 to 95 different drugs.

"That is huge," says Nichole Klatt, a microbiome researcher at the University of Miami not involved in the work. But knowing which microbes affect which drugs isn't enough. Future studies could investigate exactly how bacteria chemically modify drugs and the consequences inside the human body, she says.

Maria Zimmermann-Kogadeeva, a computational biologist at Yale University, and colleagues did show that the collective genetic makeup of an individual's gut microbiota may predict how that person will respond to a medication.

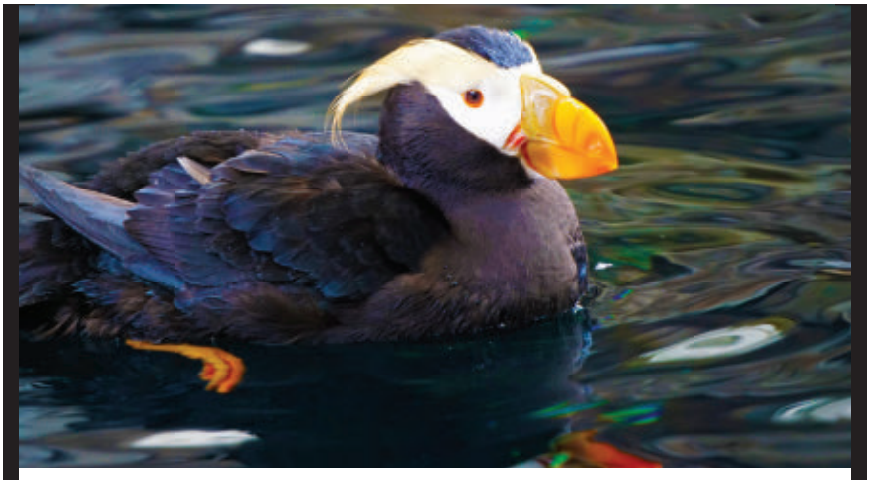
The team developed a way to identify which part of a bacterium's DNA gives the microbe the ability to modify a particular drug. The team chopped up DNA from a bacterium of interest and inserted snippets into *E. coli* cells. Seeing which *E. coli* developed the ability to alter specific drugs exposed which DNA fragments were messing with those medications.

Then, in a series of experiments with different medications, the team monitored the drug-modifying abilities of the entire microbial population in fecal samples from 28 people. In each experiment, all the microbial communities were exposed to the same drug. Afterward, the researchers searched the microbes in each stool sample for the drug-altering DNA snippets identified in the *E. coli* test, as well as bits of DNA from other microbes that were at least 50 percent similar. Such similar DNA segments are thought to have similar functions.

The amount of these same and similar-looking pieces of DNA in each sample aligned with how much that microbial population modified a certain drug. That finding suggests that genetically testing the bacteria in a patient's poop could gauge how likely that person's microbiota is to interfere with certain drugs.

Such insight may help clinicians choose medications, or decide whether to prescribe a treatment to make gut bacteria more amenable to a drug, says study coauthor Michael Zimmermann, a pharmaceutical scientist and systems biologist at Yale. Antibiotics or fecal transplants may help strategically manipulate a patient's microbial population.

Besides designing pills to avoid certain bad reactions with bacteria, drug companies could also develop medications that exploit microbial modifications that might enhance or prolong a drug's effect, Zimmermann-Kogadeeva says. ■



DS PHOTOGRAPHY/ISTOCK/GETTY IMAGES PLUS

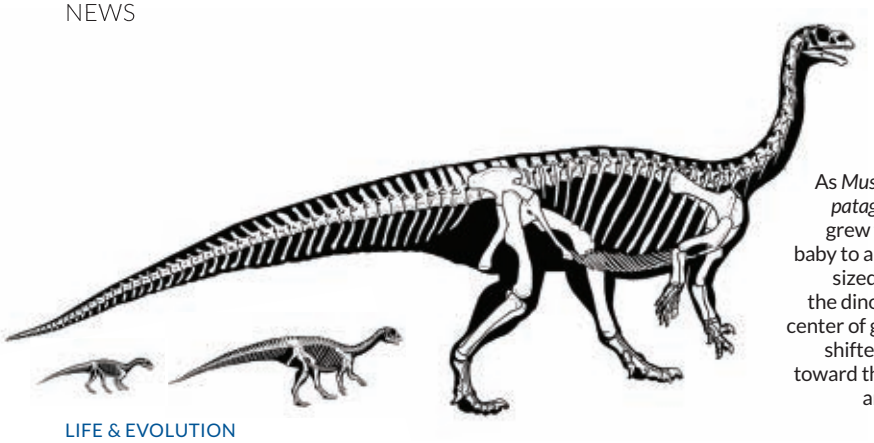
EARTH & ENVIRONMENT

Climate change suspected in bird deaths

Thousands of puffins and other seabirds in the Arctic appear to have died in the winter of 2016–2017. And climate change may be to blame, scientists say.

From October 2016 to January 2017, more than 350 dead birds, mostly tufted puffins, washed up on Alaska's St. Paul Island in the eastern Bering Sea. The birds were emaciated, pointing to starvation as the cause of death, scientists report May 29 in *PLOS ONE*. Based on a variety of factors, the team estimates that between 3,150 and 8,800 seabirds died during that period.

In the past, summertime sea ice melt in the Bering Sea has helped fuel blooms of plankton that form the base of the marine food web (*SN: 3/16/19, p. 20*). But human-caused climate change has made sea ice more scarce in the Bering Sea in the last few years, and there have been fewer plankton blooms. That has had cascading effects through the food web, including decreases in some fish species that tufted puffins (like the one above) eat. — *Carolyn Gramling*



As *Mussaurus patagonicus* grew from a baby to a rhino-sized adult, the dinosaur's center of gravity shifted back toward the hips and tail.

LIFE & EVOLUTION

Dino's walking style changed as it grew

In an early sauropod, adults made rare shift to an upright gait

BY JOHN PICKRELL

Most long-necked sauropod dinosaurs lumbered on four legs for their entire lives to support their titanic bulk. But an early relative of behemoths such as *Brachiosaurus* made the unusual transition from walking on four legs to two as it grew, a study shows.

Diminutive at hatching, *Mussaurus patagonicus* began life walking on all fours. But by the time the roughly 200-million-year-old plant eater reached its 6-meter-long adult length, it roamed what's now Argentina on two legs.

The changing length of *M. patagonicus*' arm bones relative to its body as the dinosaur grew and its inward-facing palms as an adult had previously hinted at the transition. Now, computer simulations show how a shift in the creature's center of gravity as it grew enabled a change to bipedal walking, researchers report May 20 in *Scientific Reports*.

Researchers took CT scans of fossils from six *M. patagonicus* individuals — covering different stages of the species's development, from hatchlings the size of baby chickens to adults as big as rhinoceroses. The researchers added virtual flesh to digitized bones to create 3-D models that allowed the team to estimate both the weight and center of gravity of *M. patagonicus* at many different stages of its life.

Reconstructions of the hatchlings showed that the creature's center of mass was so far forward that the dinosaur could move around only by walking on all four legs, says paleontologist Andrew Cuff of the Structure and Motion Laboratory at the Royal Veterinary College in Hatfield, England.

As the dinosaur grew, its center of mass moved back toward the hips, causing the animal to walk upright on two legs, Cuff and colleagues found. The transition "is incredibly rare," he says. "We have struggled to find any other animals aside from humans that go through that transition.... Finding it in the fossil record is pretty exceptional."

The results suggest that the adult dinosaurs turned bipedal because their tail muscles became bulkier and heavier in adulthood, moving the center of gravity backward, says Stephen Poropat, a paleontologist at Swinburne University of Technology near Melbourne, Australia, who was not involved in the research. "It is not the changing proportions of *Mussaurus*' front legs that is necessitating this change from walking on four legs to walking on two legs as an adult," he points out.

As later long-necked dinos bulked up in size (*SN Online: 9/4/14*), going to two legs may no longer have been an option. Massive sauropods instead probably started on four legs like *M. patagonicus* and stayed that way, developing trunk-like front legs to bear their weight. "What we gain from this [study] is that there may be a size limit of how big you can get being a biped in this group," Cuff says. ■

HUMANS & SOCIETY

Neandertal split came earlier

Age of last common ancestor with humans gets recalculated

BY BRUCE BOWER

Humans and Neandertals separated from a common ancestor more than 800,000 years ago — much earlier than many researchers had thought.

That conclusion, published May 15 in *Science Advances*, stems from an analysis of early Neandertal teeth found at a Spanish site called Sima de los Huesos. During hominid evolution, tooth crowns changed in size and shape at a steady rate, says Aida Gómez-Robles, a paleoanthropologist at University College London. The Neandertal teeth, which date to about 430,000 years ago, could have evolved their distinctive shapes at a pace typical of other hominids only if Neandertals originated between 800,000 and 1.2 million years ago, she finds.

The study indicates that if the last common ancestor of humans and Neandertals existed after about 1 million years ago, "there wasn't enough time for Neandertal teeth to change at the rate [teeth] do in other parts of the human family tree" to end up looking like the Spanish finds, says paleoanthropologist Bernard Wood of George Washington University in Washington, D.C.

Many researchers have presumed that a species known as *Homo heidelbergensis*, thought to have inhabited Africa and Europe, originated about 700,000 years ago and gave rise to an ancestor of both Neandertals and *Homo sapiens* by roughly 400,000 years ago. Genetic evidence that the Sima de los Huesos fossils are of Neandertals raised suspicions that the most recent common ancestor with *H. sapiens* existed well before those hominids (*SN Online: 3/14/16*). Recent Neandertal DNA studies place that common ancestor at between 550,000 and 765,000 years old. But those results rest on contested estimates of how fast and

A. OTERO ET AL/SCIENTIFIC REPORTS 2019

how consistently genetic changes accumulated over time.

With that molecular debate in mind, Gómez-Robles calculated the rate at which eight ancient hominid species evolved changes in tooth shape. That analysis enabled her to gauge how long it must have taken for Sima de los Huesos teeth to evolve after Neandertals diverged from their last common ancestor with *H. sapiens*.

Gómez-Robles used two possible evolutionary trees for the eight hominid species to estimate dental evolution rates. Aside from the Spanish Neandertals and Stone Age *H. sapiens*, teeth in her study came from African hominids dating to as early as 3.2 million years ago.

Moving back the date of an evolutionary split between Neandertals and *H. sapiens* appears reasonable based on the new data, says paleoanthropologist Aurélien Mounier of Musée de l'Homme in Paris. The timing of that split could still change, though, if further research modifies the Spanish fossils' age, he says.

Other Spanish hominid teeth dating to nearly 800,000 years ago display some Neandertal features, supporting the new study's conclusions, says New York University paleoanthropologist Shara Bailey. But it's unclear if Gómez-Robles' contention that hominid teeth evolved at a steady rate will hold true, Bailey says. ■

LIFE & EVOLUTION

Some plants munch on rocks

Hairy roots and acids help extract phosphorus

BY YAO-HUA LAW

Collecting a sample of *Barbacenia macrantha* requires chisels and hammers to unearth the plant and the rock it grows in. Specialized roots help the plant live in nutrient-poor grasslands in Brazil.

A. ABRAHÃO

No soil? No problem.

Some herbaceous plants and shrubs living on rocky mountains in Brazil use roots equipped with fine hairs and acids to dissolve rock and extract the key nutrient phosphorus. The discovery, published in the May *Functional Ecology*, helps explain how plants can survive in impoverished environments.

"While most people tend to view nutrient-poor environments as less diverse, they are actually very diverse because plants use diverse ways to get nutrients," says Patricia de Britto Costa, a plant ecologist at the University of Campinas in Brazil.

She and a team of colleagues investigated how shallow-soil regions called *campos rupestres* (meaning "rocky grasslands" in Portuguese) can sustain more than 5,000 plant species — 15 percent of Brazil's vascular plant diversity — despite occupying less than 1 percent of the country's land area. The soil there is poor, with nearly undetectable levels of the nutrients plants need. And some plants manage to survive on rocky patches with no soil.

The researchers used chisels and hammers to dig up plants. "We found the roots growing into the rocks" at least 10 centimeters deep, says team member Anna Abrahão, a plant ecologist now at the University of Hohenheim in Stuttgart, Germany. "The roots go deeper, and we always lose some of them."

Microscopic and chemical analyses of 30 specimens of two species living on quartzite rocks — *Barbacenia tomentosa* and *B. macrantha*, of the Velloziaceae family — revealed specialized segments of densely packed hairs just behind the root tip. The roots secrete malic and citric acids, probably from the fine hairs, that dissolve rock, releasing phosphates that the roots then absorb to get phosphorus. Microscopy scans suggest that the roots carve into rock, rather than growing along cracks. The scientists named these structures vellozioid roots, after the plants' family name.

Researchers had long assumed that some plants dissolve rock, but these roots, so far found only in these two species, are the first direct evidence of this ability, says team member Hans Lambers, a plant physiologist at the University of Western Australia in Perth.

The work has already inspired plant physiologist Alex Valentine of the University of Stellenbosch in South Africa. He plans to search for such roots in Velloziaceae plants in South African mountain regions. Plants living in other phosphorus-poor environments have evolved specialized roots with dense root hairs and acid secretions to harvest phosphorus from poor soils and sand, but not actual rock. Vellozioid roots use the same strategy "in an entirely new way," Valentine says, "dissolving rocks and forming new sand."

Quartzite rocks in Brazil's rocky grasslands have especially low phosphorus levels, the study found. On average, each gram of rock contains only 0.14 milligrams of the nutrient. By comparison, the lowest level found in a 2013 survey of 69 rock types worldwide was an average of 0.12 milligrams in peridotite rocks.

Further research into vellozioid roots might one day lead to more efficient crops. "If we can transfer these traits to crops," Valentine says, "it means that crops can grow in rocky or sandy soils." ■

MATH & TECHNOLOGY

Kilogram overhaul goes into effect

Small device measures mass according to new definition

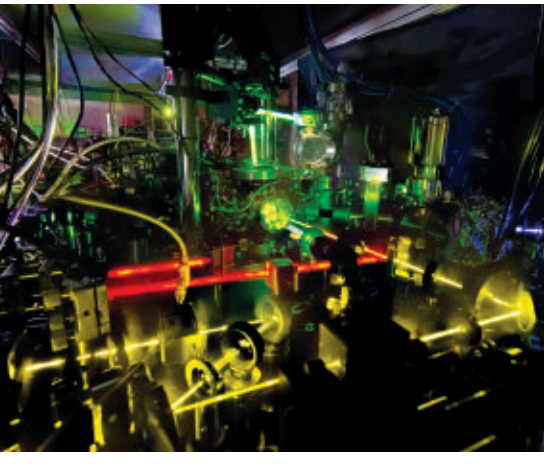
BY EMILY CONOVER

It's mass for the masses: A tabletop device makes the new definition of the kilogram more accessible.

Updates to scientists' system of measurement went into force May 20, redefining the kilogram and several other units in the metric system. The revamp does away with some outdated standards — most notably, a metal cylinder kept in a vault near Paris that had defined the kilogram for 130 years (*SN: 12/8/18, p. 7*).

Tinkering with units allows scientists to more precisely measure the quantities laid out in the International System of Units used around the globe. The kilogram, the basic unit of mass, is now defined by a quantum quantity known as the Planck constant. That value, an immutable constant of nature, is the same everywhere in space and time. That's an improvement over the Parisian artifact, which could have changed slightly if gunk or scratches marred its surface.

Scientists used the new definition of the kilogram to create a scaled-down version of a device called a Kibble balance that can directly measure masses of several grams via the Planck constant. When the prototype's kinks are worked out, the apparatus should be accurate to a few ten-thousandths of a percent, researchers at the National Institute of Standards and Technology in Gaithersburg, Md., report in the June *IEEE Transactions on Instrumentation and Measurement*.



Scientists are now considering redefining the unit of time, the second, using optical atomic clocks (one shown in this composite image). These clocks are more precise than the cesium atomic clocks currently used to keep time.

A full-scale Kibble balance requires its own laboratory space, costs millions of dollars to build and demands Ph.D.s to run it. But the new, suitcase-sized Kibble balance is just over half a meter tall, with a price tag of around $50,000. That puts the machine within reach for pharmaceutical companies, for example, which must accurately dole out small drug dosages.

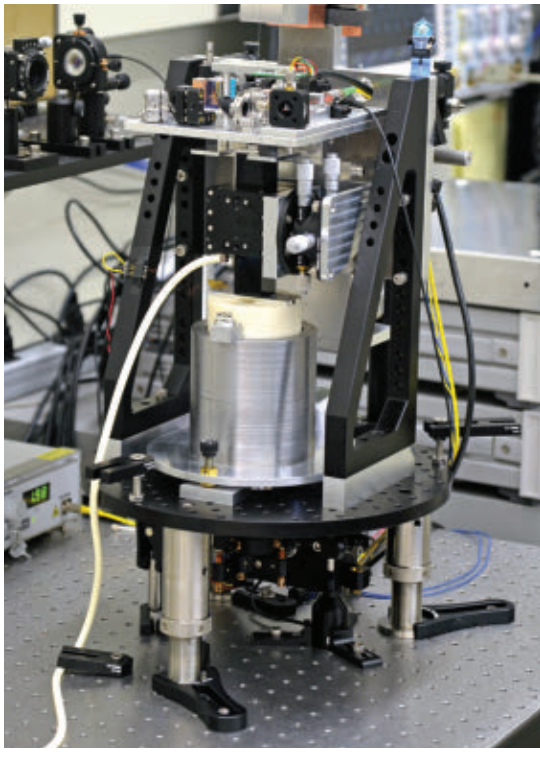
Traditional balances work by comparing the weights of masses in two different pans. But a Kibble balance compares the weight of an object with the electromagnetic force needed to hold up that object. Certain electromagnetic quantities, such as voltage and resistance, can be tied back to quantum measurements involving the Planck constant, connecting that quantity to the object's mass.

Fun times with Legos inspired the new instrument. The researchers previously had made a Lego Kibble balance to help teach the public how the instruments work, says NIST mechanical engineer Leon Chao. That experience "subconsciously planted a seed."

Along with the kilogram, several other quantities have new definitions, including the kelvin, the unit of temperature; the ampere, the unit of electric current; and the mole, the unit for an amount of a substance.

And now scientists have their sights set on updating the unit of time: the second.

Currently, the second is defined by atomic clocks made of cesium atoms. Those atoms absorb a certain frequency of light. The wiggling of the electromagnetic waves functions like the pendulum on a grandfather clock, rhythmically keeping time. One second is defined as 9,192,631,770 oscillations of the light.



Small enough to fit on a table, this Kibble balance will measure small masses, such as a few grams, to an accuracy of a few ten-thousandths of a percent.

But a new generation of atomic clocks, known as optical atomic clocks, outdo the cesium clocks (*SN: 11/11/17, p. 8*). "Their performance is a lot better than what currently defines the second," says physicist Andrew Ludlow of the NIST branch in Boulder, Colo. Because those optical atomic clocks operate at a higher frequency, their "ticks" are more closely spaced, making them about 100 times as precise as cesium clocks.

Ideally, the length of a second should be defined using the most precise timepieces available. A switch might happen in the late 2020s, Ludlow says.

The change to the kilogram's definition was carefully orchestrated so that it wouldn't affect people's everyday lives: A kilogram of flour still makes the same number of biscuits. Any change to the second will be similarly coordinated.

So, sorry, don't expect to squeeze any extra seconds into a day. ■

FROM TOP: L. CHAO/NIST; N. PHILLIPS/NIST

Bilingualism's extra brain perk doubted

Second language wasn't linked to executive functioning skills

BY LAURA SANDERS

Advantages of speaking a second language are obvious: easier logistics when traveling, wider access to great literature and, of course, more people to talk with. Some studies have also pointed to the idea that knowing another language comes with stronger executive functioning skills, brain abilities such as switching between tasks and ignoring distractions.

But a large study of bilingual children in the United States finds scant evidence of that extra benefit. Bilingual children performed no better in tests measuring those mental skills than children who knew just one language, researchers say May 20 in *Nature Human Behaviour*.

The researchers relied on a survey of U.S. adolescents called the ABCD study. From data collected at 21 research sites across the country, the team identified 4,524 kids ages 9 and 10. Of these children, 1,740 spoke English and a second language (mostly Spanish, though about 40 second languages were represented).

On three tests that measured executive function, such as the ability to quickly shift between tasks with different rules, bilingual children performed similarly to children who spoke only English, the researchers found. "We really looked," says Anthony Dick, a developmental cognitive neuroscientist at Florida International University in Miami. "We didn't find anything."

That result runs counter to earlier studies, small and large, that turned up advantages in similar tests of executive function for bilingual children, though those results have been contested by other research. Because of its size and the fact that it represents lots of U.S. communities, the ABCD dataset presented "an excellent opportunity to look at this question," Dick says.

Still, the complexity of bilingualism makes it hard to draw conclusions from the new results, says social scientist Gigi Luk of McGill University in Montreal. Nuances about whether a child speaks another language at home, when and how the second language was picked up and even whether one language is more respected than another can get lost in these sorts of large studies, she says. "We just don't have enough information about the bilingual experience that these children have every day."

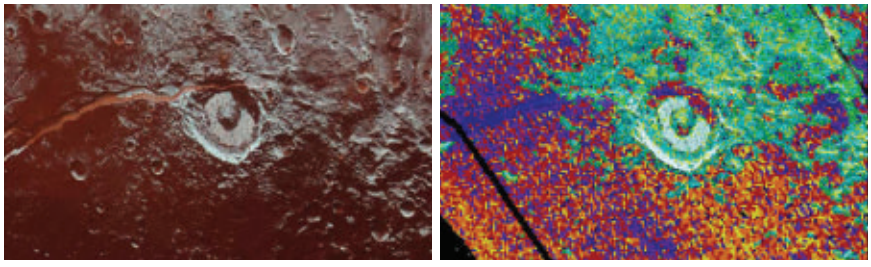
The study was aimed at the narrow question of whether bilingualism improves the brain's executive functioning. "I don't want this to be a paper about how parents should not have their children learn a second language," Dick says. To the contrary, "there are inherent benefits outside of executive function to learning a second language — huge benefits." ■

ATOM & COSMOS

Icy volcano spotted on Pluto

Remnants of watery eruption contain organic molecules

BY LISA GROSSMAN



Cutting across the surface of Pluto, the jagged red crack called Virgil Fossa (left) could represent a volcano that recently sprayed ammonia and organics-rich water. In the colored image (right), purple, red, orange and yellow pixels correspond to higher concentrations of ammonia in water ice.

Red ice found on Pluto suggests that the dwarf planet recently spewed fountains of water. And the ice hints at complex — and possibly organic — chemistry in Pluto's proposed subsurface sea, researchers report May 29 in *Science Advances*.

"This was a huge surprise to all of us," says planetary scientist Dale Cruikshank of the NASA Ames Research Center at Moffett Field, Calif. "It means there are lots of surprises waiting to be uncovered in that part of the solar system."

Cruikshank and colleagues analyzed wavelengths of light, which can act as signatures of chemical compounds, in images of Pluto's surface taken by the New Horizons spacecraft in 2015 (*SN: 12/26/15, p. 16*). Those images previously revealed a variety of ices overlaying a bedrock of water ice.

In the new analysis, researchers found signs of ammonia where that water ice is exposed. Ammonia is a fragile molecule that can be broken down by ultraviolet sunlight and cosmic rays in just 400,000 to a billion years. "If you find it at all, it suggests that it has been put there fairly recently," Cruikshank says.

Ammonia-rich water ice is clustered around a surface crack called Virgil Fossa, west of Pluto's heart-shaped feature. That crack is probably a fissure from which liquid water once erupted in a cryovolcano, the team says. A cryovolcano spews water and ice instead of lava.

Previous observations suggested that Pluto hides an ocean beneath its icy crust. But "there's a big difference between seeing evidence of liquid ocean from various surface features, and seeing parts of the ocean, the liquid, actually come out onto the surface," says planetary scientist Steven Desch of Arizona State University in Tempe, who was not involved in the new work. Evidence of a cryovolcano is vindicating, he says. "We have thought for a long time that these [small, icy] planets, Pluto included, should have cryovolcanic activity."

Ammonia can lower water's freezing point by about 100 degrees Celsius, Desch says. If the subsurface ocean has ammonia, that could explain how the water remains liquid so far from the sun.

ATOM & COSMOS

Big black holes seen in surprising places

Survey finds some giants lurking at the fringes of tiny galaxies

BY LISA GROSSMAN

CAMBRIDGE, MASS. — Big galaxies have correspondingly big black holes. But small galaxies might have big ones, too. A survey picked up dozens of massive black hole candidates in tiny dwarf galaxies.

Surprisingly, some of those potential black holes aren't at their galaxy's center. Instead, they appear to roam the outskirts, astronomer Amy Reines said May 20 at the Black Hole Initiative Conference 2019. These wonky monsters could help reveal how supermassive black holes in bigger galaxies form.

"Contrary to conventional wisdom, dwarf galaxies can, and at least some do, have massive black holes," said Reines, of Montana State University in Bozeman.

Almost every massive galaxy ever observed has a supermassive black hole at its center. These behemoths, including the Milky Way's, weigh between 100,000 and a few billion times the mass of the sun. That mass is related to the mass of the host galaxy. "In general, bigger galaxies have bigger black holes," Reines said.

When Reines stumbled upon a supermassive black hole almost 10 years ago in the dwarf galaxy Henize 2-10, some 30 million light-years from Earth, she was stunned.

Peering into thousands of dwarf galaxies, she and colleagues have since found about 100 massive black holes, given away by the glowing disks of gas that swirl around the black holes as they feed. Only the most actively feeding black holes show up in visible wavelengths, and only in galaxies with relatively low star formation. So there may be many others out there that are harder to spot.

The team is looking to radio waves to hunt for black holes that feed less aggressively. Using the Very Large Array of radio telescopes in New Mexico, the team has found 39 possible black holes in 111 dwarf galaxies. At least 14 of the candidates are likely to be black holes, Reines said. Some of the others may be supernova remnants or other objects that emit brightly glowing radio waves.

Some of these black holes are "wandering around in the outskirts of their host galaxies," Reines said. Computer simulations had suggested that up to half of all dwarf galaxies might have off-center black holes. Still, "this hasn't been seen before," she said. The black holes could have been knocked askew in a galaxy

C. M. DALLE ORE *ET AL*/*SCIENCE ADVANCES* 2019

Some scientists still want more evidence of cryovolcanism. "I'd love to believe this," says Marc Neveu, an astrobiologist at NASA Goddard Space Flight Center in Greenbelt, Md. "But the images are still a little bit too blurry to really make this a slam dunk." Lacking better pictures, scientists could use a combination of New Horizons data and lab studies to analyze the ammonia and other molecules in the mix to see how those molecules might have formed in a space environment.

The ice observations revealed another surprise: a red material that may represent complex organic molecules. This is the first hint that the subsurface ocean might contain organic molecules.

Irradiating ice rich in ammonia and organics in the lab can create molecules that are important to life, including the nucleobases that make up DNA and RNA, Cruikshank and colleagues reported in *Astrobiology* in March. Finding organics doesn't necessarily mean life got a start on Pluto, but it could mean that the chemical precursors to life can arise in surprisingly inhospitable environments. ■

merger, Reines said, or kicked off-center when two smaller black holes merged within a galaxy (*SN: 4/29/17, p. 16*).

The work "identifies a new and unique population that may have been missed by other selection techniques," says Vivienne Baldassare, an astrophysicist at Yale University.

Studying dwarf galaxies' massive black holes could help scientists figure out how even more massive black holes in larger galaxies got so big. One possibility is that supermassive black holes bulk up by adding their masses together when their host galaxies merge, or they could have started out relatively massive long ago. Dwarf galaxies, which probably haven't gone through many mergers, may preserve relics of those ancient massive black holes. Knowing how big those relics can get could help link up the supermassive monsters seen in the present-day universe with their ancient counterparts. ■

MATH & TECHNOLOGY

Progress claimed on old math problem

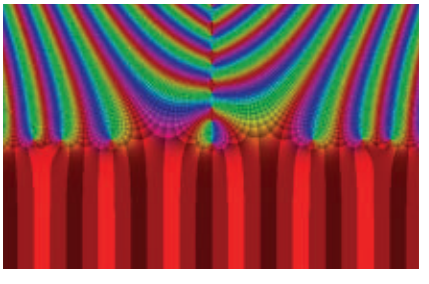
Riemann hypothesis might be one step closer to a solution

BY EMILY CONOVER

Researchers have made what might be new headway toward a proof of the Riemann hypothesis, one of the most impenetrable problems in mathematics. The hypothesis, proposed 160 years ago, could help unravel the mysteries of prime numbers.

Mathematicians made the advance by tackling a related question about a group of expressions known as Jensen polynomials, the team reports in the June 4 *Proceedings of the National Academy of Sciences*. But the conjecture is so difficult to verify that even this progress is not necessarily a sign that a solution is near (*SN Online: 9/25/18*).

At the heart of the Riemann hypothesis is an enigmatic mathematical entity known as the Riemann zeta function. It's intimately connected to prime numbers — whole numbers that can't be formed by multiplying two smaller numbers — and how they are distributed along the number line. The Riemann hypothesis suggests that the function's value equals zero only at points that fall on a single line when the function is graphed, with the exception of certain obvious points. But, as the function has infinitely many of these "zeros," this is not easy to confirm. The puzzle is considered so important and so difficult that there is a $1 million prize for a solution, offered up by the Clay Mathematics Institute.



The Riemann zeta function has an infinite number of points where the function's value is zero (located at places where all the colors converge in this plot). The Riemann hypothesis predicts that certain zeros lie along a single line (where the colorful bands meet the red).

But Jensen polynomials might be a key to unlocking the Riemann hypothesis. Mathematicians have previously shown that the Riemann hypothesis is true if all the Jensen polynomials associated with the Riemann zeta function have only zeros that are real, meaning the values for which the polynomial equals zero are not imaginary numbers — they don't involve the square root of –1. But there are infinitely many of these Jensen polynomials.

Studying Jensen polynomials is one of a variety of strategies for attacking the Riemann hypothesis. The idea is more than 90 years old, and previous studies have proved that a small subset of the Jensen polynomials have real roots. But progress was slow, and efforts had stalled.

Now, mathematician Ken Ono of Emory University in Atlanta and colleagues have shown that many of these polynomials indeed have real roots, satisfying a large chunk of what's needed to prove the Riemann hypothesis.

"Any progress in any direction related to the Riemann hypothesis is fascinating," says mathematician Dimitar Dimitrov of the State University of São Paulo. Dimitrov thought "it would be impossible that anyone will make any progress in this direction," he says, "but they did."

It's hard to say whether this progress could eventually lead to a proof. "I am very reluctant to predict anything," says mathematician George Andrews of Penn State, who was not involved with the study. Many strides have been made on the Riemann hypothesis in the past, but each advance has fallen short. With other major mathematical problems that were solved in recent decades, such as Fermat's last theorem (*SN: 11/5/94, p. 295*), it wasn't clear that the solution was imminent until it was in hand. "You never know when something is going to break," Andrews says. ■

ATOM & COSMOS

Sonic black hole's temperature taken

Lab experiments match predictions by Stephen Hawking

BY EMILY CONOVER

Taking a black hole's temperature is a seemingly impossible task. But now, physicists report the next best thing. They've measured the temperature of a lab-made sonic black hole, which traps sound instead of light.

If the result holds up, it will confirm a prediction of cosmologist Stephen Hawking, who first proposed this surprise about black holes: They aren't truly black. Instead, a relatively small stream of particles bleeds from each black hole's margin at a temperature that depends on how massive the black hole is. Such Hawking radiation is too faint to observe in true black holes. But physicists have spotted hints of similar radiation from analogs of black holes created in the lab (*SN: 12/18/10, p. 28*). In the new study, the sonic black hole's temperature agrees with that predicted by Hawking's theory, researchers report in the May 30 *Nature*.

"It's a very important milestone," says Ulf Leonhardt, a physicist at the Weizmann Institute of Science in Rehovot, Israel, who was not involved with the study. "It's new in the entire field. Nobody has done such an experiment before."

To produce the sonic black hole, physicist Jeff Steinhauer and colleagues used ultracold atoms of rubidium, chilled to a state known as a Bose-Einstein condensate, and set them flowing. Analogous to a black hole's gravity trapping light, the flowing atoms prevent sound waves from escaping, like a kayaker paddling against a current too strong to overcome. Previous experiments with this setup have shown signs of Hawking radiation, but it wasn't yet possible to measure its temperature (*SN: 11/15/14, p. 14*).

Hawking radiation comes from pairs of quantum particles that constantly pop up everywhere, even in empty space. Normally, those particles immediately annihilate one another. But at a black hole's edge, if one particle falls in, the other could escape, resulting in Hawking radiation. In the sonic black hole, a similar situation occurs: Pairs of sound waves known as phonons can appear, with one falling in and the other escaping.

Measurements of the phonons that escaped and those that fell in allowed the researchers to estimate the temperature, 0.35 billionths of a kelvin. "We found very good agreement with the predictions of Hawking's theory," says Steinhauer, of the Technion-Israel Institute of Technology in Haifa.

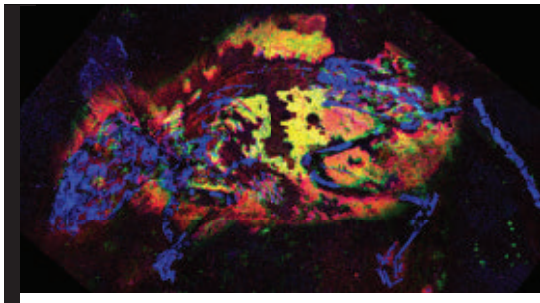
The result also agrees with Hawking's prediction that the radiation would be thermal, meaning that the particles' energies would have a distribution like that of the glow emitted by a warm object, such as the reddish light of a hot burner on an electric stove.

After Hawking proposed his theory, this predicted thermal property of the radiation led to a conundrum known as the black hole information paradox. In quantum mechanics, information can never be destroyed. But particles escaping black holes would slowly sap the behemoth's mass, and over a long period of time, the black hole would shrink into nothingness.

That means that the information that fell into the black hole (in the form of particles, encyclopedias or other objects) would no longer be contained within it. And if Hawking radiation is thermal, the information couldn't have been carried away by the fleeing particles. That's because the emitted particles are indistinguishable from those radiated by a commonplace object with a given temperature, or even by a different black hole of the same mass. That suggests that information can be lost as a black hole evaporates away, a violation of quantum mechanics.

It's unclear whether the new study could help scientists resolve the information paradox. A solution will probably demand a new theory that combines gravity and quantum mechanics into one new theory of quantum gravity — a task that is one of the biggest outstanding problems in physics.

But that theory wouldn't be relevant to sonic black holes because they aren't created by gravity. "The solution to the information paradox is in the physics of a real black hole, not in the physics of an analog black hole," Steinhauer says. ■



P.L. MANNING *ET AL/NATURE COMMUNICATIONS* 2019

LIFE & EVOLUTION

Mouse fossils have scientists seeing red

For the first time, chemical traces of red pigment have been detected in fossils.

Using a technique called X-ray spectroscopy, Phillip Manning, a paleontologist at the University of Manchester in England, and colleagues analyzed two fossils of a 3-million-year-old mouse species for a chemical signature associated with pheomelanin, the pigment responsible for reddish-brown fur or feathers. The team had already worked out which unique combination of chemical components stand for pheomelanin and for eumelanin, a dark brown or black pigment, by mapping out where trace metals such as zinc and copper bonded to organic molecules in the pigments of modern bird feathers. Pheomelanin occurs where zinc binds to organic sulfur molecules.

Mapping where both zinc and sulfur molecules occurred on the fossils revealed that the mice had reddish-brown fur on the back and sides (yellow regions in the image above), the team reports online May 21 in *Nature Communications*. — *Carolyn Gramling*

LIFE & EVOLUTION

Tiny reef fish keep predators well-fed

Small species provide much of the food in coral ecosystems

Small fishes such as the Great Barrier Reef blenny (*Ecsenius stictus*) turn out to have outsize importance on coral reefs.

TANE SINCLAIR-TAYLOR

BY SUSAN MILIUS

Little fishes that divers rarely notice could be unexpectedly important to coral reefs. A study finds that nearly 60 percent of the fish flesh that feeds bigger fishes and other predators on a reef comes from tiny fishes that stick close to crevices and other hiding places.

These tiny "cryptobenthic" species are like snack bowls that get quickly replenished. What keeps up the supply is a stay-near-home tendency among the larvae, Simon Brandl and colleagues report online May 23 in *Science*.

Unlike many larger reef fishes, the young of cryptobenthic fishes are more likely to linger close to their parents' reef, the researchers found by combing through decades of data on what species of fish larvae get caught where. The young of larger reef fishes tend to take many of the longer, dangerous journeys in open water. Cryptobenthic young stand a better chance of surviving by sticking close to the reef, where they quickly replace parents that get eaten, the team says.

In an earlier study, Brandl, a coral reef ecologist at Simon Fraser University in Burnaby, Canada, and colleagues defined the cryptobenthic group as 17 families of fish species, including gobies and blennies. In these families, at least 10 percent of known species measure less than 5 centimeters long, about as long as a pinkie finger. The majority of cryptobenthic species are smaller, Brandl says.

He and colleagues got a sense of the fishes' numbers in surveys on reefs in Australia, Belize and French Polynesia. The team fenced off plots, released clove oil and then collected fish that succumbed to the oil's anesthetic effects. With this and other data, the team created computer simulations of spawning, larval return and adult replacement. In the end, cryptobenthic fishes provide a lot of prey for the bigger, showier predators.

That role is "hugely important," says Deron Burkepile, a community ecologist at the University of California, Santa Barbara. "We've definitely overlooked these little cryptobenthic species." ■

GENES & CELLS

How bacteria near death bounce back

A protein revitalizes *E. coli* and helps it gain antibiotic resistance

BY TINA HESMAN SAEY

Mostly dead bacteria can sometimes be resurrected as antibiotic-resistant cells.

A protein that pumps toxic chemicals out of *E. coli* buys time for even a nearly dead bacterial cell to become resistant to antibiotics. Called the AcrAB-TolC multidrug efflux pump, the protein doesn't work well enough to defeat antibiotics on its own. But the pump removes enough antibiotic molecules to allow production of real resistance proteins, researchers report in the May 24 *Science*.

When bacteria come into contact, they can swap DNA, including antibiotic-resistance genes that are often carried on circles of DNA called plasmids. Geneticist Christian Lesterlin of CNRS-INSERM at the University of Lyon in France and colleagues engineered *E. coli* to make fluorescent proteins and watched under the microscope as *E. coli* swapped DNA and made resistance proteins.

Swaps happened quickly. Within three hours, about 70 percent of *E. coli* sensitive to tetracycline had become resistant to that antibiotic. In tests where tetracycline was added to *E. coli*, about a third of sensitive microbes became resistant.

Common wisdom holds that treating bacteria with antibiotics should stop bacteria in the act of swapping resistance genes, says microbiologist Kim Lewis of Northeastern University in Boston. At least, "yesterday, that's what I would have told you," he says. After reading the new study, "I have to change my views."

Once bacteria get the plasmid, they still have to turn on resistance genes to make proteins that fight off antibiotics, in this case a protein called TetA. Tetracycline blocks protein production, so when the drug is around, bacteria that haven't made TetA will be nearly killed, Lewis says. But a bacterial cell clings to life thanks to the multidrug pump — at least long enough to sometimes eke out some TetA protein, which then exports all of the antibiotic and returns the microbe to full life, the researchers found.

Disabling or removing the multidrug pump stopped bacteria from developing resistance. Drugs that disable that pump could stop the spread of resistance through plasmids. But no such drugs are safe to use in people yet, Lesterlin says. ■

MATTER & ENERGY

Uranium cube traced back to the Nazis

Germany could have built a nuclear reactor, sleuths conclude

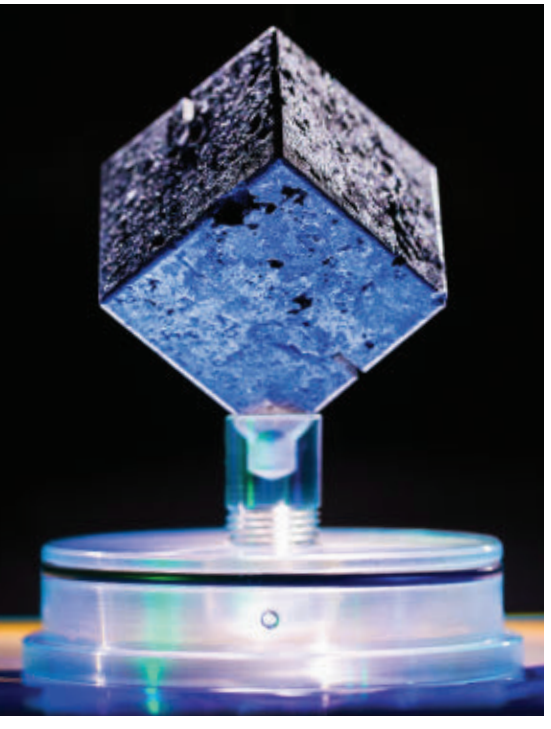
BY EMILY CONOVER

The mysterious cube arrived in the summer of 2013. Physicist Timothy Koeth had agreed to go to a parking lot for an unspecified delivery. Inside a blue cloth sack, swathed in paper towels, he found a small chunk of uranium.

It was about 5 centimeters across, with "a white piece of paper wrapped around it, like a ransom note on a stone," Koeth says. On the paper was a message: "Taken from the reactor that Hitler tried to build. Gift of Ninninger."

Koeth, a collector of nuclear memorabilia, was enthralled. "I just immediately knew what this thing was," he says. During World War II, German scientists had tried to build a nuclear reactor, until their uranium cubes were confiscated by Allied forces and shipped to the United States.

Koeth, of the University of Maryland in College Park, thought his cube could be from that cache. While working to confirm that hunch, he and University of Maryland graduate student Miriam Hiebert came to a striking conclusion, reported in the May *Physics Today*: Contrary to conventional wisdom, German scientists could have created a nuclear reactor during the war, but competition between teams stymied the effort.



This uranium cube was once part of an attempt to build a nuclear reactor in Nazi Germany.

JOHN T. CONSOLI/UNIV. OF MARYLAND

The first clue to the heritage of the cube was its surface. Pockmarked with bubbles, it pointed to primitive uranium-processing techniques used at the time. Another hint came from the name in the note. Some digging revealed that it was the misspelled last name of Robert Nininger, who had been involved with the U.S. wartime effort to build an atomic bomb. Nininger's widow confirmed that he once had owned a uranium cube and gave it to a friend. Koeth thinks the cube changed hands at least once more before it came to him. (Its radioactivity is low enough that the cube is safe to handle.)

In a nuclear reactor, atoms split through the process of fission. Get enough uranium in one place, and the neutrons released in fission trigger additional fissions, kicking off a continuing chain of reactions that releases energy. Uranium for use in modern nuclear reactors is enriched to contain more of a particular isotope, or variety of the element with a given number of neutrons. That isotope is the one that is important for nuclear fission. The German reactor attempt used uranium with its naturally existing abundance of isotopes.

Koeth and Hiebert measured the energy of gamma rays — high-energy particles of light — emitted from the cube as the atoms within decay. Those measurements confirmed that the cube is natural, unenriched uranium.

Further tests indicated that the cube was never in a working reactor. If it had been, the researchers would have detected gamma rays from the isotope cesium-137. A similar hunk of material taken from the first successful nuclear reactor at the University of Chicago in 1942 did contain the telltale cesium.

Koeth and Hiebert's sleuthing also resulted in an unexpected historical find. Computer simulations have suggested that the Germans' stash of 664 uranium cubes hadn't been enough to create a nuclear reactor. A minimum amount of the element, a critical mass, is necessary to sustain the chain of reactions that occur in a reactor. To reach that mass, the Germans, working under physicist Werner Heisenberg, would have needed a few hundred more cubes.

As Koeth and Hiebert scoured documents at the National Archives at College Park, the pair found references to another 400 or so cubes held by a different German research group during World War II. At the time, German science teams were competing against one another. Had they combined forces, they would have had enough uranium to make a reactor, Koeth and Hiebert determined. The Germans were still far from producing an atomic bomb, however.

Koeth plans to loan his cube to a museum. For now, the cube is ensconced in a custom-built display case and is the jewel of his collection of nuclear artifacts. Other items include graphite from that first reactor at the University of Chicago, greenish glass from sand fused by an atomic bomb test and uranium-infused glassware known as Vaseline glass that glows green under ultraviolet light.

"I'm humbled" by the cube, Koeth says. Uranium fuels nuclear power, which could help free humankind from fossil fuel dependence, he says. But the element can also be used in devastating weapons. Nuclear physics "has the ability to save us and to totally destroy us. And that little cube represents all of that."

The pair wants to chase down the remaining cubes from Heisenberg's reactor attempt. Koeth and Hiebert know the whereabouts of 10 others, including one at the Smithsonian Institution in Washington, D.C. Others are probably scattered around the United States. "They could be in people's basements all over the country," Hiebert says. Perhaps to some, it's just "that weird cube that my dad had in his office." ■

LIFE & EVOLUTION

Bad moods spread among ravens

The birds seem to pick up on and share negative emotions

BY CAROLYN WILKE

Pessimism seems contagious among ravens. But positivity? Not so much.

When ravens saw fellow birds' responses to a disliked food, but not the food itself, their interest in their own food options waned, researchers report online May 20 in the *Proceedings of the National Academy of Sciences*. The study suggests that the birds pick up on and even share negative emotions.

Ravens are "very good problem solvers ... but this paper's really highlighting their social intelligence as well," says Andrew Gallup, a psychologist at State University of New York Polytechnic Institute in Utica who was not involved in the study.

Known for their smarts, ravens act in ways that suggest a capacity for empathy, such as appearing to console distressed comrades. Thomas Bugnyar, a cognitive ethologist at the University of Vienna, and colleagues wanted to look into one building block of empathy — whether animals share emotions. To be able to feel for others, an animal needs to be able to feel like others, he says.

But sizing up an animal's mood is tricky. Scientists generally rely on behavioral or physiological cues to clue in to a creature's emotional state. More challenging is assessing how one animal's mood might influence another's: Similar actions appearing to stem from kindred emotions may just be mimicry.

To tune into ravens' moods, Bugnyar and colleagues set up experiments to watch whether the birds reacted positively or negatively to a neutral stimulus. This type of cognitive bias test "is basically ... asking how you would judge a glass — if it's half full or half empty," Bugnyar says.

Eight ravens, tested in pairs, were first given a choice between a box containing a cheese treat and an empty box. Once the birds learned the location of each option, they were given a third box in a new spot that hadn't been used in the training. Whether a bird acted as if the box was a trick or a treat indicated a cognitive bias, interpreted as pessimism or optimism.

Next, one bird in a pair was offered both unappealing raw carrots and tastier dried dog food before one was taken away. Birds left with the treat moved their heads and bodies as they studied it; those getting the carrots appeared crankier, spending less time attending to the offering and sometimes kicking or scratching elsewhere. The other bird in the pair watched these reactions from a separate compartment, without being able to see the researcher or which food the bird received.

Both birds then performed the cognitive bias test again. This time, observer birds that had seen their partner appearing perky showed on average the same level of interest in their own ambiguous box as they had previously. But those that had seen their partner reacting negatively typically took more than twice as long as the other group to approach the ambiguous box. This dip in the observer birds' interest was somehow influenced by seeing their partner's apparent disappointment, the researchers say.

Each bird was tested four times, half of the time with the undesired food and the other half with a treat.

It's interesting that while the negative responses seemed contagious, the positive ones did not, Gallup says. This may be because negative reactions are easier to provoke or observe, or because animals tune in more to negative information in their environment, the authors say.

The ravens study marks one of the first times the cognitive bias test has been used to examine emotions and social behavior, says coauthor Jessie Adriaense, a comparative psychologist at the University of Vienna. "Emotions are extremely important drivers of our behavior, but how they actually drive animals ... is still an open question," she says. To truly understand what motivates behavior in nonhuman animals, scientists need to delve deeper into emotions, she says. ■

N. R. CHIMENTO

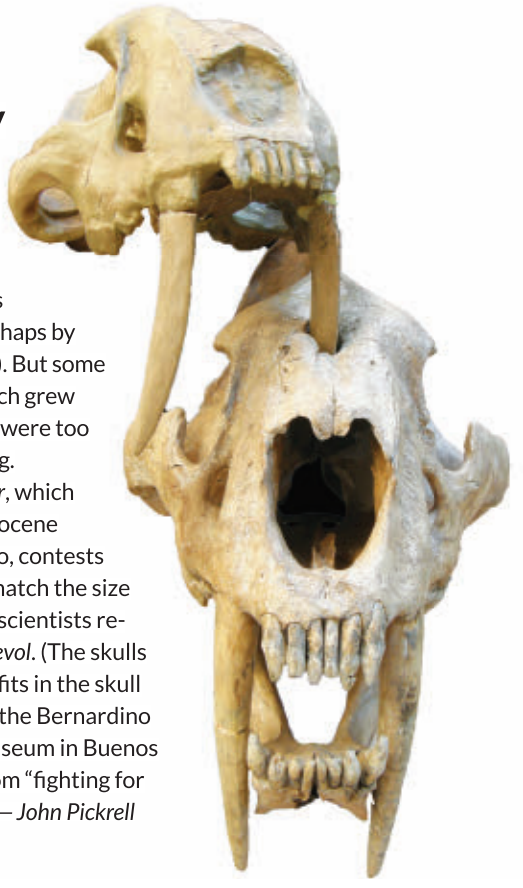
LIFE & EVOLUTION

Saber-toothed cats may have pierced rivals

Saber-toothed cats may have wielded their canine teeth as deadly weapons to puncture the skulls of rival cats.

Scientists suspected that *Smilodon* cats used their canines to take down prey, perhaps by ripping out the throat (*SN: 3/30/19, p. 20*). But some researchers argued that the canines, which grew up to 28 centimeters long in one species, were too fragile to puncture bone without breaking.

An analysis of two skulls of *S. populator*, which prowled South America in the late Pleistocene Epoch some 11,000 to 126,000 years ago, contests that idea. Holes in the top of the fossils match the size and shape of saber-toothed cat canines, scientists report online May 2 in *Comptes Rendus Palevol*. (The skulls at right show how a canine from one cat fits in the skull wound of another.) Nicolás Chimento of the Bernardino Rivadavia Argentine Natural Science Museum in Buenos Aires says the wounds probably stem from "fighting for territoriality, access to females or food." — *John Pickrell*



Shell Game

Transforming biodegradable seafood waste to cut down on plastic

By Carmen Drahl

Lobster bisque and shrimp cocktail make for scrumptious meals, but at a price. The food industry generates 6 million to 8 million metric tons of crab, shrimp and lobster shell waste every year. Depending on the country, those claws and legs largely get dumped back into the ocean or into landfills.

In many of those same landfills, plastic trash relentlessly accumulates. Humans have produced over 8 billion tons of plastic since mass production began in the 1950s. Only 10 percent of plastic packaging gets recycled successfully. Most of the rest sits in landfills for a very long time (a plastic bottle takes about 450 years to break down), or escapes into the environment, perhaps sickening seabirds that swallow tiny pieces or gathering in the Pacific Ocean's floating garbage patch (*SN Online: 3/22/18*).

Some scientists think it's possible to tackle the two problems at once. Crustaceans' hardy shells contain chitin, a material that, along with its derivative chitosan, offers many of plastic's desirable properties and takes only weeks or months to biodegrade, rather than centuries.

The challenge is getting enough pure chitin and chitosan from the shells to make bio-based "plastic" in cost-effective ways. "There's no blueprint or operating manual for what we're doing," says John Keyes, CEO of Mari Signum, a start-up company based just outside of Richmond, Va., that is devising ways to make environmentally friendly chitin. But a flurry of advances in green chemistry is providing some guideposts.

Nature's scaffold

Chitin is one of the most abundant organic materials in the world, after cellulose, which gives woody plants their structure. In addition to crustaceans, chitin is found in insects, fish scales, mollusks and fungi. Like plastic, chitin is a polymer, a molecular chain made from repeating units. The building block in chitin, *N*-acetyl-D-glucosamine, is a sugar related to glucose. Chitin and chitosan are antibacterial, nontoxic and used in cosmetics, wound dressings and pool-water treatments, among other applications.

Entrepreneurs are trying to launch new chitin products. Cruz Foam, a company in Santa Cruz, Calif., set out to produce surfboards from chitin, though the company has since pivoted to focus on the much larger market of packaging foam. Polystyrene foam, a common component in both surfboards and food packaging, takes a minimum of 500 years to biodegrade.

URBANBUZZ/SHUTTERSTOCK

Company cofounder Marco Rolandi is convinced that his Cruz Foam will biodegrade readily, based on his at-home test. "I put Cruz Foam in my backyard compost and a month later there were worms growing on it," he says. Eco-friendly surfboards and wound dressings are valuable, but they are niche products — small potatoes that won't make a dent in the massive amounts of fossil fuel–based plastics. Scientists have proposed large-scale production of chitin or chitosan in the past. But the chemistry for isolating the materials from shell waste has some big drawbacks, so the work didn't get far.

For one thing, pulling out the chitin traditionally requires corrosive chemicals. A crustacean shell contains 15 to 40 percent chitin. To get to the chitin requires removing the protein along with the minerals, largely calcium carbonate, that make the shells stiff. Hydrochloric acid, a strong acid, removes calcium carbonate while generating carbon dioxide emissions; sodium hydroxide, or lye, is a strong base that removes the protein. Producing a single kilogram of chitin requires 10 kilograms of shells, six kilograms of coal for heating purposes, nine kilograms of hydrochloric acid, eight kilograms of sodium hydroxide and 330 kilograms of freshwater. Washing the chitin to remove residual contaminants can use up to an additional 200 kilograms of water.

Getting the chitosan requires an extra step: adding hot, concentrated sodium hydroxide solution to the chitin. To do this work in a sustainable way, companies must invest in pricey corrosion-resistant reactors, wastewater treatment and carbon dioxide capture technology.

The harsh reactions used today also sever the long polymer chains that make the materials sturdy, limiting chitin's and chitosan's versatility. Mari Signum's chief technology officer, Julia Shamshina, offers a clothing analogy: It's impossible to make a sweater with a ball of yarn made only of short threads.

Approaches that reduce or eliminate corrosive reagents, recycle water and keep the polymers strong are in demand, says Pierre-Olivier Morisset of Merinov, a research center in Gaspé, Canada, that helps marine-product companies manage waste and commercialize innovations. "We're looking for technologies that can produce hundreds of kilograms" of chitin or chitosan with long polymer chains, Morisset says. But developing greener methods is not easy.

Seafood suppliers face economic drawbacks as well. Today, U.S. producers pay landfills to take their shells. But those who want to keep the waste out of the landfill and support chitin production must still pay to dry the shells and transport them to often faraway extraction facilities, like Mari Signum. For its part, Mari Signum is changing the equation by paying the transportation bills for its Gulf Coast suppliers. Once Mari Signum is profitable, the company says it will also pay those suppliers for their shells.

When Keyes was a pro bono consultant for an aquaculture business a few years ago, he faced that same food waste decision. The company planned to haul its shells to regional landfills, Keyes says, "until we ... tracked down Robin Rogers."

Making use of seafood shell waste starts with drying the shells (top). Researchers then extract chitin and chitosan (middle). The foam at left is made from chitin and could be used to make surfboards or biodegradable food packaging.

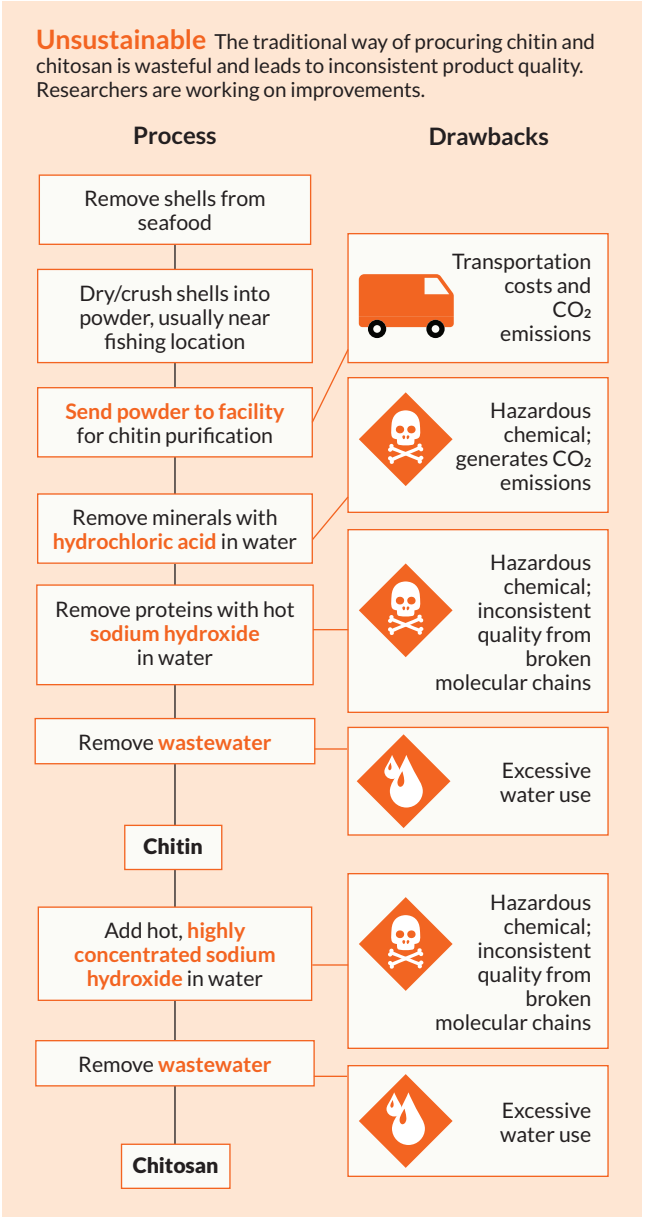
FROM TOP: MARI SIGNUM; COURTESY OF MICHAEL HOFER/FRAUNHOFER INST.; CRUZ FOAM

Get it separated

If the slight drawl doesn't give Rogers away as a native Alabaman, his ever-present blazer in Crimson Tide red does the trick. A University of Alabama chemist and a cofounder and co-owner of Mari Signum, Rogers started tackling shell waste in 2010, when the Deepwater Horizon oil spill devastated Gulf Coast shrimpers. Mari Signum licensed his technology in 2016. "We found we could take shrimp shell, dissolve the chitin directly and pull it away from everything else," Rogers says.

The key was to find a liquid that could dissolve chitin, because water cannot. Thousands of repeating sugar units in chitin entangle themselves via countless interactions known as hydrogen bonds, and neither water nor most organic solvents can penetrate that network. Rogers solved that problem by dissolving shell waste in an ionic liquid.

Ionic liquids differ chemically from water and organic solvents. The chemical bonds in a molecule of water — H_2O — are covalent: They involve shared electrons. Ionic liquids, in contrast, feature an ionic bond like that seen in table salt, sodium



chloride, in which no electrons are shared but the attraction between a positively charged ion, called a cation, and negatively charged ion, or anion, holds things together. While ionic liquids may be saltlike, they are not exactly like table salt. Transforming solid table salt crystals to a liquid requires a temperature about 1.5 times as hot as the surface of Venus, but an ionic liquid can be liquid at room temperature.

Their chemical makeup helps ionic liquids dissolve chitin where other solvents fail. To dissolve chitin in shrimp shells, Mari Signum uses 1-ethyl-3-methylimidazolium acetate. This ionic liquid belongs to the lowest chemical toxicity category, according to United Nations standards. "I tell people half of the ionic liquid we're using is vinegar," Rogers says, because negatively charged acetate is present in everyday table vinegar, which is a dilute solution of acetic acid in water. Acetate is a small molecule, in addition to being charged, so it infiltrates chitin's hydrogen bond networks. Microwave heating activates the hydrogen bonds to enable separation without cutting the polymer chains.

Mari Signum's process requires neither hydrochloric acid nor sodium hydroxide, and the ionic liquid can be used again and again. The shells' calcium carbonate is a waste by-product, but the company is looking into providing that waste to makers of paint additives or heartburn medication, where this compound is already used commercially.

Shamshina, Rogers and chemist Paula Berton of the University of Calgary in Canada showed that their chitin, extracted by ionic liquid, can be converted to fibers and hydrogels — materials that can absorb and retain water. In the April 1 *ACS Sustainable Chemistry and Engineering*, the researchers described potential uses in wound-care materials and biodegradable delivery vehicles for drugs. Plus the group produced novel materials, such as chitin microbeads that could be a biodegradable substitute for the banned plastic microbeads that were used in cosmetics (*SN Online: 1/4/19*).

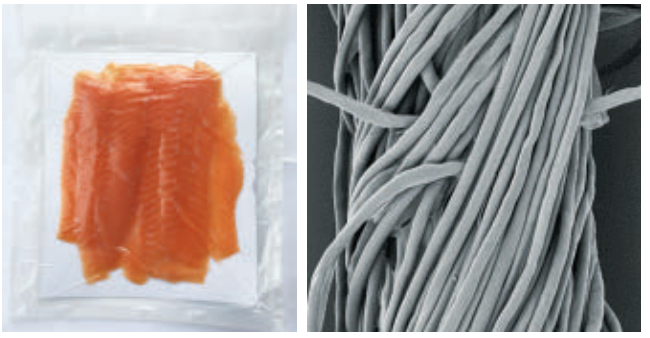
Ionic liquids aren't the only chemistry solution to the chitin extraction problem. Chemist Audrey Moores' team at McGill University in Montreal published a patent-pending approach to minimizing use of water, or any liquid, online on March 26 in *Green Chemistry*. Moores' research assistant Thomas Di Nardo takes shell powder from crustaceans or insects and pounds it with a ceramic ball inside a mechanical mill. This step loosens the hydrogen bonds between chitin's many chains. Scientists call this approach mechanochemistry.

"Instead of giving energy to your reaction in the form of heating, you're giving it in the form of mechanical force," Moores says. Next, instead of employing sodium hydroxide dissolved in water, Di Nardo adds solid sodium hydroxide to the mill, mixes for a few minutes and then transfers the mixture to a steam room–like chamber, where it ages for six days. Each of chitin's many *N*-acetyl-D-glucosamine building blocks contains a chemical group that's akin to a gloved hand. During aging, the sodium hydroxide removes most of the gloves, yielding chitosan.

Compared with the traditional conversion of chitin to chitosan, Moores estimates that the process uses only about a third to a fifth as much energy, an eighth as much sodium hydroxide and a tenth as much water. The process also produces very long polymer chains.

One drawback: Only 10 grams can be made at a time. But Moores received funding from McGill this spring to find ways to produce greater quantities. The next goal is 10 kilograms, and preliminary talks with collaborators suggest it's doable. Moores is also working with an expert on green plasticizers, to convert her sturdy chitosan into something moldable like the plastics in single-use packaging. A company that makes antibacterial clothing fibers has reached out to her as well, about potentially using her chitosan, which is naturally antibacterial, for the fibers. In May, Moores and Di Nardo launched a spin-off corporation, ChitoDry.

T. TIBBITTS, WONDERFULPIXEL/ISTOCK/GETTY IMAGES PLUS



Salmon is sealed in compostable food wrapping made from chitosan (left) that was obtained from waste langoustine shells. A piece of yarn with several fibers (right) is coated with a chitosan film made from black soldier fly skin to prevent breakage during weaving.

FROM LEFT: CUANTECH; GERMAN INST. FOR TEXTILE AND FIBER RESEARCH

Put bacteria to work

What if chitin could be extracted without adding any lab-made chemicals? Because chitin and chitosan can be made from living things, a biological extraction seems like a reasonable approach to chemist Cait Murray-Green. At CuanTec in Scotland, where she is CEO, microbes obtain chitin and chitosan from the shells of langoustines, crustaceans common to Europe's northern seas.

CuanTec's process takes advantage of clever microbial chemistry. "Our bacteria produce natural acids, which are a direct replacement for harsh hydrochloric acid," Murray-Green says. The team has also eliminated about 95 percent of the sodium hydroxide the traditional process requires and cut energy use by two-thirds, she adds. The process yields long, robust polymer chains.

The company's first product will be compostable, antimicrobial food packaging. Recent tests suggest that the packaging extends fresh salmon's shelf life by three days over traditional plastic. In April, CuanTec announced a partnership with British supermarket chain Waitrose & Partners to produce flexible film packaging for fish. Waitrose hopes the film will be available in 12 to 18 months. "This story is about using food waste to prevent food waste," Murray-Green says.

Only certain bacteria are suitable for purifying chitin from food waste. CuanTec's microbial cocktail is proprietary, but at the Fraunhofer Institute for Interfacial Engineering and Biotechnology in Stuttgart, Germany, Susanne Zibek's team selects microbes that consume the shells' protein but not the chitin.

Those same microbes secrete lactic acid, which substitutes for hydrochloric acid. Zibek leads ChitoTex, an international chitin research consortium. Among her collaborators is Protix, a Netherlands firm that produces larvae from the black soldier fly as a protein source for animal feed. The company sought to make use of chitin-rich insect skins and Zibek thought of an alternative to nonrenewable substances in the textile industry.

During the weaving process, yarn experiences mechanical stress. To prevent breakage, manufacturers add a temporary plastic coating, which they wash away prior to dyeing. Companies frequently use polyvinyl alcohol for the coating, which comes from fossil fuel sources. Zibek's team has developed an alternative using the Protix waste: a temporary chitosan coating for yarn. The most she can make in one batch is 500 grams, too small to meet a textile company's needs. Before the technology can be viable, she has to find a way to produce more material and to recycle the water required for the process.

Back at Mari Signum, water is on Keyes' mind as well. After chitin extraction, workers add water to the ionic liquid to coax chitin out of solution. But to recycle the ionic liquid, the water has to be removed. That's easy enough to do at a 20-liter pilot scale. In 1,200-liter stainless steel tanks, however, the water removal process still needs fine-tuning. So while the factory is producing some chitin, it isn't at full capacity. Keyes estimates that the plant's capacity could eventually reach 90,000 kilograms of chitin annually, with room to expand.

Green ambitions

Chitin and chitosan alone will never replace all of the world's plastic, which has an enormous range of properties. Plastics production is increasing, and even if all 6 million to 8 million tons of the world's yearly shell waste could be processed for chitin, the material would be a tiny fraction of the 311 million tons of plastic that humans produced in 2014.

Farming more shrimp would boost the amount of available chitin somewhat. Mari Signum's sister company, Global Blue Technologies, based in Rockport, Texas, is developing indoor aquaculture ponds that will not discharge any waste to the environment, thanks to proprietary filtration technology. Hurricane Harvey destroyed the facility in 2017, but when it's rebuilt, Mari Signum will be able to get shrimp shells from five to 10 molts as the shrimp grow, instead of the single shell available from fisheries.

For now, Keyes is sharing his vision with potential partner companies. He hopes to encourage a new ecosystem of businesses to operate in the Richmond area, which happens to be close to the Chesapeake Bay, famous for its crabs, as well as the port of Norfolk, which could in theory receive shipments of shell biomass from elsewhere.

Keyes likens the area to Silicon Valley, which was once primarily an agricultural region. "Then they developed this little thing called a microchip," he says, and an entire economic engine sprang to life.

The Richmond region's microchip could be high-quality chitin, Keyes contends. "It's this miracle of nature," he says. "Right now, it's basically being thrown away." But the right chemistry could keep both shells and plastic out of landfills. ■

Explore more

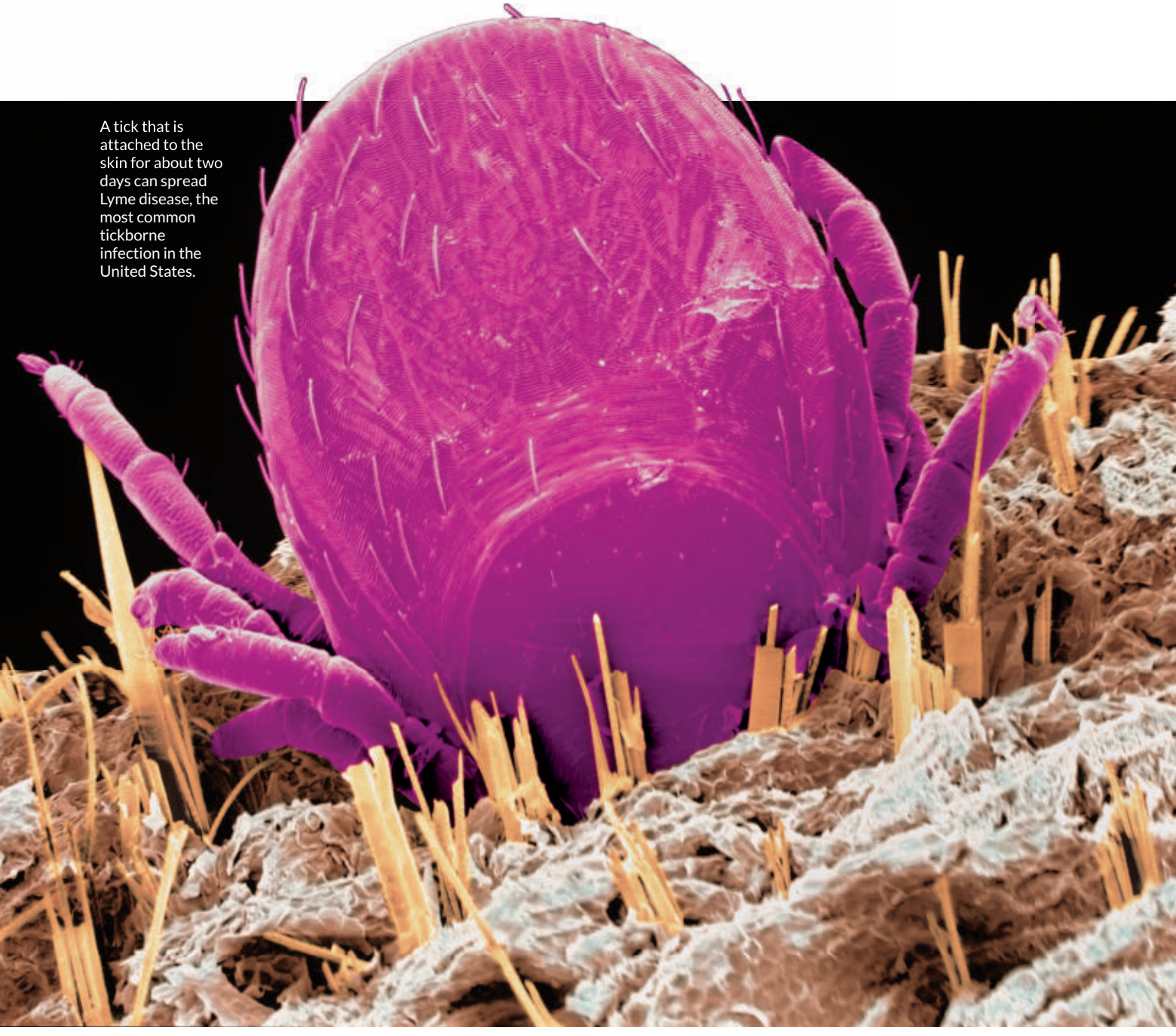
- Ning Yan and Xi Chen. "Sustainability: Don't waste seafood waste." *Nature*. August 13, 2015.

Carmen Drahl is a freelance science writer based in Washington, D.C.

THE TROUBLE WITH LYME DISEASE TESTING

New approaches may help solve a diagnosis dilemma

By Laura Beil



A tick that is attached to the skin for about two days can spread Lyme disease, the most common tickborne infection in the United States.

In 2005, Rachel Straub was a college student returning home from a three-week medical service mission in Central America. Soon after, she suffered a brutal case of the flu. Or so she thought.

"We were staying in orphanages," she says of her trip to Costa Rica and Nicaragua. "There were bugs everywhere. I remember going to the bathroom and the sinks would be solid bugs." She plucked at least half a dozen ticks off her body.

Back in Straub's hometown of San Diego, fevers and achiness tormented her for a couple of weeks. Her doctor suspected Lyme disease, which is spread by ticks, but a test came back negative, and at the time, the infection was almost unheard of in Latin America.

For years, Straub struggled off and on with crushing fatigue and immune problems. She forged on with her studies. Dedicated to physical fitness, she started writing a book about weight training. But in late 2012, she could no longer push through her exhaustion.

"My health was shattering," she says. By January 2013, she could hardly get out of bed and had to move back in with her parents. She describes a merry-go-round of physicians offering varying explanations: chronic fatigue syndrome, mononucleosis. She never got a definitive diagnosis, but a rheumatologist with expertise in immunology finally prescribed powerful antibiotics.

Almost immediately, Straub broke out in chills and other flulike symptoms, and her blood pressure plummeted, problems that sometimes arise when pathogens begin a massive die-off inside the body. She began to feel better, but slowly. Over the next four years, she could barely leave her house.

Stories like Straub's are what make Lyme disease one of the most charged and controversial of all infections. It's not hard to find tick-bitten patients who live for years with undiagnosed and unexplained symptoms that defy repeated treatment attempts.

Patient advocates point to people who agonize for years, drifting from doctor to doctor in search of relief. Battles with insurers who won't pay for therapy without a definitive diagnosis have played out in courthouses and statehouses. Desperate patients sometimes turn to solutions that may pose their own risks. The U.S. Centers for Disease Control and Prevention recently described people who had developed serious complications, or even died, after unproven treatments for Lyme disease.

Many, if not most, of these problems are caused by the lack of a reliable test for the infection. "This deficiency in Lyme disease diagnosis is probably the most prevalent thing that is responsible for the controversies of this disease," says Paul Arnaboldi, an immunologist at New York Medical College in Valhalla.

That's why Arnaboldi and other researchers are trying to devise better diagnostics (*SN: 9/16/17, p. 8*). The standard two-part test that's used now, which has changed little in concept since the 1990s, may miss about half of infected people in the early weeks of illness. The test relies on finding markers that show the immune system is actively engaged. For some people, it takes up to six weeks for those signs to reach detectable levels.

To find better ways to diagnose the disease more reliably and maybe sooner, scientists are trying to identify genetic changes that occur in the body even before the immune system rallies. Other researchers are measuring immune responses that may prove more accurate than existing tests.

The science has advanced enough, according to a review in the March 15 *Clinical Infectious Diseases*, that within the next few years, tests may finally be able to measure infections directly. The aim is to amplify traces of the Lyme bacteria's genetic material in the bloodstream. Enough approaches are in various stages of research that some patient advocates have renewed optimism that the problems with testing may finally become a thing of the past.

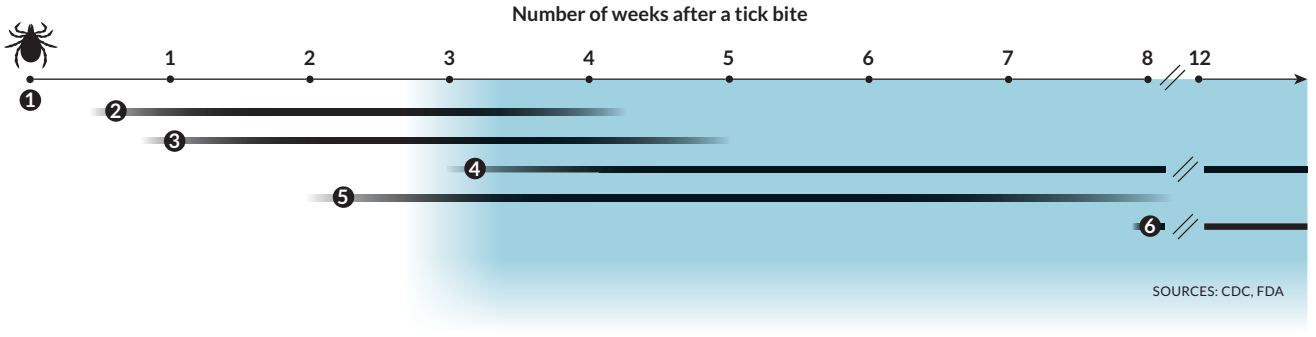
Ticked off

In the United States, ticks pass about a dozen illnesses to people, but Lyme disease is the most common (*SN: 8/19/17, p. 16*). It's most often caused by the bacterium *Borrelia burgdorferi*, which usually hitches a ride inside black-legged ticks, also known as deer ticks. When a tick bites and latches on to a person, the bacteria enter the skin, often causing a distinct, circular bull's-eye rash radiating from the bite. But about 20 to 30 percent of infected people never experience any kind of rash, and many of those who do simply never notice it.

The hallmark of a Lyme disease infection is a bull's-eye rash. But not everyone gets the rash, and many of those who do miss it completely.

OPPOSITE PAGE: VOLKER STEGER/SCIENCE SOURCE; THIS PAGE: JAMES GATHANY/CDC

The Lyme disease testing window



Hiding places

The current Lyme disease test works only after the body's immune system starts to put up a fight, sending antibodies into the bloodstream. By then (blue area shown), the bacteria may have already moved into other parts of the body.

1. 36 to 48 hours
The tick must hold on long enough to transfer the bacteria into the person.

2. 3 to 30 days
Bacteria spread in the skin, sometimes forming a bull's-eye rash. Symptoms can begin to appear: fevers, chills, headache, muscle pain, joint pain.

3. Days to weeks
Bacteria invade blood vessels, entering the circulatory system. Antibodies begin to form in reaction to the bacteria.

4. 3 weeks and onward
The window during which the current test may pick up an infection.

5. Weeks to months
Bacteria multiply and spread into other tissues, potentially causing facial palsy, nerve pain or heart inflammation.

6. Months or years
An untreated infection can affect many parts of the body, including joints, the nervous system and skin.

About 30,000 infections are reported annually in the United States, but public health experts estimate that the true number is 10 times as high.

Once in the skin, the corkscrew-shaped bacteria travel into the bloodstream and then migrate into joints and connective tissues, sometimes reaching the heart and nervous system. The problem is that treatment with antibiotics is most successful when the infection is in its earliest stages — the exact time when the standard diagnostic test is least reliable.

Doctors have an easier time diagnosing other infections using a technique called polymerase chain reaction. PCR amplifies bits of the pathogen's genetic material from a patient's blood, making the infection easier to confirm. But PCR isn't sensitive enough for many Lyme infections, says Jeannine Petersen, a microbiologist at the CDC's Division of Vector-Borne Diseases in Fort Collins, Colo. Lyme-causing bacteria congregate in very low numbers in blood samples, she says, which "makes it very hard to detect the organism itself using standard methods, such as PCR."

Indirect and ambiguous

Unable to look for the bacteria directly, at least for now, diagnosis depends on deciphering clues from the body's immune response. The standard test has two steps. The first looks for antibodies that respond to Lyme-causing bacteria. The second, called a Western blot, validates the diagnosis by confirming the presence of other antibody proteins that are more specific for Lyme. (The two steps are used together to reduce the odds of a false-positive test.)

Because antibiotics are most effective when given early, doctors in Lyme-heavy areas commonly give antibiotics to anyone who has been exposed to ticks and has infection symptoms, such as headache, fever and muscle and joint aches. Still, not all doctors are aware that they shouldn't wait for a positive test to begin treatment.

And sometimes doctors face dilemmas because results are ambiguous, says Charles Chiu, an infectious disease physician and microbiologist at the University of California, San Francisco.

Take this scenario: By definition, a positive test for someone symptomatic for less than a month must detect at least two of three proteins for a particular type of antibody. Those proteins, and the time cutoff, were chosen during a meeting 25 years ago. "But that's a rather arbitrary threshold," Chiu says. He and other doctors have seen patients whose results don't fit the criteria. Does that mean there's no infection? Or is this patient's immune response not typical?

In the Lyme light

Instead of waiting for antibodies to amass, Chiu wants to detect genetic changes that the body makes immediately to cope with a Lyme infection. He and his team are using machine learning, an algorithm that adapts or "learns" based on data it receives, to find the precise combination of genes that are activated when the immune system first encounters the bacteria.

"We look at all 23,000 genes that could potentially be expressed in response to a *B. burgdorferi* infection," he says. "We want to narrow that to the 50 or 100 genes that are specific for patients with Lyme disease." In theory, a computer could pick up a unique signature of genes that turn on as soon as an infection occurs and a person begins to feel ill. So far, the team has found about two dozen.

Working with partners from Johns Hopkins University School of Medicine, San Francisco State University and Qiagen Bioinformatics in Redwood City, Calif., Chiu's team published data in 2016 in *mBio* showing panels of specific genes

C. CHANG

activated in people who have Lyme disease. Twenty-nine volunteers were tested when they were diagnosed, after three weeks of antibiotics and then six months later. During an active infection, the Lyme patients had a genetic pattern that was different than the patterns of 13 people without the disease. That Lyme signature was also different from the signatures of other infections, including viral influenza and sepsis, an immune overreaction triggered by a different organism. And the patterns changed after treatment.

As he searches for more genes in larger groups of patients, Chiu also wants to look for genetic patterns specific to the 10 to 20 percent of patients whose symptoms persist after treatment.

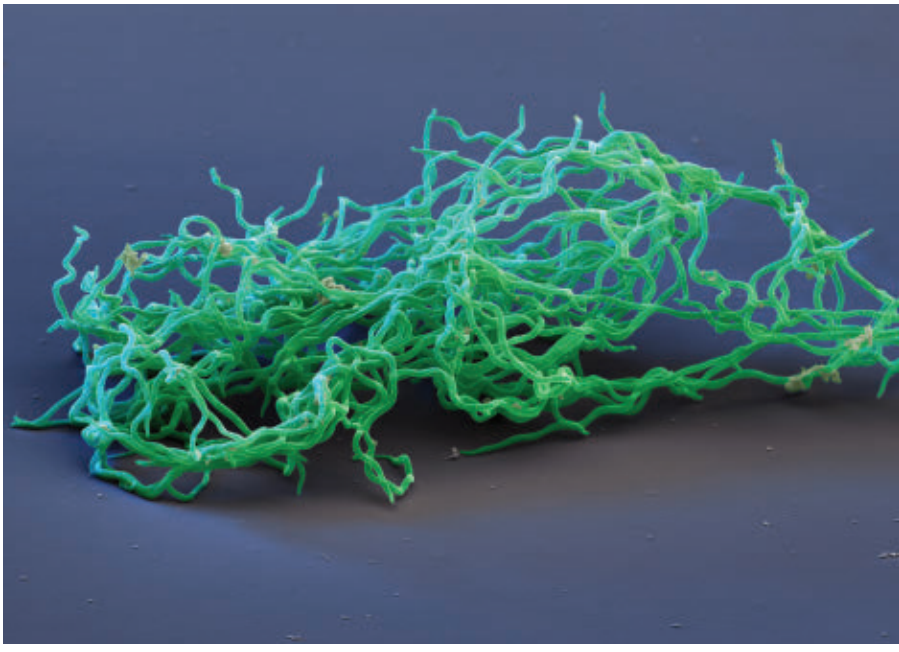
As many as 2 million Americans in 2020 will experience treatment failure, according to data published online in April in *BMC Public Health* from researchers at Brown University and the nonprofit Global Lyme Alliance in Stamford, Conn. These patients "resort to unconventional treatments and therapies. It is understandable," Chiu says. "We need objective testing to be able to document response to therapy."

Another problem impeding diagnosis and treatment is that ticks carry all kinds of bacteria. While Lyme is the most common tickborne infection, there are others, and they don't all respond to the same medicine.

"In places like Long Island, up to 45 percent of adult deer ticks are infected with multiple pathogens," says Rafal Tokarz, a microbiologist at Columbia University's Mailman School of Public Health. To address the variability of tickborne infections and be able to treat the correct disease, Tokarz and colleagues developed a prototype test to analyze a sample of blood for eight different infections simultaneously. The approach is still based on antibodies, like the current tests, but the goal is to have a more accurate product that works sooner after infection.

The researchers described the test, which they call the tickborne disease Serochip, in February 2018 in *Scientific Reports*. It looks for about 170,000 total protein fragments from eight infections, including some specific for each one.

Using the test on 150 samples from patients with confirmed Lyme disease or other tick-related infections, the chip successfully picked up all confirmed Lyme cases, plus some that had been missed by conventional testing. (It also picked up other missed infections.) Tokarz's team hopes to request approval by the U.S. Food and Drug Administration in the next two years.



EYE OF SCIENCE/SCIENCE SOURCE

The bacterium *Borrelia burgdorferi* (shown in a colorized micrograph) is carried by certain ticks and causes Lyme disease.

Testing to a T

Like today's standard two-part Lyme test, the Columbia-led team's approach depends on the activity of B cells, the white blood cells that produce antibodies against Lyme bacteria. These antibodies remain in the bloodstream for months or years, even after the bacteria have disappeared. So a positive test can remain positive long after the infection is gone. When a person is still feeling sick after treatment, the test can't tell if the old infection is hanging on, or if the person has a new Lyme infection or something else.

But the body has another type of immune response, orchestrated by T cells, which produce chemicals that recruit other cells in the immune system to fight an infection. One of these chemicals is interferon gamma. Arnaboldi, of New York Medical College, is working on a test that uses interferon gamma to detect an active Lyme infection. By not relying on antibodies, he hopes the method will distinguish an ongoing infection from one that's already been taken care of.

"When the infection has cleared, the T cell response decreases. The cells ... go quiet," he says. Arnaboldi and collaborators have determined which particular collection of proteins from Lyme-causing bacteria are recognized by activated T cells during an ongoing infection. The researchers mix these bacterial proteins with a sample of the patient's blood. The next day, the team checks for interferon gamma production.

If the person isn't fighting an ongoing infection, interferon gamma levels should remain

One potential test for active infection

1. Blood is collected from a patient and mixed with peptides from *B. burgdorferi*.

2. Tubes are incubated at 37° Celsius for 16 to 20 hours, and then plasma is separated from blood cells.

3. The plasma is put into a plate of 96 wells containing antibodies specific to interferon gamma, which T cells produce during an active Lyme disease infection.

4. If the plasma contains interferon gamma, the plasma will change color. Deeper color means more interferon gamma. Color above a certain threshold indicates that Lyme disease is present.

relatively stable because there are few activated T cells in the blood sample to produce the chemical. But if interferon gamma rises overnight, T cells are probably engaged and fighting.

Arnaboldi and colleagues at Gundersen Health System based in La Crosse, Wis., Biopeptides Corp. in East Setauket, N.Y., and Qiagen described tests on 29 Lyme patients before antibiotic treatment and two months after in 2016 in *Clinical Infectious Diseases*.

Interferon gamma was detected in 69 percent of patients before treatment; only 20 percent had detectable interferon gamma after treatment. In October 2018 in San Francisco, at the IDWeek research meeting, Arnaboldi and colleagues described a follow-up study: Twenty-two children with symptoms of Lyme were compared with seven children who were either healthy or had other infections. The test was more accurate in diagnosing Lyme disease than the current two-step test, with 78 percent sensitivity compared with 59 percent. In other words, the new test missed 22 percent of people who were infected — better than the 41 percent missed by the standard test.

Raymond Dattwyler, a collaborator on the study and an immunologist at New York Medical College, says that the T cell test also appears much less likely to say an uninfected person has Lyme than current tests, which can have a false-positive rate of about 25 percent, though the range varies widely. "We tested a few thousand people in Australia, where Lyme doesn't exist," he says, and found no false positives.

Go direct

A host of other diagnostic approaches are in testing, some using genome-sequencing technology, that may one day allow practical, direct detection of the Lyme bacteria, even with their faint presence in the bloodstream and tissues. The March review in *Clinical Infectious Diseases* — generated by a meeting of government, academic and industry experts at Cold Spring Harbor Laboratory in New York — noted that methods being developed could find tiny amounts of the bacterium's signature genetic material. "The good news is the technology is there. The knowledge is there. It's just a matter of putting them together," says Steven Schutzer, a meeting organizer and an immunologist at Rutgers New Jersey Medical School in Newark.

While promising, new direct blood tests must demonstrate that they offer improvements over the standard test in a doctor's office, says Petersen, of the CDC. "That's the challenge," she says. "You need to show the performance is equivalent or better. Tests haven't gotten to that stage yet."

Meanwhile, companies have introduced improvements of the old approach but with new technology. One product from Bio-Rad Laboratories in Hercules, Calif., which received FDA approval in March, detected 33 of 39 acute infections.

For patients, progress cannot come fast enough. Better diagnosis "is the No. 1 issue," says Patricia Smith, president of the Lyme Disease Association in Jackson, N.J., a patient advocacy group. Improved tests "would go a long way to solving a lot of the problems that Lyme patients have," she says, including an inability to get a diagnosis and treatment, difficulties with insurance reimbursement and feeling like their disease isn't being taken seriously.

Rachel Straub knows all those challenges well. After years of cycling on and off of antibiotics, along with a host of herbal and other alternative treatments, her recovery continues. She became well enough to finish her weight training book in 2016. She returned to the gym herself a year later and resumed her graduate studies in August 2017. "I'm hoping within six to 12 months I'll be a fully functional person," she says, describing her health as a work in progress.

While no one can say for certain if antibiotics in the summer of 2005 would have saved Straub more than a decade of struggle, she wishes she'd had the opportunity to find out. "If you catch Lyme early, it's simple," she says. "If we had a better diagnostic test, people wouldn't have to deal with all this." ■

Explore more

■ Steven E. Schutzer *et al*. "Direct diagnostic tests for Lyme disease." *Clinical Infectious Diseases*. March 15, 2019.

GEOLOGIC ROAD TRIP OF THE MONTH

FALL CREEK GORGE NATURAL PRESERVE

About 4 miles northwest of Williamsport in Warren County, a series of deeply carved bedrock depressions send water swirling down a narrow canyon at Fall Creek Gorge. Nicknamed the Potholes, this scenic nature preserve is known for the semicircular depressions that line the streambed. Rivulets of clear water rush over Pennsylvanian-age bedrock to form one of the most interesting areas in the Iroquois Till Plain.

After glacial ice retreated at the end of the Pleistocene Epoch, new drainage patterns collected to form Fall Creek. Meltwater quickly cut through sand, gravel, and till to expose sandstone from the Mansfield Formation, and the rapidly flowing waters abraded the sand, deepening the channel. Fall Creek became entrenched, or trapped, in the freshly carved gorge as it flowed east toward Big Pine Creek and the Wabash River. Smooth, bowl-shaped holes, called potholes, formed when swirling eddies of water carrying loose rocks ground into the streambed. The potholes at Fall Creek are exceptionally large for the size of the modern stream, reaching up to 5 feet in depth and 20 feet in diameter, because the stream volume was much larger during the ice age.

Vertical moss-covered exposures of sandstone from the Mansfield Formation loom over Fall Creek Gorge. —Courtesy of Lee Mandrell, Leman's Studios

Swirling currents of water grind loose rocks into the underlying streambed to form deep circular depressions called potholes.

The best time to visit Fall Creek Gorge is in the spring and fall, when abundant water flows over the streambed. Visitation is high during the summer months, and the trail can be difficult to access after heavy rains. To see the potholes, take US 41 north from Williamsport and turn north on Potholes Road (N 025 E). A small parking lot is located about 1.5 miles from US 41 but is limited to seven cars, so arrive early to secure a spot. Follow the short wooded path and climb the stairs down to the south branch of Fall Creek. When you reach exposed bedrock, carefully cross over the slotted tributary channel and look upstream to see the potholes filled with swirling water. A moderate 1.1-mile-long trail follows a flat-topped ridge on the southern rim of Fall Creek and offers scenic overlooks of the gorge and deep pothole pools below. A small waterfall, located at the western terminus of the trail, cascades over a sandstone ledge on its descent through the serene, water-polished gorge.

Slime
Ruth Kassinger
HOUGHTON MIFFLIN HARCOURT, $26

BOOKSHELF

Algae deserve your attention

A slew of popular-science books have set out to convince readers that some overlooked, obscure or generally disdained category of thing is actually wildly important, whether it's salt, garbage or beavers (*SN: 8/4/18, p. 28*). *Slime*, all about algae, is one of those books.

If you're skeptical that algae can sustain such an argument, you'll be surprised. Science writer Ruth Kassinger, an author of two books about plants, has found in algae an undervalued topic truly worthy of closer attention. These slimy organisms have shaped Earth for billions of years and continue to float into and out of our lives in myriad ways. Kassinger visits farmers, foodies, factories and fuel producers that are all dependent on algae. She weaves their stories into a picture of how algae serve not only as a base in the ocean's food chain, but also as a rich source of useful molecules that people have only begun to harvest.

As for what precisely algae are, though, that's a bit more difficult to say. While the word may conjure up a uniform film of bright green pond scum, the term has encompassed organisms ranging from cyanobacteria (once known as blue-green algae but now considered bacteria) and microalgae (in a rainbow of colors and more than 50,000 species) to seaweed that can tower as tall as a giant sequoia. Once classified as plants, algae are now known to be a grab bag of species defined as much by what they are not as by what they are. They're not a true taxonomic group, like cats or fungi; they have no one common ancestor. Algae can't even be defined as photosynthetic, since some have lost that ability.

It's this diversity that makes algae so important. Kassinger begins her book with the story of cyanobacteria, bacteria that around 3.7 billion years ago were the first to harness the sun's energy using a new form of photosynthesis. This radical invention added oxygen to Earth's atmosphere and allowed life to proliferate. From there, Kassinger traces the evolution of multicellular life and the spread of algae onto land, where they partnered with fungi to form lichens. She shows how algae's diversification in the sea led to today's phytoplankton, corals and seaweed.

Kassinger hits her stride when she takes readers on a tour of algae-related sites around the world. In a section on algae as food, she meets farmers who harvest wild seaweed and a restauranteur who keeps alive the Welsh tradition of laverbread, a squishy green seaweed spread. She also introduces entrepreneurs taking a more high-tech approach to seaweed aquaculture. Next, she launches into the world of algae-derived products, learning how algae are transformed into fertilizers, food additives and even polymers that go into shoes.

Algae are a diverse group of organisms. Here, a type of green algae is shown under a microscope.

And then there is algae's complex role in our warming climate. Kassinger visits companies that have bioengineered algae to produce biofuels that one day may replace fossil fuels. She goes scuba diving to learn what's killing the algal symbionts of coral, and what efforts might save them. Finally, she explores algae's potential role in drawing down greenhouse gas levels. In the end, Kassinger has us rooting for pond scum — it might just save us yet.

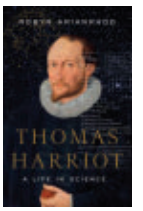
— Erika Engelhaupt

BOOKSHELF

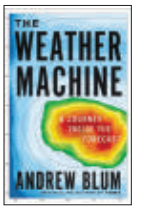
Gravity's Century
Ron Cowen
A former *Science News* reporter guides readers through a brief history of the last 100 years of efforts to test Einstein's general theory of relativity. *Harvard Univ., $26.95*

The Age of Living Machines
Susan Hockfield
Discoveries in biology and engineering will converge to spur the next technology revolution, leading to inventions like cancer-detecting nanoparticles, a former MIT president predicts. *W.W. Norton & Co., $26.95*

Supernavigators
David Barrie
Explore the many ways that dung beetles, humpback whales and other creatures know how to make their journeys around the world. *The Experiment, $25.95*



Thomas Harriot
Robyn Arianrhod
This biography honors the groundbreaking scientific accomplishments of a nearly forgotten Elizabethan navigator, astronomer and linguist. *Oxford Univ., $29.95*



The Weather Machine
Andrew Blum
A journalist offers a look at how a global network of atmospheric scientists coordinates to forecast the weather. *Ecco, $25.99*

BUCCANEERSHIP/ISTOCK/GETTY IMAGES PLUS

Top winners (from left to right) Shriya Reddy, Allison Jia, Krithik Ramesh and Rachel Seevers pose with their awards after the Intel ISEF 2019 competition.

Congratulations to Intel ISEF 2019 winners!

The Intel International Science and Engineering Fair, a program of Society for Science & the Public, is the world's largest international pre-college science and engineering competition. In May, more than 1,800 students from 80 countries, regions and territories gathered in Phoenix to compete for more than $5 million in awards and scholarships. This was the largest fair ever hosted by the Society.

KRITHIK RAMESH, 16, of Greenwood Village, Colo., was awarded the first place $75,000 Gordon E. Moore Award for developing a machine learning technology for orthopedic surgeons. The system helps these surgeons achieve greater accuracy for screw placement during spinal surgery.

ALLISON JIA, 17, of San Jose, Calif., received a $50,000 Intel Foundation Young Scientist Award for investigating toxic tau protein aggregates, which spread in neurons in the human brain and are associated with neurodegenerative diseases such as Alzheimer's.

RACHEL SEEVERS, 17, of Lexington, Ky., also received a $50,000 Intel Foundation Young Scientist Award for designing, building and testing a rigid, energy-efficient prototype of an underwater propulsion device that mimics the way jellyfish move through the water. This device could allow for greater access to the world's unexplored oceans.

SHRIYA REDDY, 15, of Northville, Mich., received the newly announced $10,000 Craig R. Barrett Award for Innovation, funded through the Society, for creating a novel, noninvasive approach for rapidly diagnosing melanoma lesions.

In addition to the top winners, more than 600 finalists received awards and prizes for their innovative research, including 22 "Best of Category" winners, who each received a $5,000 prize in addition to a $3,000 first place award for their category. The Intel Foundation also awarded a $1,000 grant to each winner's school and to the affiliated fair the student represents.

APRIL 27, 2019

Black hole bonanza

The Event Horizon Telescope captured the first image of a black hole (shown on the cover of Science News *at left). Data from the telescope array revealed that the behemoth, which resides at the center of the galaxy M87, is about 38 billion kilometers across and about 6.5 billion solar masses,* ***Lisa Grossman*** *and* ***Emily Conover*** *reported in "First picture of a black hole wows" (*SN: 4/27/19, p. 6*).*

Those measurements astounded reader **Eric Johnston**. After doing his own calculations, he wondered how a black hole that is larger and more massive than the sun could also have a fraction of the sun's density.

"This is a really interesting feature of black holes," **Conover** says. The more mass they have, the less dense they are. That's because the radius of a black hole's event horizon increases proportionally as mass increases, whereas the black hole's volume increases much faster. So the more massive the black hole, the smaller the ratio of mass to volume and the smaller the density. "In fact, the density of M87's black hole is less than the density of air at sea level!" **Conover** says.

Eyes on the sky

In 2017, telescopes around the world worked together like one giant radio dish to capture the image of M87's supermassive black hole, ***Maria Temming*** *reported in "How to take a picture of a black hole" (*SN: 4/27/19, p. 7*).*

Reader **Yancy Meyer** wondered how the observatory at the South Pole was used in the telescope network if it cannot actually see M87. "I would think all of the telescopes would need to see the target object," **Meyer** wrote.

"The South Pole observatory didn't contribute directly to observations of M87 because that galaxy does not rise above the horizon at the South Pole," **Temming** says. But the observatory did help monitor another supermassive black hole powering the quasar 3C 279. That helped scientists confirm the telescope network's performance when it viewed M87's black hole. The observatory also spotted Sagittarius A*, the black hole at the center of the Milky Way, which scientists still hope to image with the data collected from the 2017 observing run and future runs.

Fungal killer

Researchers estimate that a chytrid fungus has caused population declines in at least 500 amphibian species with 90 presumed extinctions, ***Kathleen O'Neil*** *reported in "Chytrid drives frog deaths globally" (*SN: 4/27/19, p. 5*). The pathogen can kill its host within a few weeks.*

"Killing your host is not a good strategy," online reader **Jan Steinman** wrote. If the fungus can kill so quickly, "why has it not died out as well?" **Steinman** asked. "Does it have some other reservoir species that can tolerate it without dying?"

Yes, some amphibians that become infected with *Batrachochytrium dendrobatidis*, or *Bd*, don't die. Those animals "are key in maintaining chytrid fungus and preventing it from burning out," says ecologist **Benjamin Scheele** of the Australian National University in Canberra. Lab tests show that these lurking infections can remain a risk for a long time.

Steinman also wondered if the pandemic could be stemmed by treating the reservoir species.

The fungus can infect so many kinds of amphibians that **Scheele** doesn't have much hope for finding one remedy for all creatures at risk. He predicts that researchers will need to explore a wide spectrum of options from high-tech genetic manipulations to simple protection from reservoir hosts through environmental refuges. And for conservationists, watching out for *Bd* lurking in reservoir species will be vital.

Correction

In "Bennu spits streams of dust into space" (*SN: 4/13/19, p. 10*), the credit for images taken by the OSIRIS-REx spacecraft of the asteroid Bennu is incorrect. The images should have been credited to D.S. Lauretta *et al*/ *Nature Astronomy* 2019.

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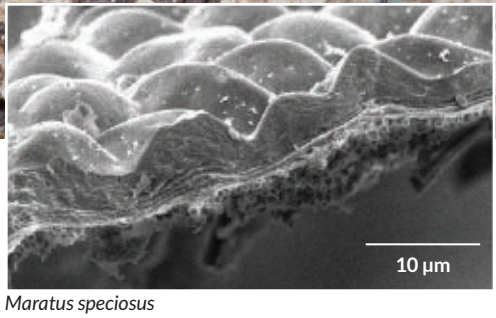
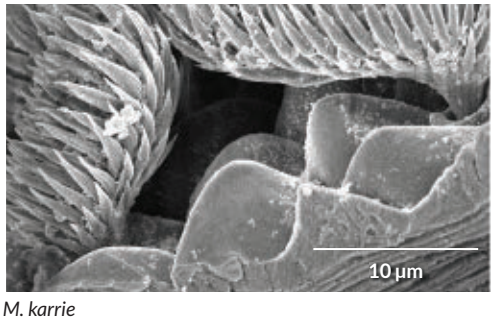
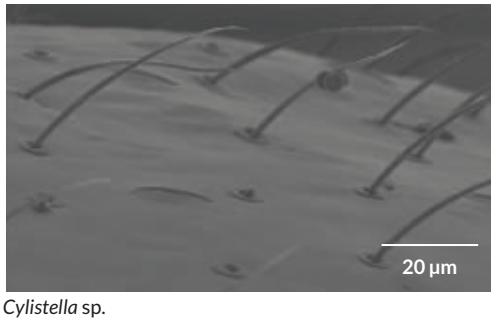


Maratus speciosus



M. karrie



Cylistella sp.

‘Superblack’ spots make spiders glow

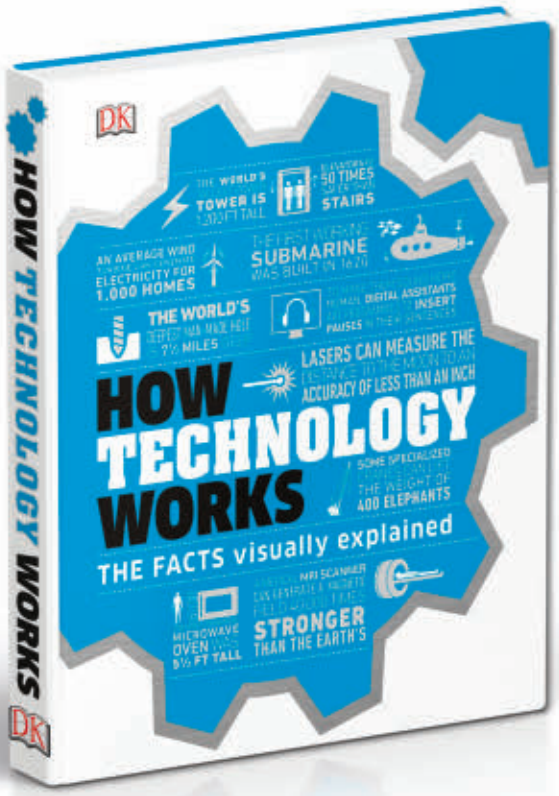
Male peacock spiders know how to put on a show for potential mates, with dancing and optical trickery. By manipulating light, microscopic bumps on the arachnids’ exoskeletons make some velvety black areas look darker than spiders’ typical black shades. This architecture reflects less than 0.5 percent of light, researchers report in the May 1 *Proceedings of the Royal Society B*.

“Superblack” spots, found near vivid colors on the spiders’ abdomens, create an “optical illusion that the colors are so bright ... they’re practically glowing,” says evolutionary biologist Dakota McCoy of Harvard University.

Male peacock spiders swing and shake their brilliantly colored abdomens during elaborate mating displays. Pigments produce the red and yellow hues, but blues and purples come from light interacting with hairlike scales (*SN: 9/17/16, p. 32*). Black areas on the spiders contain pigment, too. But scanning electron microscopy revealed a landscape of tiny bumps in superblack patches on two peacock spider species, *Maratus speciosus* (above and top image at left) and *M. karrie* (left, middle). In contrast, all-black, closely related *Cylistella* spiders have a relatively smooth texture (left, bottom).

Using simulations, McCoy and colleagues showed that the bumps make dark spots appear even darker in several ways. Curved surfaces bounce light around so less is reflected, and diffract light in a way that it evades the field of view of an onlooking female. And the bumps are microlenses, angling entering light so that it spends more time interacting with light-absorbing black melanin pigment than it would if the surface were flat. In addition to bumps, *M. karrie* sports spiky scales that also limit reflection by scattering and absorbing light. — *Carolyn Wilke*

TOP: JÜRGEN C. OTTO; OTHERS: D.E. MCCOY *ET AL/PROCEEDINGS OF THE ROYAL SOCIETY B* 2019



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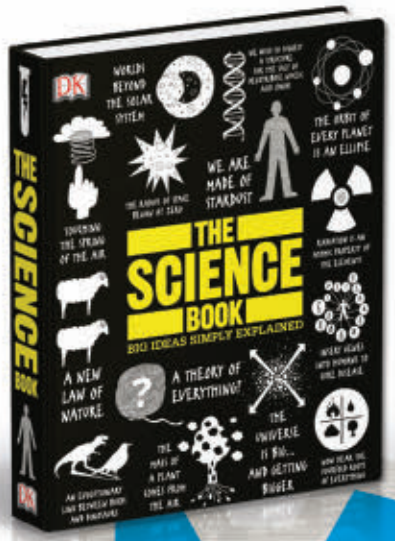

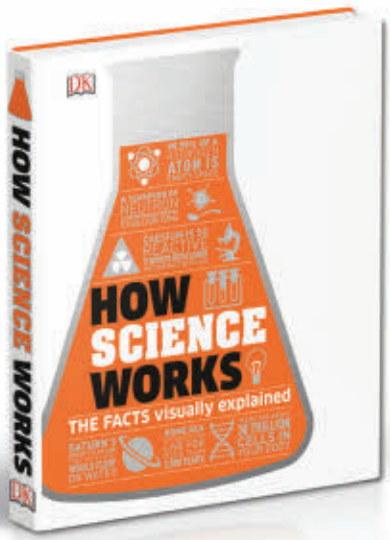

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