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JUNE 24, 2017

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COVER STORY Despite zaps from flares and challenges holding onto water, planets orbiting dim stars called M dwarfs might offer life-friendly environments. *By Christopher Crockett*

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As bad bacteria increase their ability to resist antibiotics, some scientists have considered enlisting unexpected allies — other bacteria that prey on those that cause disease. *By Elizabeth S. Eaton*

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COVER The ultracool dwarf star TRAPPIST-1 is seen from the surface of one of its seven planets (illustrated). *N. Bartmann/ESO, spaceengine.org*

Launch your imagination with *Science News* stories

Imagine for a moment that you lived on another planet. Not Tatooine, Trantor or another fictional orb, but a real-deal planet circling a star somewhere in our real-deal galaxy. What would your world look like? Would there be a rocky surface? An atmosphere? How long would a day last? How about a year? What special physiology might you need to survive there? There's no single scenario, of course. Starting with some basic facts, you can speculate in all sorts of surprising directions. That's the fun of the exercise.

Over the last quarter century or so, astronomers have confirmed more than 3,600 exoplanets — that's 3,600-plus worlds in addition to the planets, moons and other heavenly bodies known in our own solar system. People have long imagined what it would be like to live on Mars, and bold thinkers have dared to envision an existence on, say, Jupiter (see Pages 14 and 32 for the latest details about that gas giant). Today there are many more possibilities, including planets orbiting dim red stars very different from our sun. On Page 18, Christopher Crockett describes the hurdles life might face in evolving and surviving near these cool stars. On planets orbiting Proxima Centauri, TRAPPIST-1 and other M dwarfs, water could be extremely sparse, energetic flares might regularly singe the surface and you might live always in sun or forever in darkness.

Reading about these worlds, I'd say, is better than fiction — as is a lot of what *Science News* covers. You don't need a novel or a movie to escape into what feels like another reality. Just flip through these pages. The stories will take you to other worlds, as well as inner, hidden ones. On Page 22, former *Science News* intern Elizabeth S. Eaton writes about the bacteria that infect our bodies and the problem of antibiotic resistance. Picturing these invisible, single-celled organisms wreaking havoc in the body, unchecked by our best medicines, gives me goose bumps. Eaton's story is about the battle that would ensue if predatory bacteria are sent in to hunt down and kill these bad guys, as some researchers have proposed. One researcher likens the bacteria to the antagonists in the *Alien* films. There's true cinematic potential.

And it doesn't end there. On Page 9, Bruce Bower takes readers into the past, to the roots of the human evolutionary tree. Most scientists think Africa was the birthplace of hominids, but new research suggests it could have been Europe. And on Page 15, Susan Milius offers an opportunity to consider what it might be like to live in another type of body — a flamingo's. The birds have an off-kilter shape, with ankles where we'd expect knees. For flamingos, Milius reports, standing on one leg might be more stable than standing on two. After reading the story, I couldn't help but attempt to balance on just my right foot, in hopes of getting a handle on human-flamingo differences. (It was an unsuccessful 20 seconds. Thank goodness my office door was closed.)

Every issue of *Science News* includes similar inspiration. There's serious stuff to be sure, but there are plenty of chances to ponder the strangeness of reality — and to stretch it. After thinking about living on Proxima b or being a wading bird, consider being a wading bird on Proxima b. For fuel to help your imagination run, you've come to the right place. — *Elizabeth Quill, Acting Editor in Chief*

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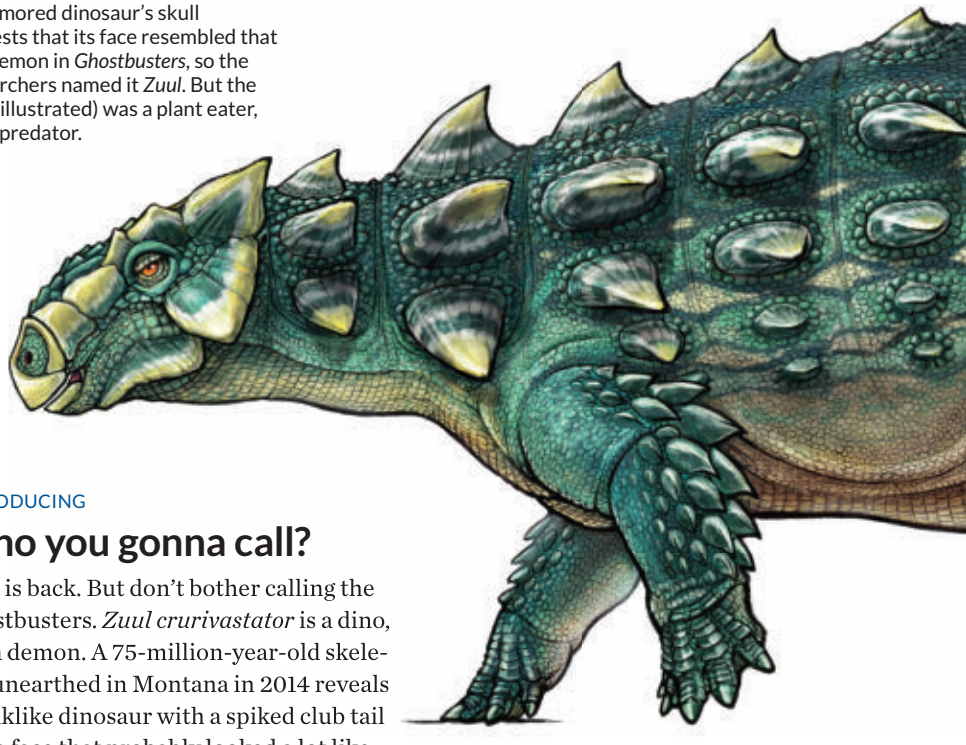
Excerpt from the June 17, 1967 issue of *Science News*

50 YEARS AGO

Light helps premature babies

Premature babies, who often develop jaundice because of an excess of bile pigment called bilirubin, can be saved from this dangerous condition by the use of fluorescent light.... The light alters the chemistry of bilirubin so it can be excreted with the bile. Exchange transfusion is the usual treatment when jaundice occurs but this drastic procedure carries a ... risk of death.

UPDATE: Preemies aren't the only babies at risk for jaundice. About 60 percent of full-term infants also develop the condition. Severe cases can cause brain damage if untreated. But today, some researchers warn that light therapy, now widely used, may not work for babies whose bilirubin levels are very high. And studies have begun to suggest a link between the therapy and certain childhood cancers (*SN Online: 1/30/15*). Though the risk of developing cancer is small, doctors should be cautious about prescribing the treatment, researchers wrote in 2016 in *Pediatrics*.



An armored dinosaur's skull suggests that its face resembled that of a demon in *Ghostbusters*, so the researchers named it *Zuul*. But the dino (illustrated) was a plant eater, not a predator.

INTRODUCING

Who you gonna call?

Zuul is back. But don't bother calling the Ghostbusters. *Zuul crurivastator* is a dino, not a demon. A 75-million-year-old skeleton unearthed in Montana in 2014 reveals a tanklike dinosaur with a spiked club tail and a face that probably looked a lot like its cinematic namesake.

The find is the most complete fossil of an ankylosaur, a type of armored dinosaur, found in North America, researchers report May 10 in *Royal Society Open Science*. It includes a complete skull and tail club, plus some preserved soft tissue, says study coauthor Victoria Arbour, a paleobiologist at the Royal Ontario Museum in Toronto. "It really gives us a good idea of what these animals looked like."

The bones reveal that *Z. crurivastator* had spikes running all the way down its tail, not just on the club itself. That arrangement means the weaponry was more than just a "massive sledgehammer," Arbour says. The club was a formidable weapon. The term *crurivastator* comes from the Latin for "shin destroyer."

Zuul crurivastator's spiky tail ended in a club (fossil shown) and could have packed a powerful wallop.

Arbour previously created mathematical models to calculate the force with which similar ankylosaurs might have swung their tails. These appendages provided a winning combination: good at absorbing impacts and able to smack an opponent hard enough to hurt, she says. Despite their armor and fearsome tail, ankylosaurs were plant eaters. So they probably used their tails to smack predators or compete with other ankylosaurs.

Arbour and museum colleague David Evans plan to investigate the thin sheet of fingernail-like material covering the bony plates on the tail, along with other details of the fossil that are typically lost in such old specimens. The rare, preserved soft tissue might even let scientists extract ancient proteins, Arbour says, providing insight into how these building blocks of life have changed since the days of dinos.

Having all this material in hand, she says, "kind of pushes the envelope about what we can identify in the fossil record." — *Laurel Hamers*

Replacing part of a ladybug's spotted wing case with transparent resin reveals wing-folding.

TEASER

Ladybugs are skilled packers

Those who struggle to fit a vacation wardrobe into a carry-on might learn from ladybugs. The flying beetles neatly fold up their wings when they land, stashing the delicate appendages underneath their protective red and black forewings.

To learn how one species of ladybug (*Coccinella septempunctata*) achieves such efficient packing, scientists needed to see under the bug's spotted exterior. So a team from Japan replaced part of a ladybug's forewing with a transparent bit of resin, to get a first-of-its-kind glimpse of the folding.

Slow-motion video of the altered ladybug showed that the insect makes a complex, origami-like series of folds to stash its wings, the scientists report in the May 30 *Proceedings of the National Academy of Sciences*. CT scans helped explain how the wings can be both strong enough to hold the insects aloft and easily foldable into a tiny package. The shape of the wing veins allows them to flex like a metal tape measure, making the wings stiff but bendable. Lessons learned from the wings could be applied to new technologies, including foldable aircraft wings or solar panels that unfurl from a spacecraft. — *Emily Conover*

THE -EST

A different kind of camera captures speedy actions

A new video camera, the fastest by far, has set a staggering speed record. It films 5 trillion frames (equivalent to 5 trillion still images) every second, blowing away the 100,000 frames per second of high-speed commercial cameras. The device could offer a peek at never-before-seen phenomena, such as the blazingly fast chemical reactions that drive explosions or combustion.

Researchers at Lund University in Sweden demonstrated the camera's speediness by filming particles of light traveling a distance as thin as a sheet of paper, then slowing down the trillionth-of-a-second journey to watch it.

The gadget works by repeatedly flashing a laser at a subject, with each flash getting a unique code. The subject reflects the flashes, and those reflections are combined into a single image. Then, an algorithm separates the image into a video sequence based on the codes, the scientists report March 15 in *Light: Science & Applications*. A German company is developing the camera for laboratory use. It could be ready in about two years. — *Ashley Yeager*

SCIENCE STATS

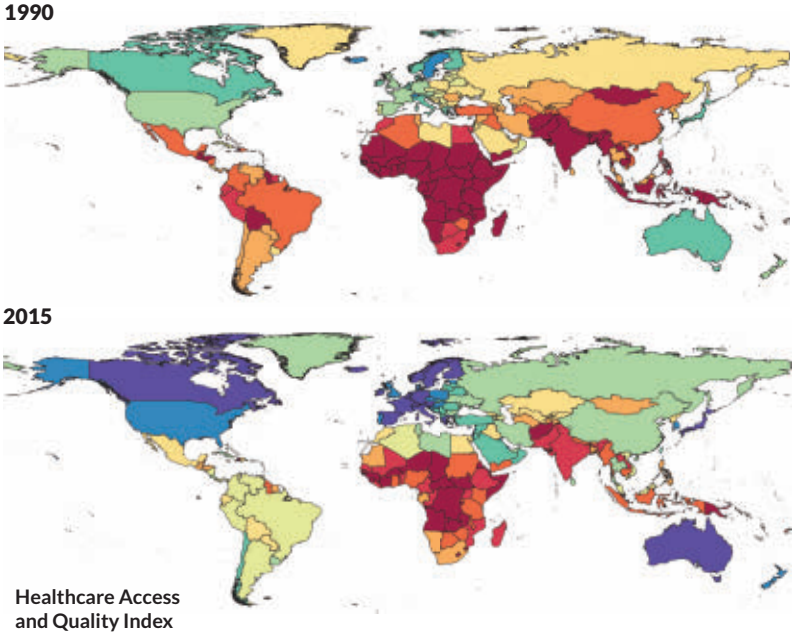
Access to quality health care has improved in most places

Health care quality and availability improved globally from 1990 to 2015, but the gap between the haves and the have-nots widened in those 25 years, researchers report online May 18 in *Lancet*.

As an approximate measure of access to quality health care, an international team of researchers analyzed mortality rates for 32 diseases and injuries that are typically not fatal when effective medical care is available. The team summarized the data on a scale from zero to 100, known as the Healthcare Access and Quality Index, for 195 countries and territories.

Canada, Australia, Japan and much of Europe had the highest scores (purple in maps at right) in 2015, while Afghanistan, Haiti, Papua New Guinea and some African countries, including the Democratic Republic of Congo, Niger and Zambia, had the lowest (red). The countries with the greatest improvement since 1990 include South Korea, Peru and China.

The widening gap in access suggests that health care inequalities due to geography may be on the rise, the authors say. — *Aimee Cunningham*



Cooler colors show countries and territories with higher scores on health care access and quality; hotter colors show those with lower scores. Overall, global scores improved between 1990 and 2015.

FROM TOP: KAZUYA SAITO 2017; R.M. BARBER ET AL/LANCET 2017

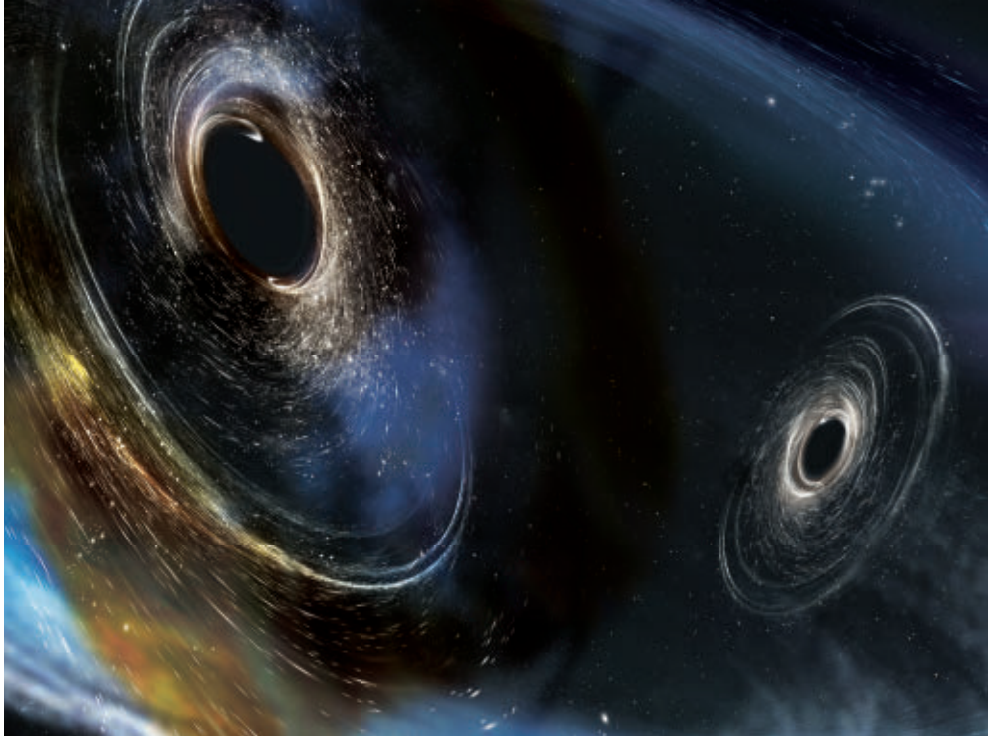
Watch a video of ladybugs folding their wings at **bit.ly/SN_ladybugwings**

ATOM & COSMOS

More gravitational waves detected

Latest data suggest massive black holes are common

BY EMILY CONOVER



Scientists have made a third detection of gravitational waves. A pair of black holes (shown here in an artist's illustration) fused into one in a powerful collision about 3 billion light-years from Earth. That smashup churned up ripples in spacetime that were detected by the LIGO experiment.

For a third time, scientists have detected the infinitesimal reverberations of spacetime: gravitational waves.

Two black holes stirred up the spacetime wiggles, orbiting one another and spiraling inward until they fused into one jumbo black hole with a mass about 49 times that of the sun. Ripples from that union, which took place about 3 billion light-years from Earth, zoomed across the cosmos at the speed of light, eventually reaching the Advanced Laser Interferometer Gravitational-Wave Observatory, LIGO, which detected them on January 4.

"These are the most powerful astronomical events witnessed by human beings," Michael Landry, head of LIGO's Hanford, Wash., observatory, said during a news conference May 31 announcing the discovery. As the black holes merged, they converted about two suns' worth of mass into energy, radiated as gravitational waves.

LIGO's two detectors, in Hanford and Livingston, La., each consist of a pair of 4-kilometer-long arms. They act as outrageously oversized rulers to measure the stretching of spacetime caused by gravitational waves. According to Einstein's theory of gravity, the general theory of relativity, massive objects bend the fabric of space and create ripples when they accelerate — for example, when two objects orbit one another. Gravitational ripples are tiny: LIGO is tuned to detect waves that stretch and squeeze the arms by a thousandth of the diameter of a proton. Black hole collisions are one of the few events in the universe that are catastrophic enough to produce spacetime gyrations big enough to detect.

The two black holes that spawned the latest waves were particularly hefty, with masses about 31 and 19 times that of the sun, scientists report online June 1 in *Physical Review Letters*. LIGO's first detection, announced in February 2016, came from an even bigger duo: 36 and 29 times the mass of the sun (*SN: 3/5/16, p. 6*). Astrophysicists don't fully understand how such big black holes could have formed. But now, "it seems that these are not so uncommon, so clearly there's a way to produce these massive black holes," says physicist Clifford Will of the University of Florida in Gainesville. LIGO's second detection featured two smaller black holes, 14 and eight times the mass of the sun (*SN: 7/9/16, p. 8*).

Weighty black holes are difficult to explain, because the stars that collapsed to form them must have been even more massive. Typically, stellar winds steadily blow away mass as a star ages, reducing the mass available to eventually make a black hole. But under certain conditions, those winds might be weak — for example, if the stars contain few elements heavier than helium or have intense magnetic fields (*SN Online: 12/12/16*). The large masses of LIGO's black holes suggest that they formed in such environments.

Scientists also aren't certain how

Sizing up gravitational waves LIGO's three gravitational wave sightings all came from merging black holes. But those mergers varied in mass, distance from Earth and other characteristics. By studying these features, researchers can learn more about how black holes form.

First detection	Second detection	Third detection
Date: September 14, 2015	**Date:** December 26, 2015	**Date:** January 4, 2017
Mass of first black hole: 36.2 solar masses	**Mass of first black hole:** 14.2 solar masses	**Mass of first black hole:** 31.2 solar masses
Mass of second black hole: 29.1 solar masses	**Mass of second black hole:** 7.5 solar masses	**Mass of second black hole:** 19.4 solar masses
Merged mass: 62.3 solar masses	**Merged mass:** 20.8 solar masses	**Merged mass:** 48.7 solar masses
Energy radiated as gravitational waves: 3 solar masses	**Energy radiated as gravitational waves:** 1 solar mass	**Energy radiated as gravitational waves:** 2 solar masses
Distance from Earth: 1.4 billion light-years	**Distance from Earth:** 1.4 billion light-years	**Distance from Earth:** 2.9 billion light-years

AURORE SIMONNET/SONOMA STATE, MIT, CALTECH, LIGO

black holes partner up. One theory is that two neighboring stars each explode and produce two black holes, which then spiral inward. Another is that black holes find one another within a dense cluster of stars, as massive black holes sink to the center of the clump (*SN Online: 6/19/16*).

The new detection provides some support for the star cluster theory: The pattern of gravitational waves LIGO observed hints that one of the black holes might have been spinning in the opposite direction from its orbit. Like a cosmic do-si-do, each black hole in a pair twirls on its own axis as it spirals inward. Black holes that pair up as stars are likely to have their spins aligned with their orbits. But if the black holes instead find one another in the chaos of a star cluster, they could spin any which way. The potentially misaligned black hole LIGO observed somewhat favors the star cluster scenario. The measurement is "suggestive, but it's not definite," says astrophysicist Avi Loeb of Harvard University.

Scientists will need more data to sort out how black hole duos form, says physicist Emanuele Berti of the University of Mississippi in Oxford. "Probably the truth is somewhere in between." Various processes could contribute to the formation of black hole pairs, Berti says.

As with previous detections of gravitational waves, the scientists used their measurements to test general relativity. For example, while general relativity predicts that gravitational waves travel at the speed of light, some alternative theories of gravity predict that gravitational waves of different energies travel at different speeds. LIGO scientists found no evidence of such an effect, vindicating Einstein once again.

Now, with three black hole mergers under their belts, scientists are looking forward to a future in which gravitational wave detections become routine. The more gravitational waves scientists detect, the better they can test their theories. "There are already surprises that make people stop and revisit some old ideas," Will says. "To me that's very exciting." ■

EARTH & ENVIRONMENT

Deep heat intensified mega-quake

Dried-out sediment magnified 2004 temblor's destruction

BY LAUREL HAMERS

Chemical transformations in minerals deep beneath the seafloor could explain why Indonesia's 2004 mega-earthquake was unexpectedly destructive, researchers report in the May 26 *Science*.

The magnitude 9.2 quake and the tsunami that it triggered killed more than 250,000 people, flattened villages and swept homes out to sea across Southeast Asia. It was one of the deadliest earthquakes in recorded history.

"It raised a whole bunch of questions, because that wasn't a place in the world where we thought a magnitude 9 earthquake would occur," says Brandon Dugan, a geophysicist at the Colorado School of Mines in Golden.

The thick but stable layer of sediment where tectonic plates meet off the coast of the Indonesian island of Sumatra should have limited the power of an earthquake, seismologists had predicted. But instead, this quake was the third-strongest on record worldwide.

Dugan spent two months aboard a research vessel with about 30 other scientists through the International Ocean Discovery Program. The team drilled down 1,500 meters below the seafloor in two places off Sumatra, extracting narrow cylinders of sediment. This sediment is slowly moving toward the fault where the 2004 quake occurred — a zone where one massive tectonic plate slides over another, pushing that plate downward.

Analyzing how sediment changes with depth can provide a snapshot of the geologic processes at play near the fault zone.

Far beneath the seafloor, the researchers identified a sediment layer where the water had a lower salinity than the water in the sediment above or below. Since seawater seeping into the sediment would be salty, the evidence of freshwater suggests that the water must have instead been released from minerals in the sediment.

For tens of millions of years, Dugan proposes, minerals sat on the seafloor taking in water — baking it into their crystal structure. Then, more sediment settled on top. It got toasty under such a thick blanket of sediment, heating up the minerals beneath. The temperature increase triggered a chemical transformation within the sediment, pushing water out of the mineral crystals and into tiny pores between the grains.

The sediment sampled in this study is still dehydrating. By the time any of it reaches the plate boundary, Dugan says, it'll be buried under kilometers of more sediment and will probably be completely dehydrated.

At first, the liberated water would have softened the material, actually decreasing the risk of a big earthquake by allowing it to absorb more force, Dugan says. As the sediment got closer to the fault over millions of years, though, the water flowed away, leaving it brittle and unstable — the perfect setup for a mega-quake.

The timing of this sediment dehydration process can make or break a quake. Had the sediment near the fault been in a softened state when the quake struck in 2004, the temblor might not have been as deadly, Dugan says. But since enough time had passed for it to become brittle, the tectonic plates were able to rapidly slip past each other for a much greater distance during the quake. That massive movement displaced the seafloor itself, setting a tsunami into motion.

"It's really the tsunamis from these earthquakes that prove to be the deadliest," says Roland Bürgmann, a seismologist at the University of California, Berkeley who wasn't part of the study. And quakes that displace the seafloor are far more likely to trigger tsunamis.

The findings could apply to other faults with similarly thick sediment. But more evidence is needed before applying such analysis to faults beyond this one, Bürgmann says. The Sumatran fault is "only one data point. It doesn't yet make for a pattern." ■

LIFE & EVOLUTION

Wild orangutans set nursing record

Babies can suckle for more than 8 years, tooth tests show

BY SUSAN MILIUS

The supermoms of the mammal world are big, shy redheads. Studying growth layers in orangutan teeth shows that mothers can nurse their youngsters for eight-plus years, a record for wild mammals.

Teeth from a museum specimen of a young Bornean orangutan (*Pongo pygmaeus*) don't show signs of weaning until 8.1 years of age. And a Sumatran orangutan (*P. abelii*) was still nursing during the few months before it was killed at 8.8 years, researchers report May 17 in *Science Advances*.

These tests also show that orangutan youngsters periodically start to taper off their dependence on their mother's milk and then, perhaps if solid food grows scarce, go back to what looks like an all-mom diet. Such nursing cycles aren't known in other wild mammals, says study coauthor Tanya Smith, an evolutionary anthropologist at Griffith University in Nathan, Australia.

By analyzing tooth chemistry, scientists estimated the age of weaning for wild orangutans.

Weaning information for orangutans has been sparse. Field biologists' best efforts to track weaning in Bornean orangutans with known birthdays had pegged 7.5 years as the longest probable nursing time, Smith says. She knows of no such reports for Sumatra's orangutans.

Orangutans don't make weaning easy to detect, says Serge Wich of Liverpool John Moores University in England, who was not involved in the study. He started watching the apes in 1993, and points out that "lactating happens very high up in trees, so we are always under a bit of an awkward angle to observe. Also, they're quite furry." Determining whether an infant is suckling or just cuddling is not an exact science.

For more accurate dating, Smith and colleagues turned to teeth. Primate teeth grow a distinct microscopic layer every day, starting before birth. Babies grow bones and teeth using milk calcium, which moms pull from their own skeletons. A similar element, barium, hitchhikes along and ends up in bones and teeth, too. "Mothers dissolve parts of themselves to feed their children," as Smith puts it. Greater concentrations of barium in a tooth layer mark a time when the tooth was being built up with a greater proportion of mother's milk.

To read the history of mother's milk, Smith and colleagues tracked barium in molars from four immature specimens, two of each orangutan species, which were preserved in museum collections. The teeth came from decades ago when collectors "went around randomly shooting endangered species," Smith says.

Now, Bornean and Sumatran orangutans rank as critically endangered. A fever of logging and oil palm planting is eating away their forests, and the pet trade rewards hunters who shoot a mom to bag a baby to sell. Neither species had lush resources to begin with, as the apes evolved in forests with booms and long busts in food supplies. Prolonged nursing of young may be part of their slow-lane accommodation to uncertainty and scarcity in their environment.

Researchers debate whether some similar uncertainty shaped human evolution. Among apes, the human species evolved a "stretched-out" childhood, but with different pacing from that of orangutans, Smith says. "Studying our cousins puts our own history in context." ■

MATTER & ENERGY

Sci-fi technology could go quantum

In theory, 'matter wave' tractor beam would pull in atoms

BY EMILY CONOVER

The wavelike properties of quantum matter could lead to a scaled-down version of *Star Trek* technology. A new kind of tractor beam could use a beam of particles to reel in atoms or molecules, physicists propose in the May 5 *Physical Review Letters*.

Scientists have created tractor beams using light or sound waves, which can pull small particles a few millimeters or centimeters (*SN: 11/15/14, p. 16*). But "the idea of doing this with matter waves is really groovy," says physicist David Grier of New York University.

Sound or light waves can pull small particles under carefully controlled conditions. For certain types of beams, waves can scatter forward off of a particle, pushing the particle back toward the source of the beam due to the law of conservation of momentum.

"We have used a very similar reasoning here," says study coauthor Andrey Novitsky, a physicist at the Technical University of Denmark in Kongens Lyngby. But rather than light or sound, "we have something more elusive" — matter waves.

In quantum mechanics, particles behave like waves, spread out so that they have no definite position. Quantum waves represent the probability that a particle will be found in a particular spot if its location is measured. Novitsky and colleagues calculated that such matter waves could produce a pulling effect similar to light or sound waves.

Matter wave tractor beams could be made with beams of electrons, Novitsky says. Such beams could provide new ways of manipulating matter on small scales. These tractor beams could be used to separate mixtures of atoms or ions, for example, reeling in one type but not another. ■

TIM LAMAN

Hominid roots may go back to Europe

Graecopithecus' teeth suggest it was member of human family

BY BRUCE BOWER

Europe, not Africa, might have spawned the first members of the human evolutionary family around 7 million years ago, researchers say.

Tooth characteristics of a chimp-sized primate that once lived in southeastern Europe suggest that the primate, known as *Graecopithecus*, may have been a hominid, not an ape as many researchers assume. One tooth in particular, the second lower premolar, is telling. Its two roots are partially fused, a trait characteristic of early hominids but not ancient apes, a team led by geoscientist Jochen Fuss of the University of Tübingen in Germany reports May 22 in *PLOS ONE*.

> "Europe is as likely a place of [hominid] origins, and even of the last common ancestor of chimpanzees and humans, as Africa."
>
> DAVID BEGUN

Scientists suspect the first hominids appeared sometime between 8 million and 6 million years ago. New age estimates for previously discovered fossils position *Graecopithecus* as potentially the earliest known hominid. A lower jaw, found in Athens with most teeth still in their sockets, dates to around 7.175 million years ago, a group led by Tübingen geoscientist Madelaine Böhme reports May 22 in a separate paper in *PLOS ONE*. An isolated tooth from Bulgaria, an upper second premolar, dates to about 7.24 million years ago, the scientists say.

Armed with only jaw and tooth fossils, the teams don't have a slam-dunk case for pegging *Graecopithecus* as a hominid. Although sediment analyses date both finds to around the time of hominid origins, it's not known whether this creature regularly walked upright, a signature hominid behavior.

For now, there is no way to know whether *Graecopithecus* was an ape with some hominid-like features or a hominid with some apelike features, says paleoanthropologist Bernard Wood of George Washington University in Washington, D.C. "My guess is the former."

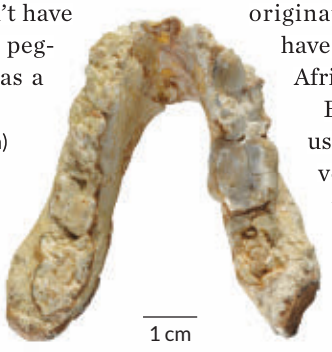
But fossil evidence of hominid origins in Africa is also sparse and controversial (*SN: 4/9/05, p. 227*), says paleoanthropologist David Begun of the University of Toronto, a coauthor of Fuss' study. That debate has focused on fossils from two potential hominid lines dating to about 7 million to 6 million years ago, *Sahelanthropus* and *Orrorin*. "Europe is as likely a place of [hominid] origins, and even of the last common ancestor of chimpanzees and humans, as Africa," he says.

Many mammals, including apes, giraffes, antelopes and hippos, lived in Africa and in Europe's eastern Mediterranean region 9 million to 7 million years ago, Begun says. These creatures probably moved back and forth between continents, he holds, making it difficult to pin down where each line of animals originated. *Graecopithecus* could have evolved in either Europe or Africa, Begun contends.

Begun, Fuss and colleagues used CT scans to produce 3-D versions of *Graecopithecus* teeth, including roots hidden by the jawbone. Among several similarities of the teeth to those of early hominids, partial fusion of the second premolar roots stands out, the researchers say. Previous studies have suggested that genes tightly control the number of premolar roots, meaning that this trait doesn't change much in response to environmental conditions. In that case, root fusion in *Graecopithecus*, as found in later hominids, indicates a direct evolutionary connection, Begun says.

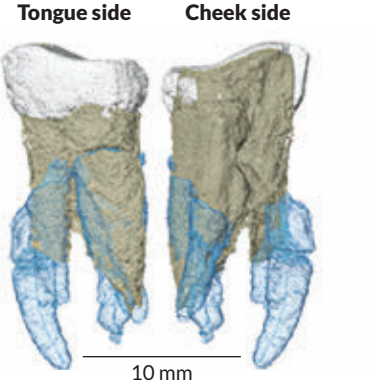
Other researchers take a skeptical view of *Graecopithecus* as a possible hominid. Even among early hominids, the number of premolar roots varies enough to raise serious questions about whether *Graecopithecus* can be classified as a hominid, says paleoanthropologist Yohannes Haile-Selassie of the Cleveland Museum of Natural History. In 1997, a team led by Haile-Selassie discovered remains of a 5.8-million- to 5.6-million-year-old East African hominid, *Ardipithecus kadabba* (*SN: 3/6/04, p. 148*). Haile-Selassie has argued that *Sahelanthropus* and *Orrorin* can be grouped in with *A. kadabba*, making it the oldest known hominid.

A lack of fossils from chimp and gorilla ancestors adds to the difficulty of establishing whether creatures such as *Graecopithecus* and *A. kadabba* are truly hominids, says biological anthropologist Matthew Skinner of the University of Kent in Canterbury, England. Though that leaves *Graecopithecus*' status unresolved, Skinner agrees with Begun that researchers should look for hominid origins in Europe as well as in Africa. ■



Graecopithecus (jaw shown) lived a little over 7 million years ago in southeastern Europe. If it was a hominid, as researchers claim, it would be the earliest known member of the human evolutionary family.

FROM TOP: J. FUSS ET AL/PLOS ONE 2017; W. GERBER/UNIV. OF TÜBINGEN



This reconstruction of a right lower premolar tooth, shown from two angles, is based on CT scans of a *Graecopithecus* jaw. Partial fusion of the tooth's two roots near where they split supports classifying *Graecopithecus* as an early hominid, researchers contend.

GENES & CELLS

Selfish DNA fooled scientists for years

Worm's poison-antidote genes break normal inheritance rules

BY SUSAN MILIUS

A strain of wild Hawaiian worms has helped unmask long-studied genes as just plain selfish. The scammers beat the usual odds of inheritance and spread extra fast by making mother worms poison some of their offspring.

Biologists have for decades discussed how two genes in the familiar lab nematode *Caenorhabditis elegans* might help embryos build their feeding organs. Working with a little-studied wild strain, however, caused a rethink of the genes' supposedly beneficial role "that flipped it on its head," says UCLA geneticist Leonid Kruglyak.

Instead of doing some body sculpting, the gene *sup-35* doses the eggs with a toxin that will kill them after fertilization, two postdocs in Kruglyak's lab discovered. The toxin gene doesn't poison itself out of the gene pool because it's linked to a partner, *pha-1*, that lets embryos manufacture an antidote. Embryos die unless they inherit a copy of the antidote gene in either egg or sperm, and so the poison-antidote duo can spread unusually fast through populations by eliminating worms that don't have it.

Making a mom on occasion poison some of her offspring doesn't benefit her but certainly helps the genes. Thus the long-known *sup-35* and *pha-1* form what's called a selfish genetic element, Kruglyak's team proposes online May 11 in *Science*.

That analysis is "very clearly accurate," says evolutionary geneticist Jack Werren of the University of Rochester in New York. The idea that a gene could behave selfishly, promoting its own spread regardless of its host's interests, was once controversial (*SN: 3/19/16, p. 12*). But as molecular biology techniques have improved, researchers have found more and more examples. Many of the most dramatic forms of selfishness — the murderous cheats — come from bacteria, so Werren welcomes the *C. elegans* scam as a rare case discovered in animals.

> The toxin gene *sup-35* doesn't poison itself out of the gene pool because it's linked to a partner, *pha-1*, that lets embryos manufacture an antidote.

Kruglyak's lab has described an earlier example in *C. elegans*: a gene that doses sperm with a toxin that kills embryos unless an antidote gene rescues them. Finding a second selfish element in the nematode, says Kruglyak, suggests that these bits of DNA may not be as rare in animals as researchers previously thought.

The big community of researchers regularly studying *C. elegans* had missed discovering the selfish role for a simple reason: The main lab strain of nematodes carries the selfish element, explains study coauthor Eyal Ben-David. Whenever the standard strain mates or self-fertilizes (the species has both males and hermaphrodites), all the offspring inherit *sup-35* and *pha-1*. And researchers see no weird die-offs.

In Kruglyak's lab, however, Ben-David and fellow postdoc Alejandro Burga were doing an experiment that required crossing the usual lab nematodes with the DL238 strain from Hawaii. In its natural state, this strain has somehow escaped invasion by the selfish *sup-35/pha-1* pair.

A series of oddities in interbreeding the disparate strains pushed the researchers to reconsider the two genes. For instance, much higher percentages of offspring died in mixed-parent crosses than the routine few percent in same-strain pairings. And when Ben-David and Burga looked at the genes in the Hawaiian strain isolated from the wild, *sup-35* and *pha-1* just weren't there.

Many lab *C. elegans* worms grow a normal body (top) with a wide, inner feeding tube. Without a gene antidote, a worm grows a deformed tube (bottom) and can't pump in food.

That was a shock. Earlier experiments in the lab strain had shown that disabling *pha-1* caused death in offspring — which it certainly does. The feeding tube of the dying embryos was not forming properly, so researchers at first speculated that the gene controlled feeding tube development. Later work suggested a more nuanced role for it, Ben-David says, but the overall hypothesis remained that the genes helped regulate embryo development.

The Hawaiian strain changed that thinking: "How is this wild isolate alive and happy without a gene that's supposed to be essential for development?" Kruglyak wanted to know.

A better way of interpreting the old experiments, he and his colleagues suggest, is that the embryos died because *pha-1* wasn't providing the antidote to the *sup-35* toxin.

"No one had previously considered the possibility," says David S. Fay of the University of Wyoming in Laramie, who has done much of the work exploring the role of these genes. "All the data, including a lot of our previous published and unpublished findings, seem to fit the [selfish gene] model perfectly," he says. And perhaps the highest praise: "I wish we had somehow come up with the solution ourselves." ■

E. BEN-DAVID, A. BURGA AND L. KRUGLYAK/*SCIENCE* 2017

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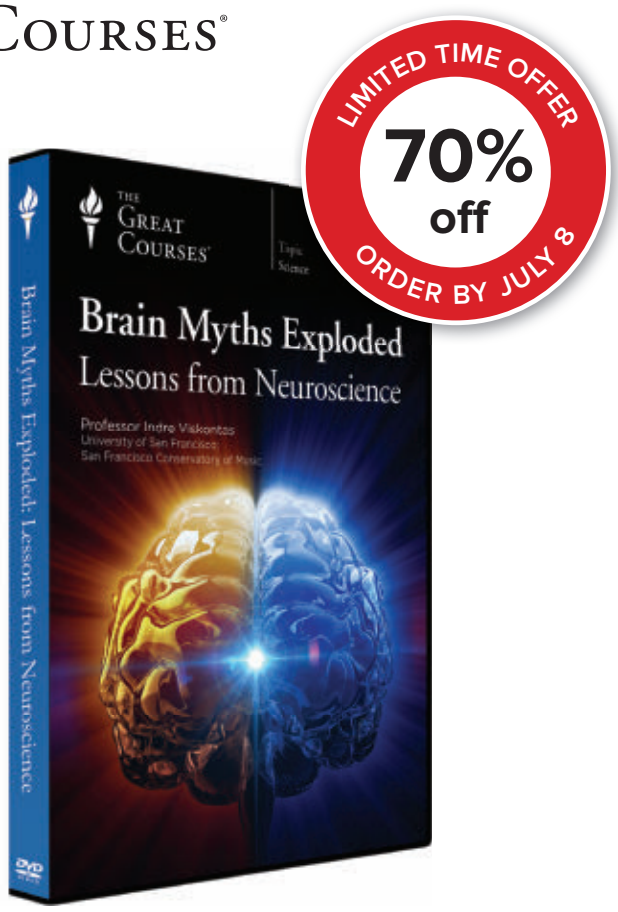

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BODY & BRAIN

Zika virus went undetected for months

Genetic analyses provide new details about epidemic's spread

BY LAURA BEIL

The Zika virus probably arrived in the Western Hemisphere from somewhere in the Pacific more than a year before it was detected, a genetic analysis of the epidemic shows. Researchers also found that as Zika fanned outward from Brazil, it entered neighboring countries and Florida multiple times without being noticed.

Though Zika took root in northeast Brazil by early 2014, months passed before health authorities received reports of unexplained fever and skin rashes. Zika was confirmed as the culprit in May 2015.

The World Health Organization did not declare the epidemic a public health emergency until February 2016, after babies of Zika-infected mothers began to be born with severe neurological problems. Zika, which is carried by mosquitoes, infected an estimated 1 million people in Brazil alone in 2015, and is now thought to be transmitted in 84 countries, territories and regions.

Zika's path was documented starting in 2015 through records of human cases, but less was known about how the virus spread so silently before detection, or how outbreaks in different parts of Central and South America were connected. Now two separate groups, reporting online May 24 in *Nature*, have compared samples from different times and locations to read the history recorded in random mutations of the virus's 10 genes.

One team, led by scientists in the United Kingdom and Brazil, drove over 1,200 miles across northeast Brazil — "a *Top Gear*–style road trip," one scientist quipped — with a portable device that could produce a complete catalog of the virus's genes in less than a day. A second team, led by scientists at the Broad Institute of MIT and Harvard, analyzed over 100 Zika genomes from infected patients and mosquitoes in nine countries and Puerto Rico. Based on where cases originated, and the estimated rate at which genetic changes appeared, the team recreated Zika's evolutionary timeline.

The studies reveal an epidemic that was silently churning long before anyone knew. "In each of the regions we could analyze, Zika virus circulated undetected for many months, up to a year or longer, before the first locally transmitted cases were reported," says infectious disease geneticist Bronwyn MacInnis of the Broad Institute.

The epidemic exploded out of Brazil, but the scientists found a remote possibility of early settlement in the Caribbean. "It's not immediately clear whether Zika stopped off somewhere else in the Americas before it got to northeast Brazil," says Oliver Pybus, an infectious disease researcher at the University of Oxford.

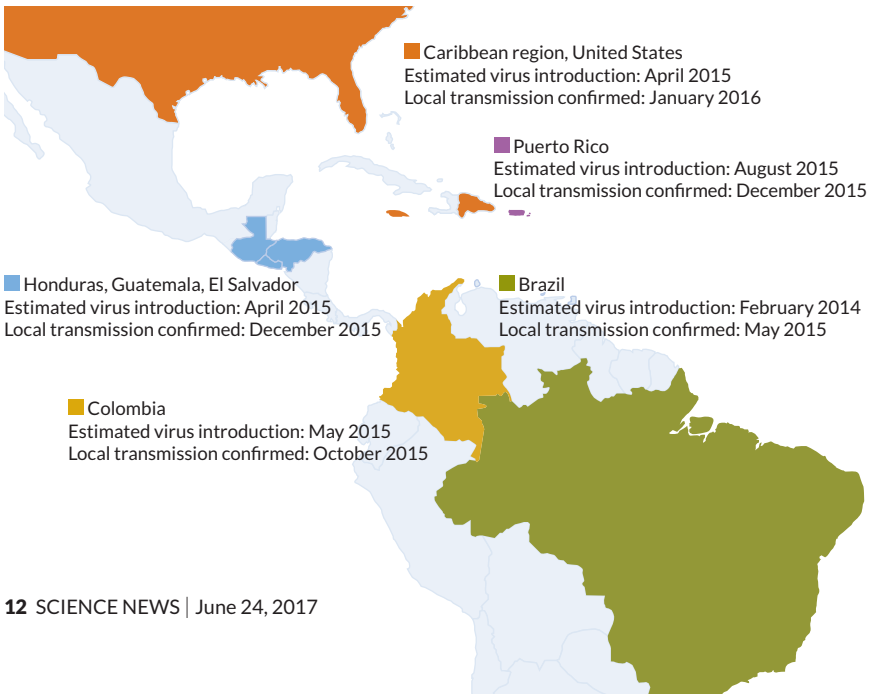
In a third study reported in *Nature*, researchers from more than two dozen institutions followed a trail of genetic clues to determine when and how Zika made its way to Florida. Those researchers conclude people infected with Zika arrived in the Miami area multiple times, probably from the Caribbean, before local mosquitoes picked it up. The number of human cases increased in step with the rise in mosquito populations, says Kristian Andersen, an infectious disease researcher at the Scripps Research Institute in La Jolla, Calif.

Previous studies have found traces of the virus's footprints across the Americas, but none had so many different samples, says Young-Min Lee of Utah State University, who has studied Zika's genes. The new studies give a higher-resolution look at the timing of the epidemic's spread, he says, but in terms of Zika's origins and progression, "the big picture is consistent with what we suspected."

In addition to revealing Zika's history, genetic studies are valuable in fighting current and future outbreaks. Since diagnostic tests and vaccine development are based on Zika's genetics, it's important to monitor mutations during an outbreak. Researchers have developed quick genomic analyses for Ebola in recent years, for example, that could aid a faster response during the next outbreak.

Faster analysis of viral threats in the field might improve the odds of stopping the next epidemic, Lee says. A single infected traveler stepping off a plane can spark an epidemic long before doctors notice. "If one introduction can cause an outbreak, you have a very narrow window to try to contain it." ■

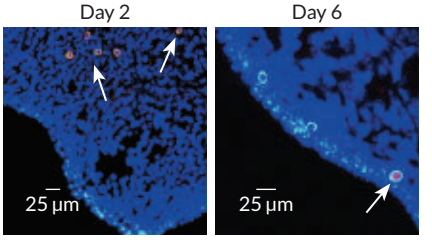
Stealth spread An analysis of more than 100 Zika genomes reveals that the virus showed up in several countries in the Western Hemisphere months earlier than the first confirmed cases of infection. Colors indicate areas with closely related Zika strains. SOURCE: BROAD INSTITUTE



H. THOMPSON, L. LO

Stem cells help sterile mice grow eggs

Transplant success raises hope for human infertility treatments



Germline stem cells (arrows, left) put into a mouse's ovary move toward the ovary's edge (arrow, right). The cells start to make a protein that signals they're becoming eggs.

BY LAUREL HAMERS

With an assist, an old mouse might be able to make new eggs.

Sterilized female mice produced healthy babies after receiving a transplant of egg-generating stem cells from another mouse, researchers report online May 18 in *Molecular Therapy*. If such a procedure worked in humans — still a distant prospect — it could help women with early menopause or chemotherapy-induced infertility conceive.

These egg-generating cells are germline stem cells — precursors that become eggs or sperm. While male germline stem cells differentiate (or become specialized) throughout a man's life to produce sperm, a woman's are believed to differentiate into a stockpile of eggs before she's born. Some recent studies have questioned that conventional wisdom, though the idea that germline stem cells still exist in women after birth is controversial.

"It's been a debate for many years," says Evelyn Telfer, a reproductive biologist at the University of Edinburgh.

Isolating germline stem cells and coaxing them to become eggs has proven tricky. Scientists have previously shown that germline stem cells from mice can turn into eggs in a petri dish. "The argument is whether these cells will do it in the body normally," Telfer says.

Developmental biologist Ji Wu of Shanghai Jiao Tong University and colleagues took germline stem cells from the ovaries of a 6-day-old mouse, grew them in a petri dish and then transplanted them into sterilized adult female mice's ovaries. The stem cells gradually moved to a spot just under the ovary's surface, where they started turning into eggs.

Five to eight weeks after the transplant, those mice mated with males. Six of the eight stem cell recipients became pregnant and delivered healthy pups.

The results show that germline stem cells can indeed restore fertility when transplanted into other mice, Wu says.

The study also offers more evidence that germline stem cells collected after a female mammal is born can still turn into viable eggs, Telfer says. But the stem cells were from very young mice, she notes. "Maybe a cleaner experiment would have been to take them from an adult." ■

C. WU ET AL/MOLECULAR THERAPY 2017

ATOM & COSMOS

Juno reveals more complex Jupiter

Diffuse core, other surprises appear in data from first flyby

BY ASHLEY YEAGER

Jupiter's scientific portrait is getting repainted.

NASA's Juno spacecraft swooped to within less than 5,000 kilometers of Jupiter's cloud tops on August 27, 2016, giving scientists their first intimate look at the gas giant. The data reveal surprising details about Jupiter's gravity, magnetic field and ammonia-rich weather system. The findings, which appear in two studies in the May 26 *Science*, suggest researchers need to revamp their view of Jupiter, as well as their ideas about how planetary systems form and evolve.

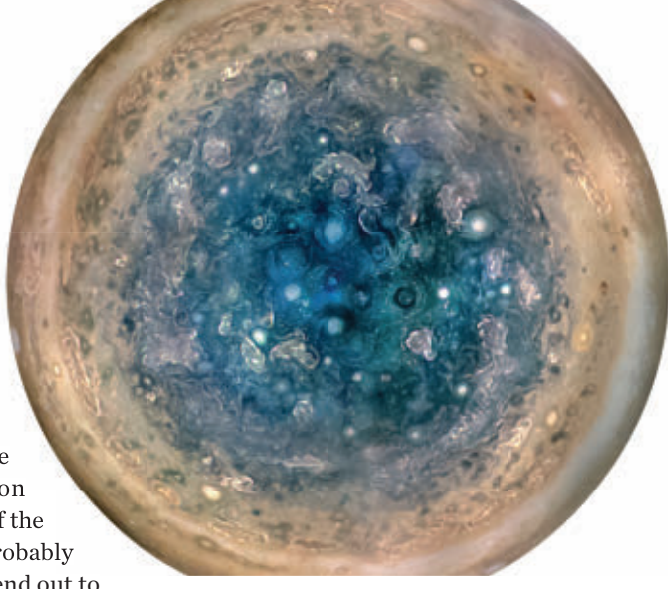
"We went in with a preconceived notion of how Jupiter worked, and I would say we have to eat some humble pie," says Juno mission leader Scott Bolton, a planetary scientist at the Southwest Research Institute in San Antonio.

Scientists thought that beneath its thick clouds, Jupiter would be uniform and boring. But Juno revealed the planet is anything but, Bolton says. "Jupiter is much more complex deep down than anyone anticipated."

For starters, measurements of Jupiter's gravity, determined from the tug of the planet on Juno, suggest that Jupiter doesn't have a solid, compact core, Bolton and colleagues report in one of the papers. Instead, the core is probably large and diffuse — it may extend out to half the planet's radius, the team reports. "Nobody anticipated that," Bolton says.

Imke de Pater, a planetary scientist at the University of California, Berkeley who was not involved in the studies, says the new gravity measurements should allow scientists to get a better handle on the structure of the planet's core. But, she notes, because of the mathematics involved, it won't be an easy task.

She was even more surprised by new measurements of Jupiter's magnetic field — the strongest among the solar system's planets. The Juno data reveal that the magnetic field is almost twice as strong as expected in some places. But the field's strength varies, growing stronger than expected in some areas and weaker in others, Bolton's team reports. The data support the idea that the magnetic field originates from circulating electric currents in one of the planet's outer layers of molecular hydrogen.



The Juno spacecraft's first closeup views of Jupiter (south pole shown) offer new insights into the planet's hidden interior.

In a complementary paper, astrophysicist John Connerney of NASA's Goddard Space Flight Center in Greenbelt, Md., and colleagues look at how Jupiter's magnetic field interacts with the solar wind, a stream of charged particles flowing from the sun. That interaction influences Jupiter's auroras, which Juno captured

JPL-CALTECH/NASA, SWRI, MSSS, BETSY ASHER HALL, GERVASIO ROBLES

GENES & CELLS

40 more genes linked to intelligence

DNA variants account for small amount of difference in smarts

BY LAURA SANDERS

Smarty-pants have 40 new reasons to thank their parents for their clever brains. By sifting through the DNA of nearly 80,000 people, researchers have uncovered 40 genes that may make certain people smarter. That brings the number of suspected "intelligence genes" to 52.

Combined, these genetic attributes explain only a very small amount of overall smarts, or lack thereof, researchers write online May 22 in *Nature Genetics*. But studying these genes, many of which play roles in brain development, may ultimately help scientists understand how intelligence is built into brains.

Historically, intelligence research has been mired in controversy, says neuroscientist Richard Haier of the University of California, Irvine. Scientists disagreed on whether intelligence could actually be measured and, if so, whether genes had anything at all to do with the trait, as compared with education and other life experiences. But now "we are so many light-years beyond that, as you can see from studies like this," says Haier. "This is very exciting and very positive news."

The results were possible only because of the gigantic number of people studied, says study coauthor Danielle Posthuma, a geneticist at VU University Amsterdam. She and colleagues combined data from 13 earlier studies on intelligence, some unpublished. The team looked for links between intelligence, measured in different ways in the studies, and variations in the genetic instruction books of 78,308 children and adults. Called a genome-wide association study, or GWAS, the method looks for signs that certain quirks in people's genomes are related to a trait.

This technique identified versions of 22 genes, half of which weren't previously known to have a role in intellectual ability. Another technique found 30 more intelligence genes, only one previously known. Many of the 40 genes newly linked to intelligence are thought to help with brain cell development. The *SHANK3* gene, for instance, helps nerve cells connect to partners.

The genetic variants identified by the

in ultraviolet and infrared images. Studying the brilliant light shows at the planet's poles, the team observed particles falling into the planet's atmosphere, similar to what happens on Earth. But, unlike on Earth, beams of electrons shoot out of Jupiter's atmosphere. The finding suggests the gas giant interacts very differently with the solar wind, the team writes.

Another oddity, described by Bolton's team, is how ammonia wells up from the depths of Jupiter's atmosphere (see Page 32). The upwelling resembles a feature on Earth called a Hadley cell, where warm air at the equator rises and creates trade winds, hurricanes and other weather. Jupiter's ammonia cycling looks similar. But because Jupiter lacks a solid surface, the upwelling probably works in a different way. Figuring out how the phenomenon occurs on Jupiter may help scientists better understand the atmospheres of other planets.

"What we learn about Jupiter will impact our understanding of all giant planets," Bolton says. Most planetary systems have Jupiter-like planets. By helping reveal how the one in our solar system formed and operates, the new data could give clues to how other planetary systems evolved as well. ■

GWAS account for only about 5 percent of individual differences in intelligence, the authors estimate. Those genes are "accounting for so little of the variance that they're not telling us much of anything," says differential developmental psychologist Wendy Johnson of the University of Edinburgh.

Still, understanding the genetics of intelligence might one day point out ways to enhance it for people at both the high and low ends of the curve. "If we understand what goes wrong in the brain, we might be able to intervene," Haier says.

But ethical and technical concerns exist. Brain biology is incredibly intricate, so changing one gene might have many unanticipated effects. Scientists would need to know everything about the genetics of intelligence before they could change it, Posthuma says. ■

ROB FELT/GEORGIA TECH (PHOTO); Y-H CHANG AND L.H. TING/*BIOLOGY LETTERS* 2017

LIFE & EVOLUTION

Flamingos' bones favor one-leg stance

Bird balancing act needs little muscular effort, study suggests

BY SUSAN MILIUS

A question flamingo researchers get asked all the time — why the birds stand on one leg — may need rethinking. The bigger puzzle may be why flamingos bother standing on two.

Balance aids built into the birds' basic anatomy allow for a one-legged stance that demands little muscular effort, tests find. This stance is so stable that a bird sways less to keep itself upright when it appears to be dozing than when it's alert with eyes open, two Atlanta neuromechanists report May 24 in *Biology Letters*.

"Most of us aren't aware that we're moving around all the time," says Lena Ting of Emory University, who measures postural sway in standing people as well as in animals. Just keeping the human body vertical demands constant sensing and muscular correction for wavering. Even standing robots expend "quite a bit of energy," she says. That could have been the case for flamingos, she points out, since effort isn't always visible.

Ting and Young-Hui Chang of the Georgia Institute of Technology tested balance in young Chilean flamingos on a platform attached to a device to measure how much they sway. Keepers at Zoo Atlanta hand-rearing the test subjects let researchers visit after feeding time in hopes of catching youngsters inclined toward a nap — on one leg on a machine.

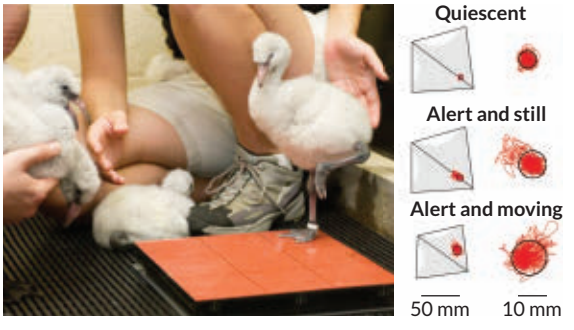
As a flamingo standing on one foot shifted to preen a feather or joust with a neighbor, the instrument tracked wobbles in the foot's center of pressure, where the bird's weight was focused. When a bird tucked its head onto its pillowy back and shut its eyes, the center of pressure made smaller adjustments (within a radius of 3.2 millimeters on average, compared with 5.1 millimeters when active).

Museum bones revealed features of the skeleton that might enhance stability, but bones alone didn't tell the researchers enough. Deceased Caribbean flamingos donated to science gave a better view. "The 'ah-ha!' moment was when I said, 'Wait, let's look at it in a vertical position,'" Ting remembers. All of a sudden, the bird specimen settled naturally into one-legged lollipop alignment.

The bird's distribution of weight looked just right for one-footed balance. The flamingo's center of gravity was close to the inner knee where bones started to form the long column to the ground, giving the precarious-looking position remarkable stability. The specimen's body wasn't as stable on two legs, the researchers found.

Reinhold Necker of Ruhr University in Bochum, Germany, doesn't see this study as evidence that a one-legged stance saves energy overall. "The authors do not consider the retracted leg," says Necker, who has studied flamingos. Keeping that leg retracted could take some energy.

The new study is a step toward understanding how flamingos stand on one leg but doesn't explain why, says comparative psychologist Matthew Anderson of St. Joseph's University in Philadelphia. He's found that more flamingos rest one-legged when temperatures drop, so thermoregulation might have something to do with it. ■



A young flamingo sets one foot on an instrument that tracks posture. The smallest shifts (red squiggles, right) in the foot's center of pressure, where weight is focused, occur when the bird is quiescent. For active birds, shifts are bigger.

EARTH & ENVIRONMENT

When it's hot, trees boost air pollution

Simulations show how much city shrubs add to ozone formation

BY ASHLEY YEAGER

Planting trees is often touted as a strategy to make cities greener, cleaner and healthier. But during heat waves, trees actually boost air pollution levels. When temperatures rise, as much as 60 percent of ground-level ozone is created with the help of chemicals emitted by urban trees and shrubbery, new simulations suggest.

While the findings seem counterintuitive, "everything has multiple effects," says Robert Young, an urban planning expert at the University of Texas at Austin who wasn't involved with the study. The results, he cautions, don't mean that cities should stop planting trees. Instead, more stringent measures are needed to control other sources of air pollution, such as vehicle emissions.

City trees help reduce storm water runoff, provide cooling shade and store carbon. But trees and shrubs also release chemicals that can interact with their surrounding environment to produce polluted air. One chemical, isoprene, can react with human-made compounds, such as nitrogen oxides, to form ground-level ozone, a gas that can be hazardous to human health. Monoterpenes and sesquiterpenes also react with nitrogen oxides, and when they do, tiny particles similar to soot build up in the air. In cities, cars and trucks are major sources of these oxides.

In the new study, reported online May 17 in *Environmental Science & Technology*, Galina Churkina of Humboldt University of Berlin and colleagues compared simulations of chemical concentrations emitted from plants in the Berlin-Brandenburg metropolitan area. The team looked at two summers: 2006, when there was a heat wave, and 2014, when temperatures were more typical.

At normal daily maximum summer temperatures, roughly 25° Celsius on average, plants' chemical emissions contributed to about 6 to 20 percent of ozone formation in the simulations. At the height of the 2006 heat wave, when temperatures soared to over 30°, plant emissions spiked, boosting their share of ozone formation to up to 60 percent. Churkina says she wasn't surprised to see the seemingly contrary relationship between plants and pollution. "Its magnitude was, however, quite amazing."

The results, she notes, suggest that campaigns to add trees to urban spaces can't be done in isolation. Radical reduction of air pollution from various sources is also needed, she says. ■

NEWS IN BRIEF

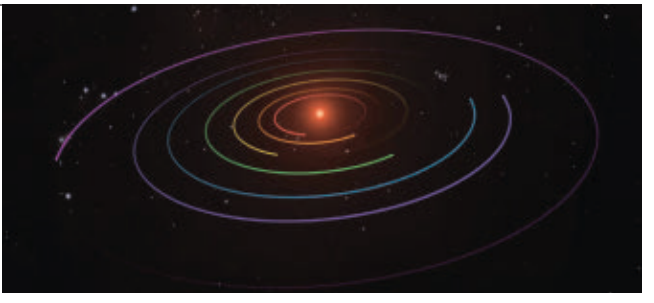
ATOM & COSMOS

TRAPPIST-1's seventh planet is a chilly world

When astronomers announced in February the discovery of seven planets orbiting a supercool star, details about the outermost planet were sketchy (*SN: 3/18/17, p. 6*). No more. The seventh planet is chilly and definitely no place for life, the international team reports May 22 in *Nature Astronomy*.

The seven-planet system TRAPPIST-1 is 39 light-years from Earth in the constellation Aquarius. Follow-up observations of the system reveal that TRAPPIST-1h is about three-quarters the size of Earth and orbits its star in just under 19 days. Although TRAPPIST-1h is much closer to its star than Earth is to the sun, the exoplanet's star has only 8 percent of the sun's mass. As a result, TRAPPIST-1h gets about as much starlight as the icy dwarf planet Ceres, in the asteroid belt, gets from the sun.

Such limited light makes the planet too cold (–100° Celsius) to harbor liquid water and therefore life as we know it, the researchers report. Other TRAPPIST-1 planets (see Page 18) are more likely to be life-friendly. — *Ashley Yeager*



TRAPPIST-1h, the outermost planet in its seven-planet system (orbital paths shown), receives too little light from its star to support liquid water.

NASA

GENES & CELLS

Mouse sperm survive space to fertilize eggs

Mouse sperm could win awards for resilience. Sperm freeze-dried and sent into space for months of exposure to high levels of solar radiation later produced healthy babies, researchers report online May 22 in *Proceedings of the National Academy of Sciences*.

If humans ever embark on long-term space flights, we'll need a way to reproduce. One potential hurdle (beyond the logistical challenges of microgravity) is the high amount of solar radiation in space — radiation exposure is 100 times as high on the International Space Station as on Earth. Those doses might cause damaging genetic mutations in banked eggs and sperm.

To test this possibility, Japanese researchers sent freeze-dried mouse sperm up to the space station, where the sperm spent nine months. When rehydrated back on Earth, the sperm showed some signs of DNA damage compared with earthly sperm.

But when the researchers used the space sperm to fertilize eggs in the lab and then injected the eggs into female mice, the mice birthed healthy pups that were able to have their own offspring. The researchers suspect that some of the initial DNA damage might have been repaired after fertilization.

If mouse sperm can survive a trip to space, perhaps human sperm can, too. — *Laurel Hamers*

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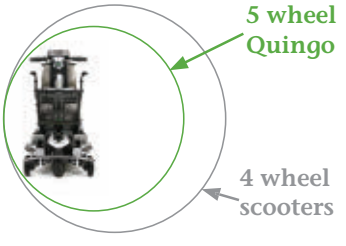

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The Opportunity ZONE

Exoplanets found in a narrow band around M dwarf stars could host a very different kind of life

By Christopher Crockett

Our corner of the galaxy teems with alien worlds. In the 25 years since the discovery of the first planets beyond our solar system, astronomers have found more than 3,600 worlds orbiting other stars. A select few have become tantalizing targets in the search for life despite orbiting stars that are much smaller, cooler — and in many ways harsher — than the sun.

Just 39 light-years away, seven planets, all roughly the size of Earth, whirl around a dim red star dubbed TRAPPIST-1, astronomers announced in February (*SN: 3/18/17, p. 6*). Three are potentially habitable. In April, a team reported the discovery of another world snuggled up to a red sun, LHS 1140b, described by researchers at the European Southern Observatory as perhaps the best candidate in the search for signs of life. And last August, astronomers revealed that not only does a small planet named Proxima b orbit the star closest to the sun, a red neighbor, but it too could support life (*SN: 9/17/16, p. 6*).

All of these worlds orbit faint ruddy stars known as M dwarfs, the most common type of star in the galaxy. Of the roughly 200 planets that have been spied around M dwarfs, dozens are in the coveted habitable zone. It's this region around a star where a planet could have temperatures that support liquid water, widely considered an essential ingredient for life.

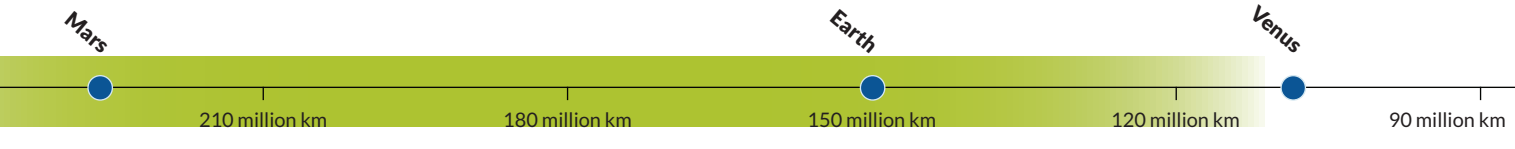
TRAPPIST-1 (illustrated) is on a growing list of dim red suns with planets that could support life. Three of its seven planets are in the habitable zone.

But M dwarfs are quite different from the sun, and their planets might be rough places to eke out a living — "the low-rent district of the galaxy," says Victoria Meadows, an astrophysicist at the University of Washington in Seattle. Harsh flares, bright beginnings and a tight gravitational grip on the innermost planets could be disastrous for any liquid water that's available.

Many more planets are expected to be found in habitable zones around M dwarfs. So researchers want to get a better handle on what these planets are up against. New observations and computer simulations reveal that, while it's difficult for M dwarf planets to hold on to substantial amounts of water, not all hope is lost.

"There are always ways around these things," says astrophysicist Rory Barnes, also at the University of Washington. M dwarfs and their planet families are plentiful, and there are many conditions in which these worlds can grow and evolve.

JPL-CALTECH/NASA



What's becoming clear is that any habitable locales around these stars will probably be quite different from Earth.

An optimistic list

M dwarfs make up about 70 percent of the several hundred billion stars in the galaxy. They are cool and tiny — at least for a star. Proxima Centauri, an M dwarf and the closest star to the sun, is roughly 2,800° Celsius. That's about 2,700 degrees cooler than the sun, giving Proxima a soft glow. Many M dwarfs aren't much bigger than Jupiter, which is only about one-tenth as wide as the sun. All this means that none are visible from Earth to the unaided eye. Proxima Centauri is about one one-hundredth as bright as the faintest stars our eyes can see without a telescope.

Because M dwarfs are so lightweight, they don't burn through their nuclear fuel as fast as their heavier cousins. So they live for an extraordinarily long time. A star that weighs about one-tenth as much as the sun, for example, has a projected lifetime of roughly 12 trillion years — more than 800 times the current age of the universe. That's plenty of time for life to arise and evolve on any planets orbiting these stars.

M dwarfs appear to be prolific planet producers. The dim stars harbor 3.5 times as many small planets, defined as planets between one and 2.8 times as wide as Earth, as do stars more like our sun. Compared with slightly warmer stars called K dwarfs and with suns like ours, M dwarfs probably have the lead on habitable worlds.

"Habitable" doesn't mean inhabited, nor does it necessarily mean a pleasant place to live. For most exoplanets, astronomers cannot directly measure anything about the climate or atmosphere. All they know is that the planet receives the right amount of solar energy to conceivably have liquid water on its surface. Though aliens might have very different needs than Earth-based critters, and may not even require water, scientists lean on a go-with-what-works approach in the search for life.

By one conservative estimate, 13 known exoplanets are "habitable," and 11 are around M dwarfs. That estimate comes from the Planetary Habitability Laboratory at the University of Puerto Rico at Arecibo. A precise number is elusive, however, because there are different ways to estimate the boundaries of the habitable zone. It's also not clear how massive a planet can be and still have a solid surface for life to take hold. Broadening their criteria to include larger planets and a wider habitable zone, the Arecibo researchers identified an additional 39 habitable exoplanets (20 orbiting M dwarfs and six around sunlike stars). That puts the more optimistic list of potential habitables at 52.

M dwarfs feature prominently partly because it's easier to find habitable planets around these stars. For a planet to stay warm around such a cool star, it has to huddle up close, offering the best chance to get noticed. A close-in planet will have a stronger gravitational tug on its star, making it easier to detect the star's wobble. And because these planets loop around their star faster than remote worlds, dips in the star's brightness as well as changes in the star's speed will be seen more often.

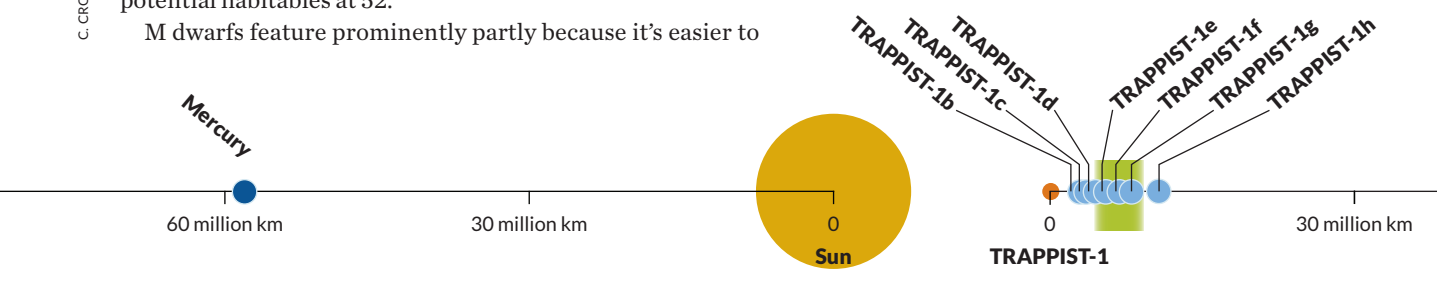
M dwarf planets will probably continue to dominate lists of habitable worlds. But when it comes to a climate that's suitable for liquid water, M dwarf planets have plenty of hurdles, says James Kasting, a geophysicist at Penn State.

Holding water

One of the biggest challenges — uncovered only recently — is how to survive the star's early years. M dwarfs are faint, but they don't start off that way. When they first begin to shine, M dwarfs can be roughly as bright as our sun, up to about 100 times as bright as they'll eventually become, Barnes says. It can take several hundred million years for an M dwarf to settle down to the low-level luminosity it will maintain for the rest of its life. Stars like the sun also start brighter than they end up, but they fade much faster, needing only about one-tenth as much time as M dwarfs.

A small world that today sits in the habitable zone of an M dwarf spent hundreds of millions of its early years blasted with more intense light. Using computer simulations, Barnes and Washington graduate student Rodrigo Luger showed that prolonged exposure to bright starlight could strip a planet's atmosphere of its water, leaving behind a barren world. The amount of water lost depends on the planet's mass, proximity to its star and initial inventory of water, the team reported in 2015 in *Astrobiology*. A "habitable" M dwarf world such as Gliese 667Cc, roughly 3.7 times as massive as Earth and about one-twelfth the distance from its star as Earth is from the sun, could have lost as much as 10 times the amount of water as is currently found in Earth's oceans.

"Once you've lost all the water, you're sunk," Barnes says. A once-promising planet could "potentially turn into Venus, and Venus is not a good place to live," he adds. While Venus



Huddle up In our solar system, the habitable zone (green) extends more than 160 million kilometers, from just beyond Venus (at about 110 million kilometers from the sun) to beyond Mars. Around the relatively cool star TRAPPIST-1, a mere 11 percent as wide as the sun, the habitable zone is much closer and narrower. (Planets are not to scale.)

SOURCES: NASA SPACE SCIENCE DATA COORDINATED ARCHIVE; PLANETARY HABITABILITY LAB/UNIV. OF PUERTO RICO AT ARECIBO; M. GILLON *ET AL*/*NATURE* 2017

C. CROCKETT

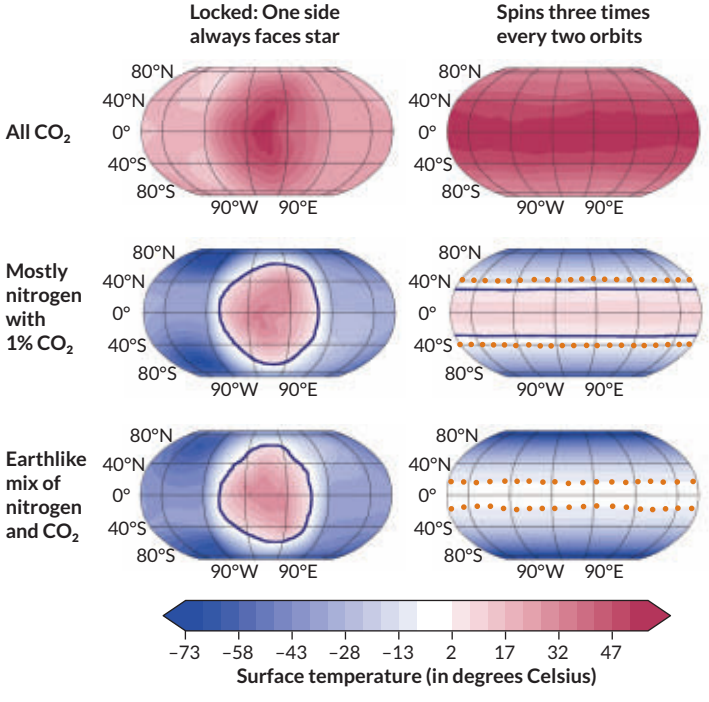
might have once had oceans and a more temperate climate (*SN Online: 8/26/16*), today it is home to a crushing carbon dioxide atmosphere and surface temperatures exceeding 460° C — hot enough to melt lead.

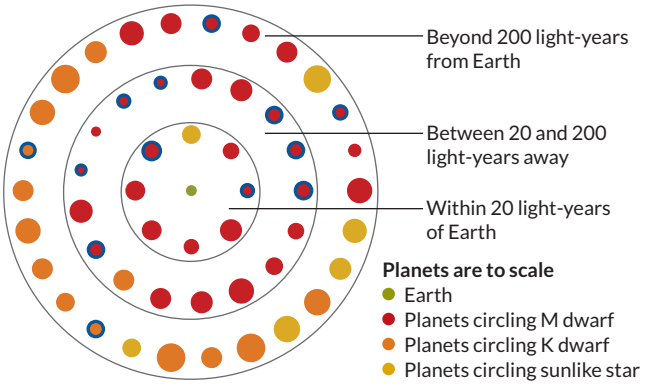
Ultraviolet radiation could strip not only the water vapor from a habitable M dwarf planet, but also the oxygen and nitrogen in just tens of millions of years, astrophysicist Vladimir Airapetian of NASA's Goddard Space Flight Center in Greenbelt, Md., and colleagues suggested in the February 10 *Astrophysical Journal Letters*. And Proxima b could have lost significant amounts of water during its formative years, astronomer Ignasi Ribas of the Institute of Space Sciences in Barcelona and colleagues reported in 2016 in *Astronomy & Astrophysics*.

But there's room for optimism. Ribas and collaborators came up with equally likely scenarios in which Proxima b loses less water than the volume of Earth's oceans. Astrophysicist Emeline Bolmont of the Saclay Nuclear Research Centre in France and colleagues took a similar look at the three innermost planets of TRAPPIST-1 (before the other four planets were discovered). While the two closest planets could have lost 15 times as much water as is in all of Earth's oceans, the third planet — still closer to the star than the habitable zone — might have lost less than one ocean, they reported in the January *Monthly Notices of the Royal Astronomical Society*.

There may also be ways to sequester and protect some of a planet's water — probably delivered by icy asteroids (*SN: 5/16/15, p. 18*) — during those first billion years. As proof that a planet can take a beating and hold on to its water, one need look no farther than Earth.

Proxima forecast Surface temperatures on Proxima b, a small planet orbiting the dim red star nearest to Earth, depend on the planet's spin and the makeup of its atmosphere. In six of many possible scenarios (shown below), solid lines mark areas where liquid water could endure year-round. Orange dots mark zones with seasonal water potential.





Getting there Of the 52 potentially habitable exoplanets identified so far, 51 have a known distance from Earth. Among those, most that are closest to Earth (center dot) orbit M dwarfs (red). The rest circle K dwarfs (orange) and sunlike stars (yellow). Blue circles show the 13 planets with the greatest chance of being life-friendly. SOURCE: PLANETARY HABITABILITY LAB./UNIV. OF PUERTO RICO AT ARECIBO

"We had a moon-forming impact that pretty much destroyed everything, and we still retained water and an atmosphere," Meadows says. While researchers debate the origin of the moon, the prevailing story is that Earth had a run-in with a protoplanet the size of Mars (*SN: 4/15/17, p. 18*), which probably blew away most of Earth's atmosphere. Water and other gases trapped deep in the planet's mantle could have trickled up and built a second atmosphere. As long as the mantle is not desiccated, there's an option to vent water and carbon dioxide over the lifetime of a planet, Meadows says. "We call them zombie planets."

Starting with a world that's akin to a miniature Neptune — one that's between one and 10 times as massive as Earth with a thick atmosphere of up to 50 percent hydrogen and helium — might be another way to make a habitable M dwarf planet, Luger and colleagues suggested in 2015 in *Astrobiology*. Ultraviolet radiation from the star, coupled with some movement of the planet toward its sun, could evaporate much of that primordial atmosphere and leave behind a rocky, possibly water-rich world.

Locked in space

If a planet manages to get through its first billion years with some water remaining, it faces another potential problem: gravity. Habitable M dwarf planets huddle much closer to their stars than any of the planets in our solar system do. Mercury orbits the sun once every 88 days; all of the potentially habitable worlds at TRAPPIST-1 whip around their star in about six to 12 days.

At such close proximity, the star's gravity can force one side of the planet to always face the star, resigning the other half to eternal darkness. The climate on such a world would be quite different from Earth's. Our planet's relatively brisk spin helps circulate the atmosphere and spread out heat from the sun. The dayside of a planet close to an M dwarf, however, might become so hot that water escapes to space; on the frigid nightside, the atmosphere could freeze to the surface.

FROM TOP: C. CROCKETT; M. TURBET *ET AL./ASTRONOMY & ASTROPHYSICS* 2016

But locked rotation isn't the deal-breaker it was once thought to be. "There are plenty of ways around it," says astronomer Jacob Haqq-Misra of the Blue Marble Space Institute of Science in Seattle. A little bit of CO_2 in the atmosphere, for example, can help store heat and distribute it around the planet.

A thick, permanent cloud deck might also form on the side facing the star, astrophysicist Jun Yang of Peking University in Beijing and colleagues reported in 2014 in *Astrophysical Journal Letters*. Rising parcels of hot air could trigger cloud formation, which would reflect lots of sunlight and prevent the dayside from becoming too hot. The researchers also found that this might widen the habitable zone around a star. With a protective cloud shield, a planet could be much closer to the star and remain temperate.

As long as a locked planet holds on to a relatively tiny amount of water (as little as 0.001 percent of that found in Earth's oceans in some cases), there's still a chance for liquid water to endure somewhere on the surface, a recent simulation suggests. Martin Turbet, a graduate student at the Laboratoire Météorologie Dynamique in Paris, and colleagues looked at possible climates for Proxima b. They reported last year in *Astronomy & Astrophysics* that for a range of conditions — different rotation rates, abundances of atmospheric gases and initial amounts of water — the planet could hold on to some surface water, enough to maintain at least a few habitable niches.

"Since it's such a different configuration from what we have on Earth, there's a lot of climate science still to be explored," Haqq-Misra says. Ruling out M dwarf planets as totally uninhabitable is premature. "There are lots of ways to keep liquid water on the surface."

Look to the skies

There are other potential pitfalls too, though. Strong solar flares, which some M dwarfs are known for, could rip away a planetary atmosphere. And computer simulations disagree on how easy it is to get water to a rocky planet around an M dwarf in the first place.

To test these ideas, astronomers need data. The best source now comes from planets that periodically pass in front of, or transit, their star (*SN: 4/30/16, p. 32*). During a transit, some starlight passes through the planet's atmosphere, and molecules in the atmosphere absorb specific frequencies of that light. Careful analysis of what frequencies are absorbed, and by how much, can directly reveal the presence of water vapor and other compounds, and can divulge climate parameters, such as temperature and pressure, that determine if liquid water is sustainable.

When it comes to habitable M dwarf planets, "we don't have any data yet," Barnes says. "Every data point is going to be huge and open up a new window into these worlds." One recent detection is telling: A planet orbiting a roughly 5-billion-year-old M dwarf, named Gliese 1132, appears to have an atmosphere that might contain either water vapor or methane, John Southworth, an astrophysicist at Keele University in England, and colleagues reported in the April *Astronomical Journal*. The planet, which is about 1.6 times as massive as Earth, is too close to its star to be considered habitable. But it shows that 5 billion years after its formation, a planet snuggled up to an M dwarf can retain an atmosphere.

DESIREE STOVER/NASA

NASA's James Webb Space Telescope will study exoplanet atmospheres for signs of life. The 6.5-meter-wide primary mirror recently moved into a clean room at the Goddard Space Flight Center in Greenbelt, Md.

Atmospheres have been reported on only three other small worlds: one around an M dwarf, one around a K dwarf and one orbiting a star similar to the sun. The first two, about 2.5 times as wide as Earth, give few clues about their atmospheres. Only the planet orbiting the sunlike star gave hints of methane in its atmosphere.

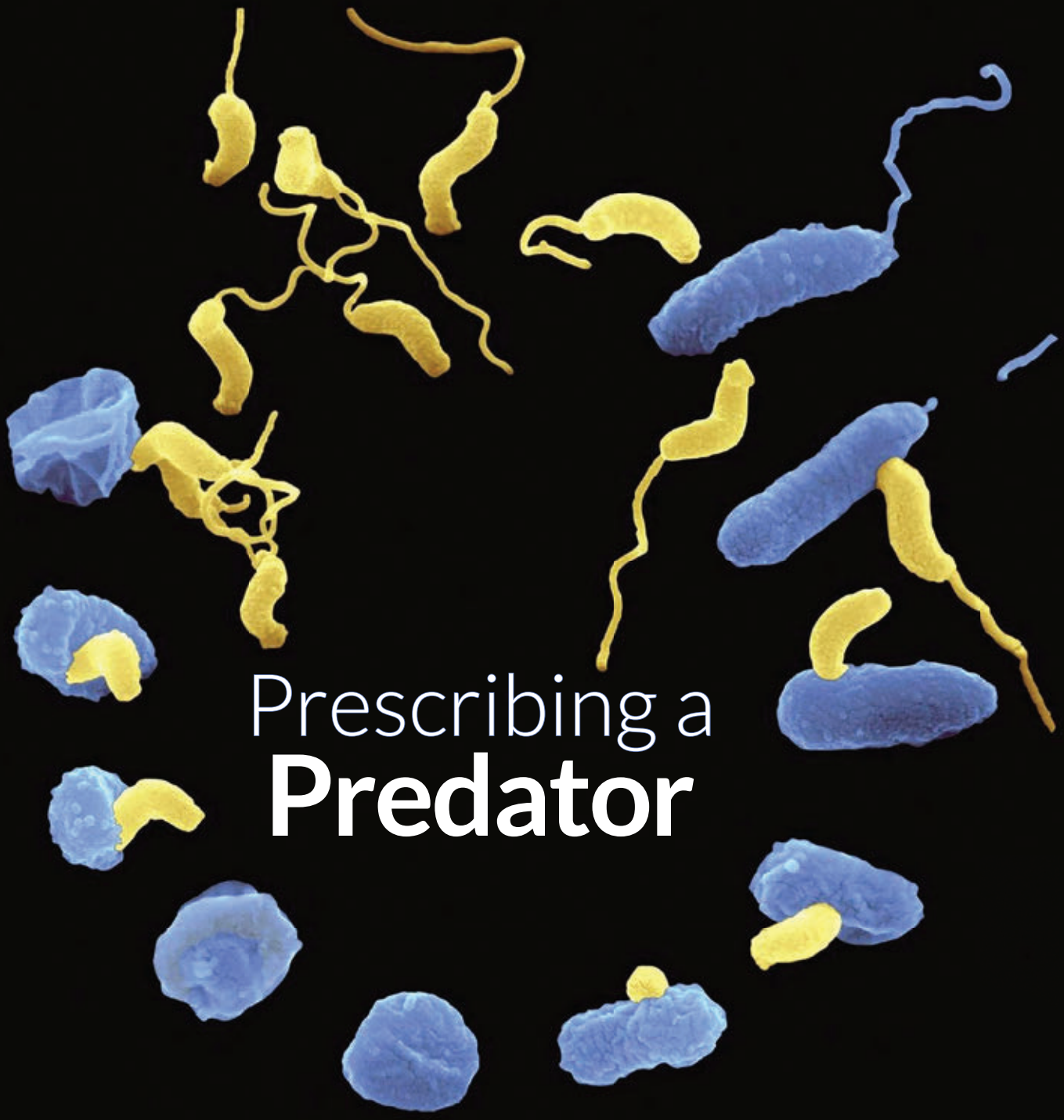
These measurements are exceedingly difficult for existing observatories. But NASA's James Webb Space Telescope, scheduled to launch in October 2018, will investigate hundreds of transiting exoplanets, many of them around M dwarfs. The TRAPPIST-1 system has jumped to the top of the list. It has three planets in the habitable zone, three too close to the M dwarf and one too far out (see Page 16). All of them are transiting, which makes TRAPPIST-1 an ideal test for all sorts of ideas about how M dwarf planets and their climates evolve, Meadows says.

With planets orbiting M dwarfs quickly becoming the darlings in the search for life beyond our solar system, a new generation of observatories are poised to discover hundreds of worlds around these stars. Climate simulations hint at diverse alien environments that could be harsh but also potentially habitable. "I just think it's really exciting that finally we'll be able to look at some of these planets," Kasting says. "There have been lots of surprises in the exoplanet business, so I'm prepared to be surprised again." ■

Explore more

- Aomawa L. Shields, Sarah Ballard and John Asher Johnson. "The habitability of planets orbiting M-dwarf stars." *Physics Reports*. December 5, 2016.

Christopher Crockett is a freelance science writer based in Alexandria, Va.



Prescribing a **Predator**

Bdellovibrio bacteria (yellow) attack larger bacteria (blue), using the prey's remains to replicate. *Bdellovibrio* microbes are a kind of living antibiotic.

Scientists study an out-there approach to fight infections

By Elizabeth S. Eaton

The woman in her 70s was in trouble. What started as a broken leg led to an infection in her hip that hung on for two years and several hospital stays. At a Nevada hospital, doctors gave the woman seven different antibiotics, one after the other. The drugs did little to help her. Lab results showed that none of the 14 antibiotics available at the hospital could fight the infection, caused by the bacterium *Klebsiella pneumoniae*.

Epidemiologist Lei Chen of the Washoe County Health District sent a bacterial sample to the U.S. Centers for Disease Control and Prevention. The bacteria, CDC scientists found, produced a nasty enzyme called New Delhi metallo-beta-lactamase, known for disabling many antibiotics. The enzyme was first seen in a patient from India, which is where the Nevada woman broke her leg and received treatment before returning to the United States.

> "The ability of future generations to manage infection is at risk. It's a global problem."
>
> ELIZABETH TAYLER

The enzyme is worrisome because it arms bacteria against carbapenems, a group of last-resort antibiotics, says Alexander Kallen, a CDC medical epidemiologist based in Atlanta, who calls the drugs "our biggest guns for our sickest patients."

The CDC's final report revealed startling news: The bacteria raging in the woman's body were resistant to all 26 antibiotics available in the United States. She died from septic shock; the infection shut down her organs.

Kallen estimates that there have been fewer than 10 cases of completely resistant bacterial infections in the United States. Such absolute resistance to all available drugs, though incredibly rare, was a "nightmare scenario," says Daniel Kadouri, a microbiologist at Rutgers School of Dental Medicine in Newark, N.J.

Antibiotic-resistant bacteria infect more than 2 million people in the United States every year, and at least 23,000 die, according to 2013 data, the most recent available from the CDC.

It's time to flip the nightmare scenario and send a killer after the killer bacteria, say a handful of scientists with a new approach for fighting infection. The strategy, referred to as a "living antibiotic," would pit one group of bacteria — given as a drug and dubbed "the predators" — against the bacteria that are wreaking havoc among humans.

The approach sounds extreme, but it might be necessary. Antimicrobial resistance "is something that we really, really have to take seriously," says Elizabeth Tayler, senior technical officer for antimicrobial resistance at the World Health Organization in Geneva. "The ability of future generations to manage infection is at risk. It's a global problem."

The number of resistant strains has exploded, in part because doctors prescribe antibiotics too often. At least 30 percent of antibiotic prescriptions in the United States are not necessary, according to the CDC. When more people are exposed to more antibiotics, resistance is likely to build faster. And new alternatives are scarce, Kallen says, as the pace of developing novel antibiotics has slowed.

In search of new ideas, DARPA, a Department of Defense agency that invests in breakthrough technologies, is supporting work on predatory bacteria by Kadouri, as well as Robert Mitchell of Ulsan National Institute of Science and Technology in South Korea, Liz Sockett of the University of Nottingham in England and Edouard Jurkevitch of the Hebrew University of Jerusalem. This work, the agency says, represents "a significant departure from conventional antibiotic therapies."

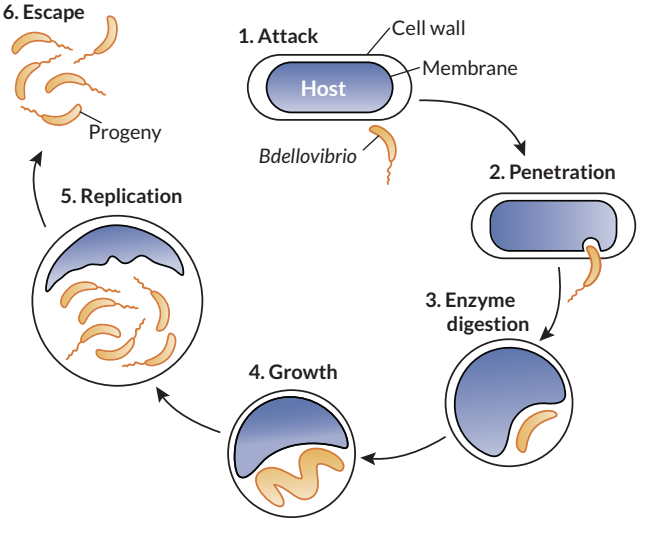
The approach is so unusual, people have called Kadouri and his lab crazy. "Probably, we are," he jokes.

A movie-worthy killer

The notion of predatory bacteria sounds a bit scary, especially when Kadouri likens the most thoroughly studied of the predators, *Bdellovibrio bacteriovorus*, to the vicious space creatures in the *Alien* movies.

B. bacteriovorus, called gram-negative because of how they are stained for microscope viewing, dine on other gram-negative bacteria. All gram-negative bacteria have an inner membrane and outer cell wall. The predators don't go after the other main type of bacteria, gram-positives, which have just one membrane.

When it encounters a gram-negative bacterium, the predator appears to latch on with grappling hook–like appendages. Then, like a classic cat burglar cutting a hole in glass, *B. bacteriovorus*



In and out *Bdellovibrio*, a bacterium, may offer a new way to fight infections. It enters its bacterial host by force, squeezing in between the cell wall and inner membrane. The predator's enzymes break down the prey's innards. Next, the predator replicates, eventually bursting out of the dead prey with its progeny. SOURCE: A.R. WILLIS *ET AL/CURRENT BIOLOGY* 2016

OPPOSITE: STEPHAN CHRISTOPH SCHUSTER; THIS PAGE: T. TIBBITTS

forces its way through the outer membrane and seems to seal the hole behind it. Once within the space between the outer and inner membranes, the predator secretes enzymes — as damaging as the movie aliens' acid spit — that chew its prey's nutrients and DNA into bite-sized pieces.

B. bacteriovorus then uses the broken-down genetic building blocks to make its own DNA and begin replicating. The invader and its progeny eventually emerge from the shell of the prey in a way reminiscent of a cinematic chest-bursting scene.

"It's a very efficient killing machine," Kadouri says. That's good news because many of the most dangerous pathogens that are resistant to antibiotics are gram-negative (*SN: 6/10/17, p. 8*), according to a list released by the WHO in February.

It's the predator's hunger for the bad-guy bacteria, the ones that current drugs have become useless against, that Kadouri and other researchers hope to harness.

Pitting predatory against pathogenic bacteria sounds risky. But, from what researchers can tell, these killer bacteria appear safe. "We know that [*B. bacteriovorus*] doesn't target mammalian cells," Kadouri says.

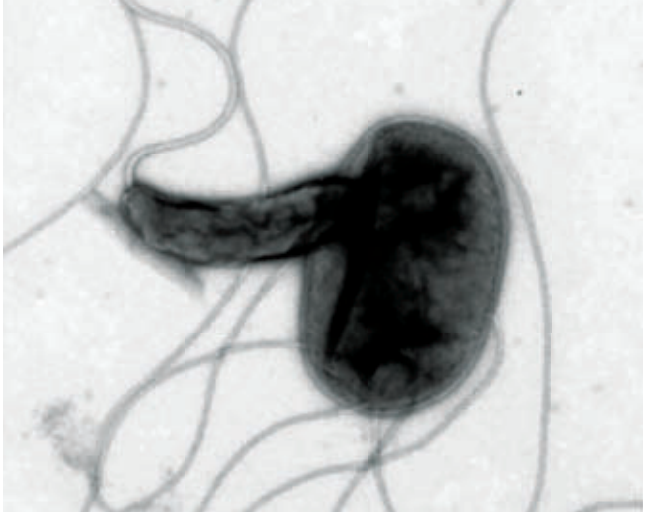
Saving the see-through fish

To find out whether enlisting predatory bacteria might be crazy good and not just plain crazy, Kadouri's lab group tested *B. bacteriovorus*' killing ability against an array of bacteria in lab dishes in 2010. The microbe significantly reduced levels of 68 of the 83 bacteria tested.

Since then, Kadouri and others have looked at the predator's ability to devour dangerous pathogens in animals. In rats and chickens, *B. bacteriovorus* reduced the number of bad bacteria. But the animals were always given nonlethal doses of pathogens, leaving open the question of whether the predator could save the animals' lives.

Sockett needed to see evidence of survival improvement. "If we're going to have *Bdellovibrio* as a medicine, we have to cure something," she says. "We can count changes in numbers of bacteria, but if that doesn't change the outcome of the infection — change the number of [animals] that die — it's not worth it."

So she teamed up with cell biologist Serge Mostowy of Imperial College London for a study in zebrafish. The aim was to see how many animals predatory bacteria could save from a deadly infection. The team also tested how the host's immune system interacted with the predators.



Under the microscope, the predatory bacterium *Bdellovibrio* enters its larger prey, *Salmonella enteritidis*. In one study, the predator decreased *Salmonella* infection in young chickens.

The researchers gave zebrafish larvae fatal doses of an antibiotic-resistant strain of *Shigella flexneri*, which causes dysentery in humans. Before infecting the fish, the researchers divided them into four groups. Two groups had their immune systems altered to produce fewer macrophages, the white blood cells that attack pathogens. Immune systems in the other two groups remained intact. *B. bacteriovorus* was injected into an unchanged group and a macrophage-deficient group, while two groups received no treatment.

All of the untreated fish with fewer macrophages died within 72 hours of receiving *S. flexneri*, the researchers reported in December in *Current Biology*. Of the fish with a normal immune system, 65 percent that received predator treatment survived compared with 35 percent with no predator treatment. Even in the fish with impaired immune systems, the predators saved about a quarter of the lot.

"This is the first time that *Bdellovibrio* has ever been used as an injected therapy in live organisms," Sockett says. "And the important thing is the injection improved the survival of the zebrafish."

The study also pulled off another first. In previous work, researchers had been unable to see predation as it happened within an animal. Because zebrafish larvae are transparent, study coauthor Alexandra Willis captured images of *B. bacteriovorus* gobbling up *S. flexneri*.

"We were literally having to run to the microscope because the process was just happening so fast," says Willis, a graduate student in Mostowy's lab. After the predator invades, its rod-shaped prey become round. Willis saw *Bdellovibrio* "rounding" its prey within 15 minutes.

R. ATTERBURY *ET AL/APPLIED AND ENVIRON. MICROBIOL.* 2011

Priority pathogens

Twelve different bacteria, most gram-negative (blue), pose the greatest threat to human health, according to the World Health Organization, because they resist multiple antibiotics. In laboratory tests, *Bdellovibrio bacteriovorus* has shown effectiveness against four (marked with asterisks).

Priority 1: CRITICAL

- *Acinetobacter baumannii**
- *Pseudomonas aeruginosa*
- *Enterobacteriaceae**

Priority 2: HIGH

- *Enterococcus faecium*
- *Staphylococcus aureus*
- *Helicobacter pylori*
- *Campylobacter spp.*
- *Salmonellae**
- *Neisseria gonorrhoeae*

Priority 3: MEDIUM

- *Streptococcus pneumoniae*
- *Haemophilus influenzae*
- *Shigella spp.**

SOURCES: WHO; A. DASHIFF *ET AL/ J. APPLIED MICROBIOL.* 2010

From start to finish, the predatory cycle took about three to four hours.

The predator's speed may be what gave it the edge over the infection, Mostowy says. *B. bacteriovorus* attacks fast, chipping away at the pathogens until the infection is reduced to a level that the immune system can handle. "Otherwise there are too many bacteria and the immune system would be overwhelmed," he says. "We're putting a shocking amount of *Shigella*, 50,000 bacteria, into the fish."

Within 48 hours, *S. flexneri* levels dropped 98 percent in the surviving fish, from 50,000 to 1,000.

The immune cells also cleared nearly all the *B. bacteriovorus* predators from the fish. The predators had enough time to attack the infection before being targeted by the immune system themselves, creating an ideal treatment window. Even if the host's immune system hadn't attacked the predators, once the bacteria are gone, Willis says, the predators are out of food. Unable to replicate, they eventually die off.

A clean sweep

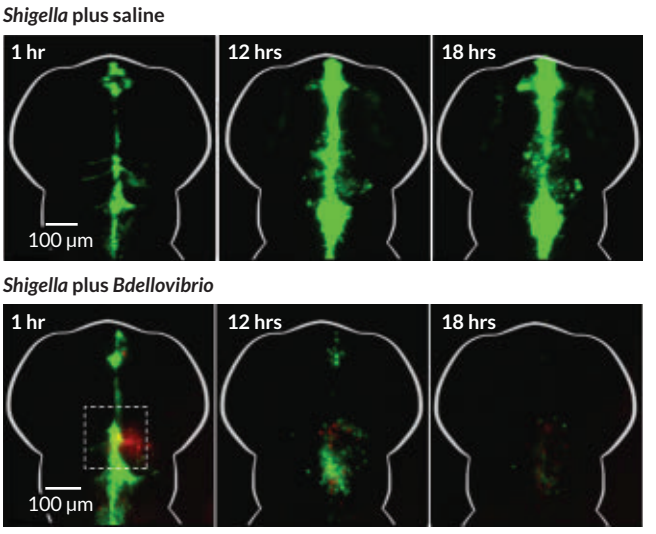
Predatory bacteria are efficient in more ways than one. They're not just good killers — they eliminate the evidence too.

Typical antibiotic treatments don't target a bacterium's DNA, so they are likely to leave pieces of the bacterial body behind. That's like killing a few bandits, but leaving their weapons so the next invaders can easily arm themselves for a new attack. This could be one way that multidrug resistance evolves, Mitchell says. For example, penicillin will kill all bacteria that aren't resistant to the drug. The surviving bacteria can swim through the aftermath of the antibiotic attack and grab genes from their fallen comrades to incorporate into their own genomes. The destroyed bacteria may have had a resistance gene to a different antibiotic, say, vancomycin. Now you have bacteria that are resistant to both penicillin and vancomycin. Not good.

Predatory bacteria, on the other hand, "decimate the genome" of their prey, Mitchell says. They don't just kill the bandit, they melt down all the DNA weapons so no pathogens can use them. In one experiment that has yet to be published, *B. bacteriovorus* almost completely ate up the genetic material of a bacterial colony within two hours — showing itself as a fast-acting predator that could prevent bacterial genes from falling into the wrong hands.

On top of that, even if pathogenic bacteria mutate, a common way they pick up new forms of resistance, they aren't protected from predation. Resistance to predation hasn't been reported in lab experiments since *B. bacteriovorus* was discovered in 1962, Mitchell says. Researchers don't think there's a single pathway or gene in a prey bacterium that the predator targets. Instead, *B. bacteriovorus* seem to use sheer force to break in. "It's kind of like cracking an egg with a hammer," Kadouri says. That's not exactly something bacteria can mutate to protect themselves against.

Some bacteria manage to band together and cover themselves with a kind of built-in biological shield, which offers protection against antibiotics. But for predatory bacteria, the shield is more of a welcome mat.



Zebrafish cleanup Left unchecked, injected *Shigella flexneri* bacteria (green) quickly spread through a zebrafish's hindbrain (top). In fish treated with *Bdellovibrio* (red) within 90 minutes of the *S. flexneri* injection, the bulk of the infectious bacteria was gone within 18 hours (bottom, far right).

Going after the gram-positives

When bacteria cluster together on a surface, whether in your body, on a countertop or on a medical instrument, they can form a biofilm. The thick, slimy shield helps microbes withstand antibiotic attacks because the drugs have difficulty penetrating the slime. Antibiotics usually act on fast-growing bacteria, but within a biofilm, bacteria are sluggish and dormant, making antibiotics less effective, Kadouri says.

But to predatory bacteria, a biofilm is like Jell-O — a tasty snack that's easy to swallow. Once inside, *B. bacteriovorus* spreads like wildfire because its prey are now huddled together as confined targets. "It's like putting zebras and a lion in a restaurant and closing the door and seeing what happens," Kadouri says. For the zebras, "it can't end well."

Kadouri's lab has shown repeatedly that predatory bacteria effectively eat away biofilms that protect gram-negative bacteria, and are in fact more efficient at killing bacteria within those biofilms.

Gram-positive bacteria cloak themselves in biofilms too. In 2014 in *Scientific Reports*, Mitchell and his team reported finding a way to use *Bdellovibrio* to weaken gram-positive bacteria, turning their protective shield against them and perhaps helping antibiotics do their job.

The discovery comes from studies of one naturally occurring *B. bacteriovorus* mutant with extra-scary spit. The mutant isn't predatory. Instead of eating a prey's DNA to make its own, it can grow and replicate like a normal bacterial colony. As it grows, it produces especially destructive enzymes.

A. R. WILLIS ET AL/CURRENT BIOLOGY 2016

Among the mix of enzymes are proteases, which break down proteins.

Mitchell and his team tested the strength of the mutant's secretions against the gram-positive *Staphylococcus aureus*. A cocktail of the enzymes applied to an *S. aureus* biofilm degraded the slime shield and reduced the bacterium's virulence. Biofilms can make bacteria up to 1,000 times more resistant to antibiotics, Mitchell says. The next step, he adds, is to see if degrading a biofilm resensitizes a gram-positive bacterium to antibiotics.

Mitchell and his team also treated *S. aureus* cells that didn't have a biofilm with the mutant's enzyme mix and then exposed them to human cells. Eighty percent of the bacteria were no longer able to invade human cells, Mitchell says. The "acid spit" chewed up surface proteins that the pathogen uses to attach to and invade human cells. The enzymes didn't kill the bacteria but did make them less virile.

Predatory bacteria can efficiently eat other gram-negative bacteria, munch through biofilms and even save zebrafish from the jaws of an infectious death. But are they safe?

No downsides yet

Predatory bacteria can efficiently eat other gram-negative bacteria, munch through biofilms and even save zebrafish from the jaws of an infectious death. But are they safe? Kadouri and the other researchers have done many studies, though none in humans yet, to try to answer that question.

In a 2016 study published in *Scientific Reports,* Kadouri and colleagues applied *B. bacteriovorus* to the eyes of rabbits and compared the effect with that of a common antibiotic eye drop, vancomycin. The vancomycin visibly inflamed the eyes, while the predatory bacteria had little to no effect. The eyes treated with predatory bacteria were indistinguishable from eyes treated with a saline solution, used as the control treatment. Other studies looking for potential toxic effects of *B. bacteriovorus* have so far found none.

In 2011, Sockett's team gave chickens an oral dose of predatory bacteria. At 28 days, the researchers saw no difference in health between treated and untreated chickens. The makeup of the birds' gut bacteria was altered, but not in a way that was harmful, she and her team reported in *Applied and Environmental Microbiology*.

Kadouri analyzed rats' gut microbes after a treatment of predatory bacteria, reporting the results in a study published March 6 in *Scientific Reports*. Here too, the rodents' guts showed little to no inflammation. When they sequenced the bacterial contents of the rats' feces, the researchers saw small differences between the treated and untreated rats. But none of the changes appeared harmful, and the animals grew and acted normally.

If the rats had taken common antibiotics, it would have been a different story, Kadouri points out. Those drugs would have given the animals diarrhea, reduced their appetites and altered their gut flora in a big way. "When you take antibiotics, you're basically throwing an atomic bomb" into your gut, Kadouri says. "You're wiping everything out."

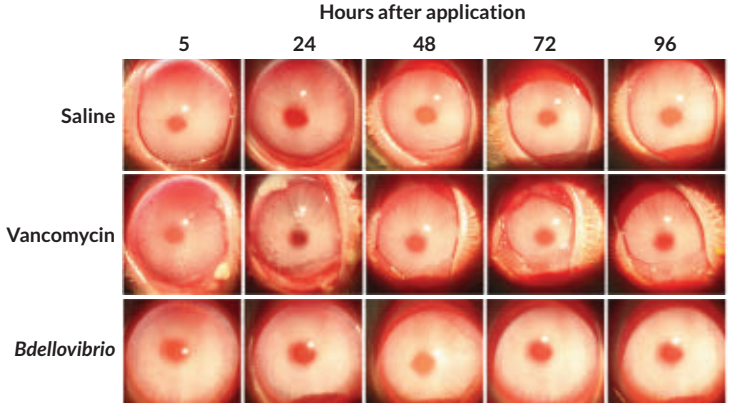
Both Mitchell and Kadouri tested *B. bacteriovorus* on human cells and found that the predatory bacteria didn't harm the cells or prompt an immune response. The researchers separately reported their findings in late 2016 in *Scientific Reports* and *PLOS ONE*.

Microbiologist Elizabeth Emmert of Salisbury University in Maryland studies *B. bacteriovorus* as a means to protect crops — carrots and potatoes — from bacterial soft rot diseases. For humans, she calls the microbes a "promising" therapy for bacterial infections. "It seems most feasible as a topical treatment for wounds, since it would not have to survive passage through the digestive tract."

There are plenty of questions that need answering first. Mitchell guesses that there will probably be 10 more years of rigorous testing in animals before moving on to human clinical studies. But pursuing these alternatives is worth the effort.

"The drugs that we're taking are not benign and cuddly and nice," Kadouri says. "We need them, but they don't come without side effects." Even though a living antibiotic sounds a bit crazy, it might be the best option in this dangerous era of antibiotic resistance. ■

Seeing the difference Researchers applied a saline solution, antibiotic or *Bdellovibrio* predatory bacteria to the eyes of rabbits to compare toxicity. Eyes treated with predatory bacteria or saline showed little inflammation. But eyes treated with the antibiotic vancomycin were inflamed, swollen and produced mucus.

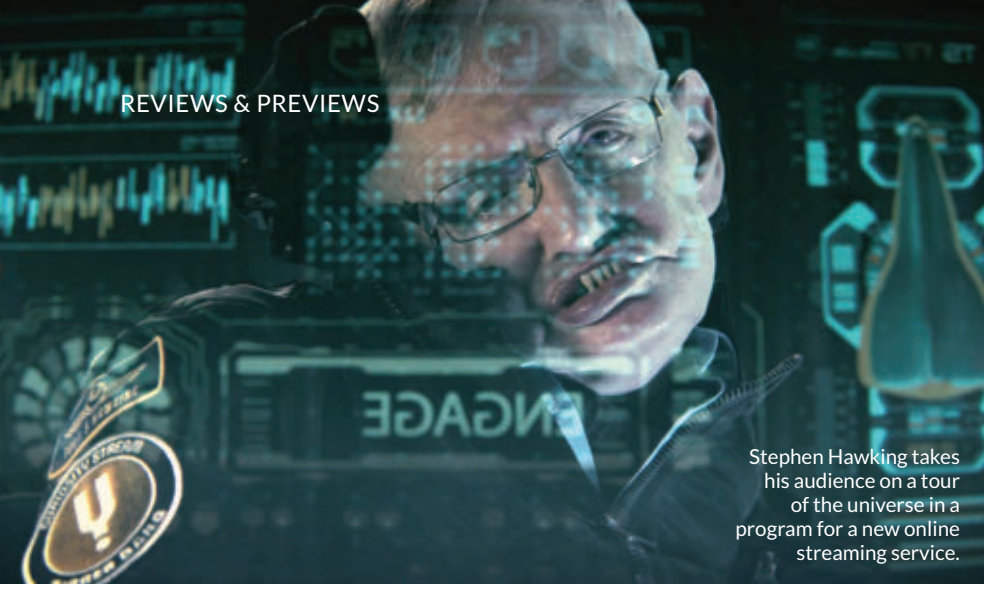


E.G. ROMANOWSKI *ET AL/SCI. REPORTS* 2016

Explore more

- Kenneth Shatzkes *et al*. "Effect of predatory bacteria on the gut bacterial microbiota in rats." *Scientific Reports*. March 6, 2017.
- Alexandra Willis *et al*. "Injections of predatory bacteria work alongside host immune cells to treat *Shigella* infection in zebrafish larvae." *Current Biology*. December 19, 2016.

Elizabeth S. Eaton is a former Science News *intern and a freelance science writer.*



Stephen Hawking takes his audience on a tour of the universe in a program for a new online streaming service.

SCREENTIME

CuriosityStream is for science-hungry viewers

Take a trip to a black hole with Stephen Hawking as a guide, watch glowing bioluminescent earthworms wriggle away from predators and discover the fascinating mathematics of origami — all while cuddled up in front of a laptop. That's the promise of the online streaming service CuriosityStream, which offers hefty doses of science for viewers who prefer fact-based documentaries over reality TV, sports and the political bickering that dominate today's television programming.

CuriosityStream, which recently celebrated its second birthday, operates much like Netflix. With plans starting at $2.99 per month, users can browse more than 1,700 commercial-free programs covering science, technology, history and the arts. The service works on computers, mobile devices and streaming players such as Roku and Apple TV.

CuriosityStream aims to supplement the media diet of science-starved viewers. "When you look at television ... there's very little science on anymore," says Steve Burns, CuriosityStream's chief programming officer. Subscribers, he says, "crave the substance that they've been missing on TV for so long."

Along with a slew of documentaries from the BBC and other public broadcasters, CuriosityStream offers more than 600 original programs that you won't find anywhere else. One standout is *David Attenborough's Light on Earth*, in which the naturalist takes viewers on an engaging survey of bioluminescent life, from flickering fireflies and luminous mushrooms to eerily glowing ocean creatures.

Another enjoyable original is *Stephen Hawking's Favorite Places*, in which the famed physicist tours a black hole, exoplanet Gliese 832c, Saturn and other cosmic locales. Computer-generated imagery of the turbulent region around a black hole, for example, provides a brilliant visual background to Hawking's explanations of relevant research. One episode is currently available, and two new ones are slated to go online later in the year.

Some shows are more engaging than others. Another original, *The Hunt for Dark Matter*, takes a deep dive into the technology behind the search for the invisible substance thought to pervade the universe. But the show will likely fall flat for many viewers, as its introduction lacks some of the background on the physics of dark matter that is necessary to grasp the relevance of the work.

CuriosityStream provides a wealth of options to choose from, including a variety of shorter shows, each 10 or 15 minutes long. With new programs added regularly, the service should provide enough binge-worthy fodder to keep even the most avid documentary lovers busy. — *Emily Conover*

TO DO

Phillip and Patricia Frost Museum of Science

NOW OPEN
A 250-seat planetarium and a three-level aquarium showcasing South Florida's coastal and marine life are among the highlights of this newly opened museum.
MIAMI

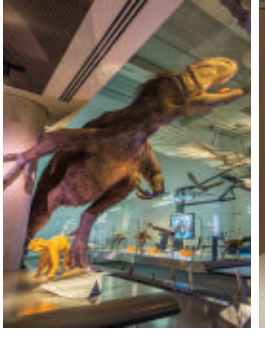
Robots

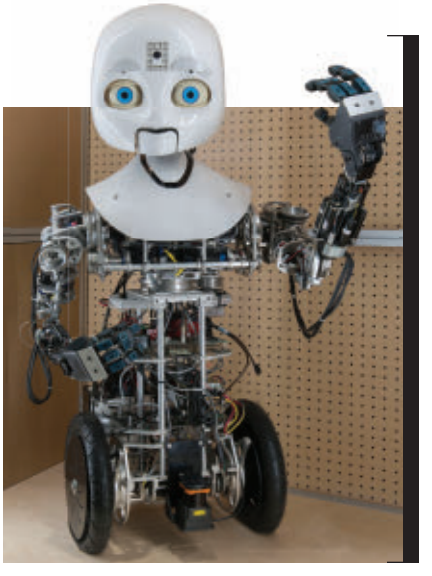
THROUGH SEPTEMBER 3
Spanning more than 500 years of technology, this exhibit brings visitors in close contact with over 100 robots.
SCIENCE MUSEUM, LONDON

Animal Architects: Influences on Human Creativity

THROUGH SEPTEMBER 3
The mixed-media artwork in this exhibit takes inspiration from nests, webs and other natural engineering wonders.
MONMOUTH MUSEUM, LINCROFT, N.J.

Nexi (right) is one of many robots now on display in London. Miami's new science museum (below) traces the history of flight.

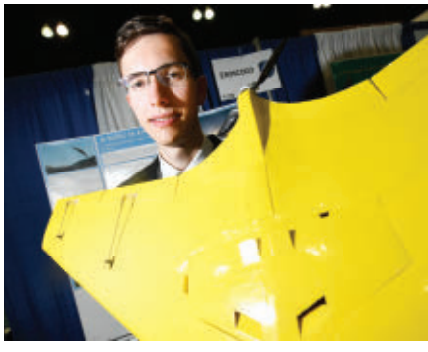




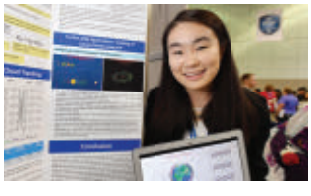
CLOCKWISE FROM TOP: CURIOSITYSTREAM; JENNIE HILLS; RA-HAUS/FROST SCIENCE

Learn more about CurosityStream at **curiositystream.com**

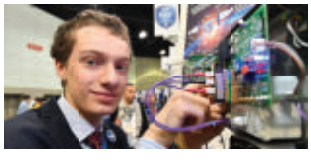
Teen scientists garner $4 million in prizes



At this year's Intel International Science and Engineering Fair (ISEF), **IVO ZELL**, 18, of Hessen, Germany, earned the top prize for his design and construction of a small "flying wing" drone. Flying wings are more efficient than traditional aircraft designs, but also less stable in flight because they have smaller fuselages or tails — or none at all. Zell's working prototype aircraft addresses this issue, using an unusual bell-shaped lift profile for improved stability. The modified shape allows Zell's aircraft to operate smoothly and safely in challenging flight situations without the need for a complex electronic stabilization system and without significantly sacrificing fuel efficiency. Potential applications range from drone delivery systems to larger aircraft design. Zell received the Gordon E. Moore Award of $75,000, named in honor of the Intel cofounder and fellow scientist.



AMBER YANG, 18, of Windermere, Fla., received a $50,000 Intel Foundation Young Scientist Award for her innovative approach to predicting the locations of space debris clouds that move in low Earth orbit. An estimated 500,000 space trash objects pose a potential hazard for spacecraft. Yang developed her own artificial neural network to recognize space objects in a specific debris cloud and predict their future locations.



VALERIO PAGLIARINO, 17, of Castelnuovo Calcea, Italy, also received an Intel Foundation Young Scientist Award for his prototype of a novel laser-based, wireless, high-speed network. Motivated by the lack of reliable Internet access in his rural locale, Pagliarino designed his new system using off-the-shelf components and then built and tested a small version of the network.

Intel ISEF is a program of Society for Science & the Public and the world's largest international pre-college science competition. This year, Intel ISEF featured nearly 1,800 young scientists selected from 425 affiliated fairs in 78 countries, regions and territories. The winners are ninth-through-12th-graders who earned the right to compete at the Intel ISEF 2017 by winning a top prize at a local, regional, state or national science fair.

Read more about the students' projects at **www.societyforscience.org/2017-ISEF-Projects**

View the full list of Grand Award winners at **www.societyforscience.org/2017-ISEF-Winners**

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MAY 13, 2017

Imagine that

Science News' special report on gravitational waves (*SN: 3/5/16*) recently won an Imagination Award from the Association of Magazine Media. The award recognizes work that is innovative in creating and distributing content across multiple platforms. Read the stories and watch an explainer video at bit.ly/SN_cosmicvibrations

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Water woes

A recent survey of lakes around the globe found that from 1985 to 2009, most warmed while only several cooled, ***Alexandra Witze*** *reported in "In hot water"* (SN: 5/13/17, p. 18)*. Rising temperatures have consequences for every part of a lake's food web, from algae to walleye to freshwater seals.*

"This article indicates that no pattern could be found to predict which lakes would warm (or cool) more rapidly than others," reader **Harold Paschal** wrote. "Lake latitude and elevation were mentioned as criteria that were investigated. What about the lakes' inputs? Would lakes fed by springs or mountain streams behave differently from ones that derive most of their water from plains' rivers?" he asked.

Those specific inputs were not examined in the lake surveys by the researchers. "I suspect those are probably mostly covered under other categories they did consider, such as high elevation, cold winter and so on," **Witze** says. It is hard to say if lake temperatures are significantly affected over the long term by the temperatures of the waters feeding into them. "The researchers do talk about inputs in one interesting area, though," she says. "Among the few lakes that are cooling are some on the Tibetan Plateau, which are getting doses of cold water as the glaciers above them melt."

Pump it up

Windmill-powered pumps on buoys throughout the Arctic Ocean could help bring back shrinking sea ice, ***Sid Perkins*** *reported in "Radical idea could restore Arctic Ocean's sea ice"* (SN: 5/13/17, p. 4)*.*

"Coating the Arctic with more ice by freezing seawater sounds to me like a frightening idea because of all the heat that would be pumped into the air," reader **E.G. Howard** wrote. He wondered if heat generated by the process could affect the weather and climate outside the Arctic where most people live.

Steven Desch, the researcher who proposed the pumps, estimates that the heat released by freezing ice using his technique would probably raise temperatures in the Arctic by less than 1 degree Celsius during winter months, when most ice would be produced, **Perkins** says. But if the ice produced lasts throughout the Arctic summer, ocean waters would absorb less sunlight then, so temperatures in the region would be substantially cooler. "Desch hasn't yet calculated the effect of his ice-making scheme on global temperatures," **Perkins** says.

Mosquito madness

Attempts 50 years ago to conquer disease-carrying Aedes aegypti *mosquitoes in the United States failed, largely due to dwindling resources and the public's resistance to pesticides,* **Cassie Martin** *reported in "Mosquitoes on the way out"* (SN: 5/13/17, p. 4)*.*

Readers online debated the pros and cons of today's mosquito control methods, as well as the potential of the gene-editing tool CRISPR to combat the pests. "I think it would be a good idea, but only after regulations have been put into place on where it can be used," **Robert Rockey** wrote.

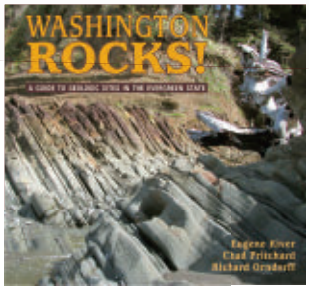
Researchers are experimenting in the lab, using CRISPR to hobble genes necessary for mosquitoes' reproduction and survival (*SN: 12/12/15, p. 16*), but no CRISPR mosquitoes have been tested in the wild.

Last summer, the National Academies of Sciences, Engineering and Medicine suggested new types of regulations that should be considered before these genetically modified mosquitoes can be released in the wild. "There is still a long way to go, but scientists are cautiously optimistic," **Martin** says.

Clarification

In her story "In hot water" (*SN: 5/13/17, p. 18*), **Alexandra Witze** reported that Siberia's Baikal seals are the only freshwater seals in the world. Other seals live in freshwater lakes in Alaska, Russia and Finland, but they are subspecies of saltwater seals. The Baikal seal is the only seal species that lives exclusively in freshwater, researchers say.

GEOLOGIC ROAD TRIP OF THE MONTH



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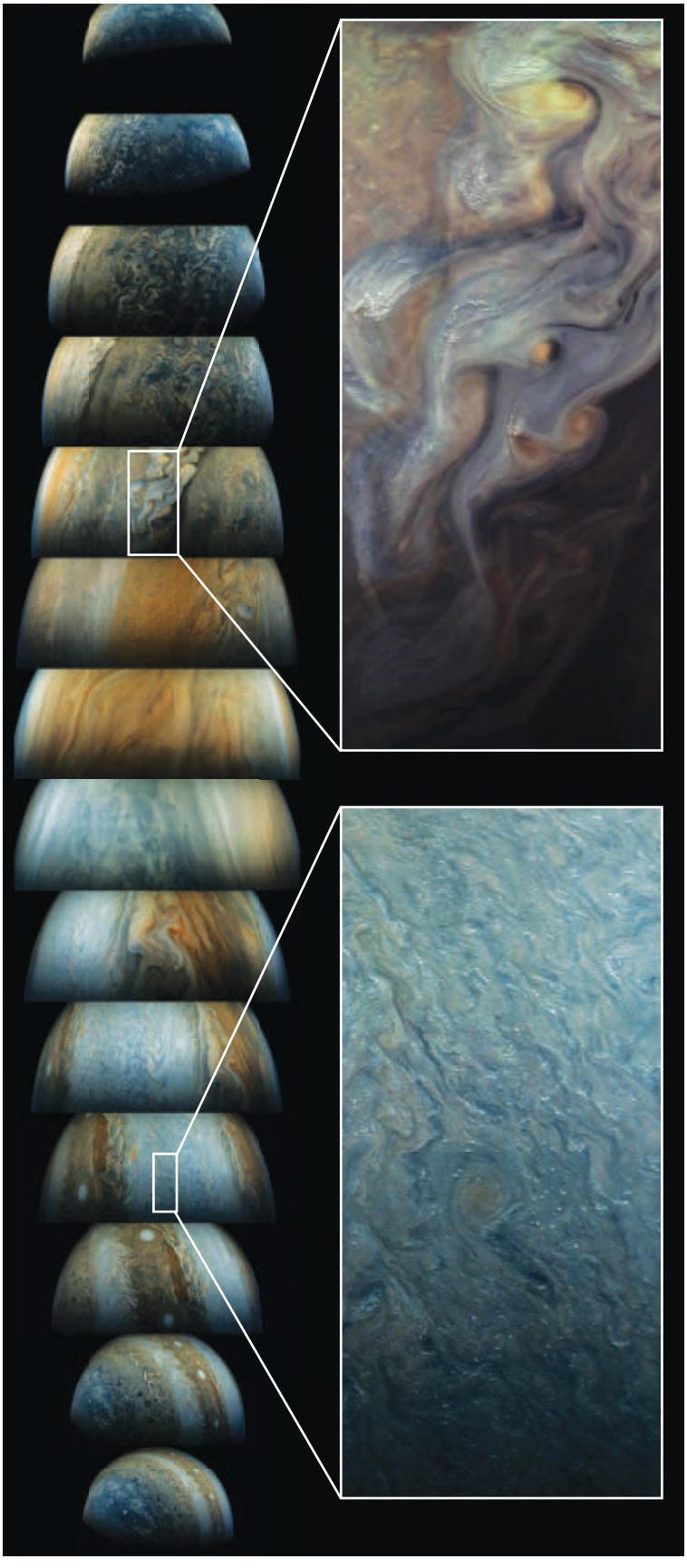
PALOUSE FALLS

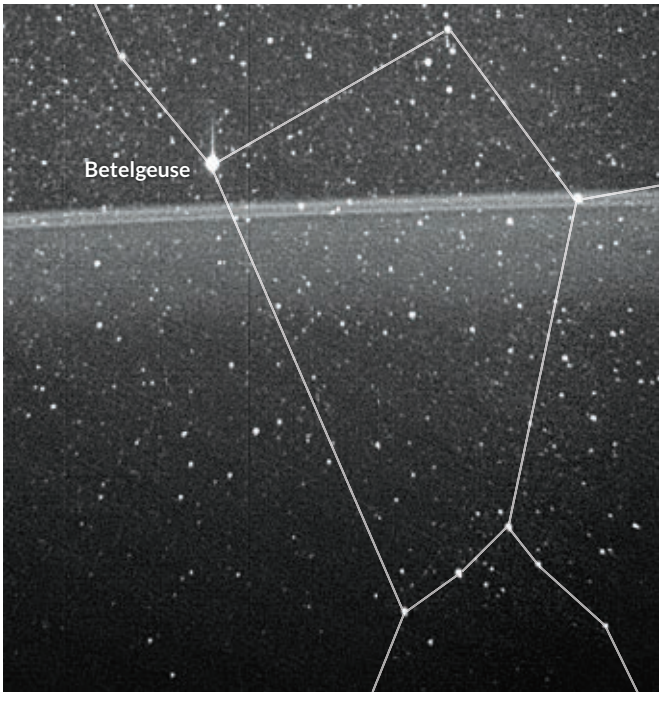
The ice age floods forever changed the course of the lower Palouse River in the southeastern part of the Columbia Plateau. The river abandons its large, wide valley, known as Washtucna Coulee, between the towns of Hooper and Washtucna and flows through an arrow-straight canyon toward Palouse Falls. Washtucna Coulee is a massive valley carved by the floodwaters, but apparently it wasn't big enough to hold it all. Floodwaters spilled over a drainage divide and followed a fracture in the basalt bedrock to the nearby Snake River. The thundering rush of Missoula floodwater dropping hundreds of feet into the Snake River canyon generated a waterfall that proceeded to cut headward nearly 6 miles to its present position at Palouse Falls, leaving a steep-walled canyon in its wake. The divide crossing was lowered enough by the floods that the Palouse River maintained its new course, abandoning forever its former westward channel along Washtucna Coulee.

Palouse Canyon looking south from near Palouse Falls toward the Snake River 6 miles away. Notice the zigzag pattern in the river, formed as the Missoula Floods carved out preexisting fractures in the basalt.

Palouse Falls and the lower canyon at sunrise at Palouse Falls State Park.

The modern river spills 186 feet over Palouse Falls to a plunge pool below. The starkness of the basalt cliffs and the beauty of the waterfall have captured the attention of generations of people, including artists and photographers. The steepness and angularity of the topography and the thin to absent soils in the area are indicative of its geologically recent formation. In 2014 Palouse Falls was recognized as Washington State's official waterfall. Impressive as the waterfall is, especially during the spring runoff, it is a puny trickle compared to the 8-mile-wide stream of water that roared down the canyon and surrounding area at 50 or more miles per hour during larger outburst floods from Glacial Lake Missoula.





A recurring rendezvous

Once every 53 days, Jupiter pulls Juno close. Locked in orbit since July 2016, the spacecraft has made five close flybys of the planet so far. It takes Juno only two hours to zip from pole to pole — a mad, north-to-south trek shown here in a sequence of 14 enhanced-color images (left) taken May 19.

As Juno zooms closer, to about 3,400 kilometers above the cloud tops, new details of Jupiter emerge. Turbulent clouds signal massive equatorial tempests (inset, top). New Juno data reveal that near the equator, ammonia rises from unexpectedly deep in the atmosphere (see Page 14). The upwelling might fuel such storms, but it's too early to tell. And what look like white freckles across the south tropical zone (inset, bottom) are 50-kilometer-wide cloud towers probably made of ice crystals.

"It's snowing on Jupiter, and we're seeing how it works," said Juno mission leader Scott Bolton of the Southwest Research Institute in San Antonio in a May 25 news conference. Or "it could be hail," he added. But it's not the snow or hail we know; the precipitation is probably mostly ammonia ice and, perhaps, some water ice.

Juno doesn't have eyes only for Jupiter. On its initial science flyby last August, Juno captured the first image of Jupiter's main ring seen from the inside looking out (above). In the background of the newly released image, parts of the constellation Orion wink from afar. These rendezvous won't go on forever but could last till 2019. — *Emily DeMarco*

FROM LEFT: NASA, SWRI, MSSS, GERALD EICHSTÄDT, SEAN DORAN; JPL-CALTECH/NASA, SWRI

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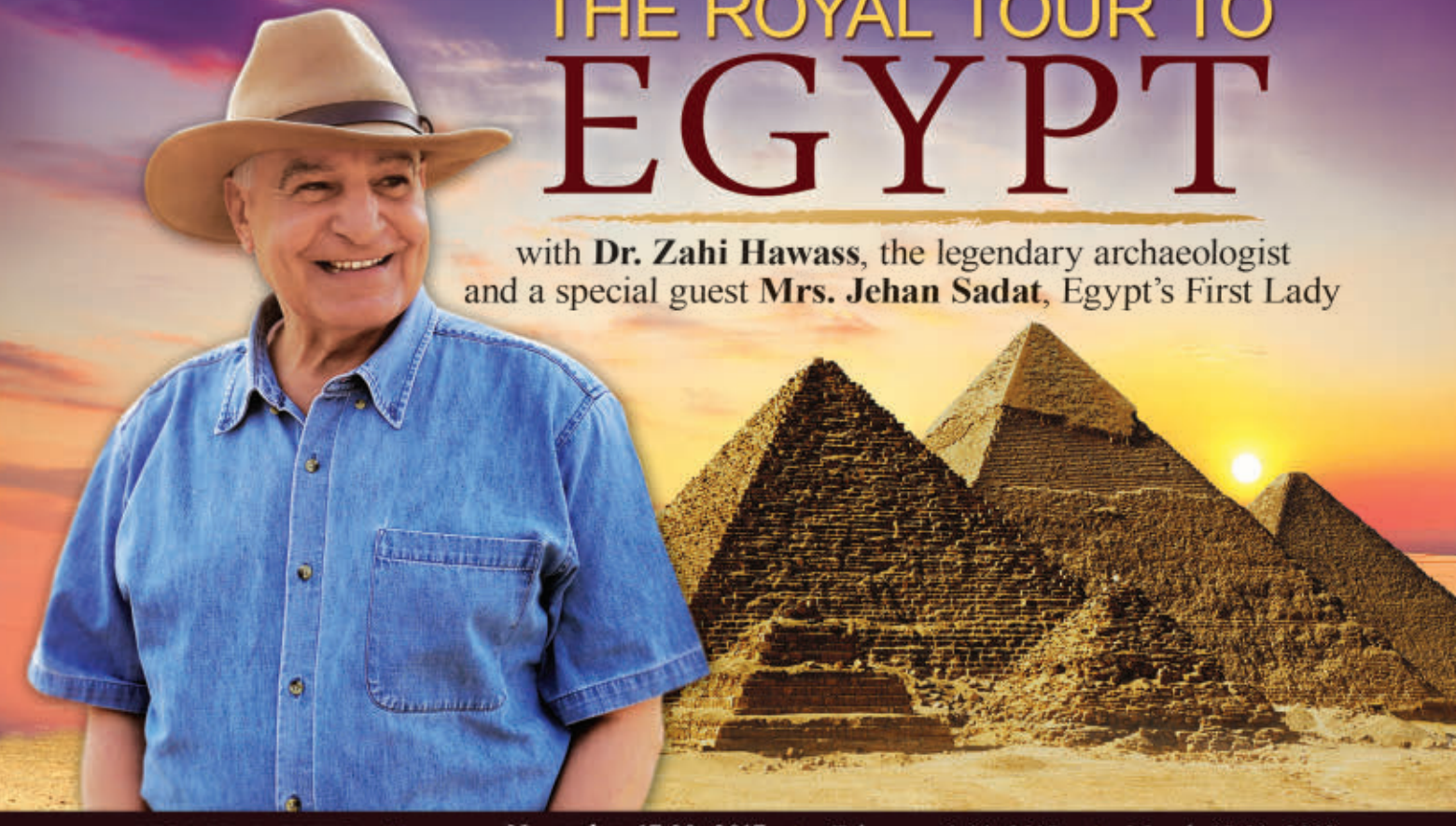

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