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SCIENCE NEWS MAGAZINE
SOCIETY FOR SCIENCE & THE PUBLIC
APRIL 27, 2019

Fossils Spark Dino Debate

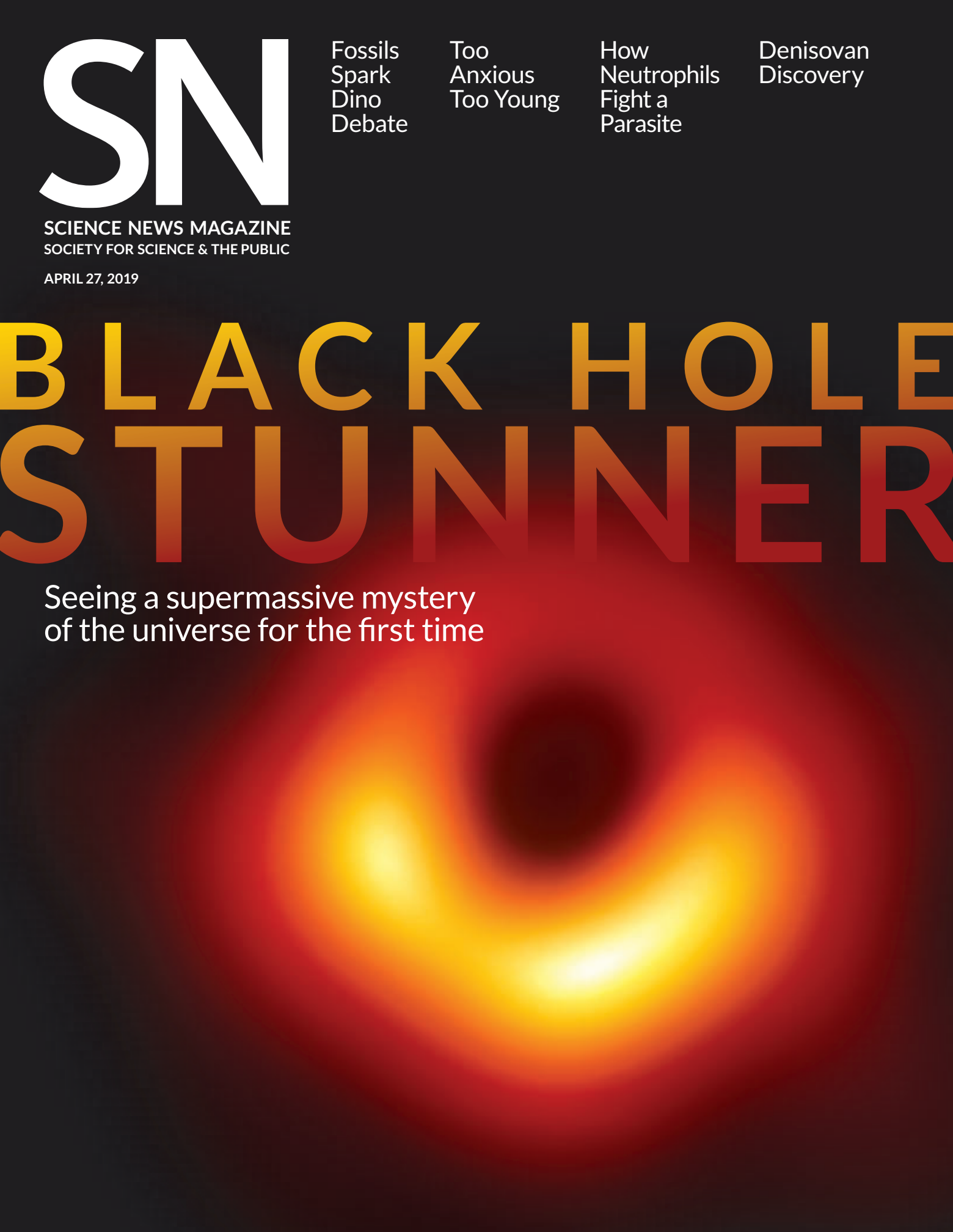
Too Anxious Too Young

How Neutrophils Fight a Parasite

Denisovan Discovery

BLACK HOLE STUNNER

Seeing a supermassive mystery of the universe for the first time



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VOL. 195 | NO. 8

ScienceNews

18

Features

News

12

4

Departments

COVER The first-ever picture of a black hole shows the monster in galaxy M87, 55 million light-years from Earth. *EHT collaboration et al.*

FROM TOP: GRACIA LAM; D. MEARNS; A.P. FAYOMI *ET AL*/*SCIENCE* 2019

Seeing very far away and hitting closer to home

The big science news of this issue, and so far this year, is the first-ever view of a black hole, announced at 9:07 a.m. April 10 by the Event Horizon Telescope collaboration, an international effort that linked radio telescopes around the globe to create a planet-sized "camera." This issue of *Science News* went to press that very afternoon, and we had a marvelous time making sure the news made it in the magazine before we put it to bed. You can read our coverage on Pages 6 and 7. For more black hole news, including a timeline and a video featuring astronomy writer Lisa Grossman and physics writer Emily Conover, check out our website at www.sciencenews.org.

But we also examine pressing questions much closer to home in this issue. Social sciences writer Sujata Gupta became intrigued by the question of what can be done to help young children with anxiety after she wrote a news article on how mental health problems in preschool often carry over into adulthood (*SN Online: 2/3/19*). She was eager to find out why.

There's actually quite a bit of research on mood disorders in the very young, despite the fact that until just a few decades ago it was commonly thought that small children were too immature to have such problems. The next question is whether it's appropriate to treat anxiety in this age group, and if so, which treatments work best (Page 18). Because the brain is so malleable in young children, researchers hypothesize that treating anxiety early on will make it less likely that an anxious child will grow up to be an anxious adult.

Gupta knew that to give readers a clear sense of how anxiety disorders affect children, she would have to go beyond interviewing researchers; she had to talk with families. "That was the most challenging part," she says. Researchers are barred from sharing the names of study participants without their permission, and since there's still stigma surrounding mental health, people can be reluctant to go public. That's particularly true in the age of the internet, when Googling a person's name can surface articles written years earlier.

But Gupta found a family. One of the researchers she interviewed for the news article connected her with Kate Fitzgerald, a child psychiatrist at the University of Michigan who runs a research program called Camp Kid Power for children with anxiety. Fitzgerald connected Gupta with Rachel, whose young daughter Molly had participated in the camp.

To protect her daughter's privacy, Rachel asked us not to use the family's last name. And while our policy is to fully identify sources in the interest of accountability and transparency, we decided that in this case, protecting a child's sensitive health information justified omitting the last name. That's not a decision we take lightly; when we do make that call, we will let our readers know why.

In my years as a journalist, I've found many people willing to share deeply personal health information with me and by extension with the world. They did so because they believed, as I do, that people's stories are powerful tools that can help us become more informed, empathetic citizens. I am grateful to every single one of them. —*Nancy Shute, Editor in Chief*

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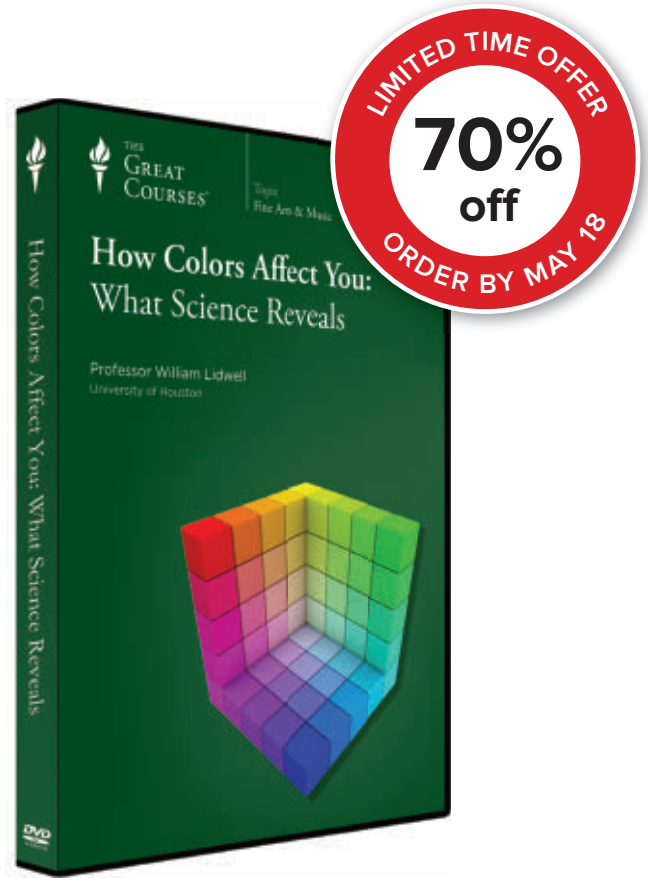

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Professor William Lidwell lectures at the Gerald D. Hines College of Architecture at the University of Houston. He also serves as Director of Innovation and Development at the Stuff Creators Design Studio in Houston, Texas.

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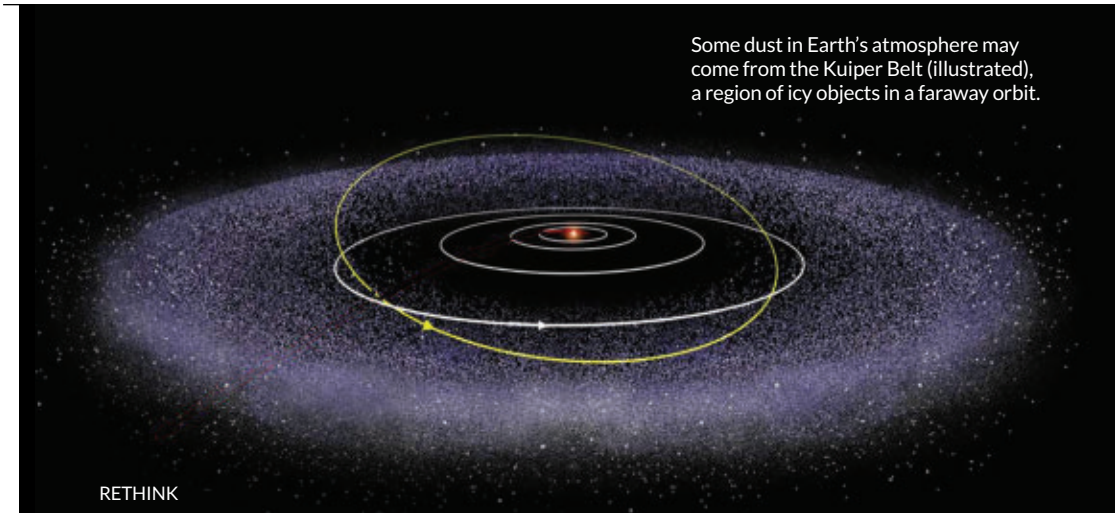
Excerpt from the April 26, 1969 issue of *Science News*

50 YEARS AGO

Another route to 104

In 1964, a few radioactive atoms existed for three-tenths of a second in a Soviet laboratory, and G.N. Flerov and his colleagues, who detected it, announced the discovery of element 104. But the announcement was met with skepticism in the United States.... Now, U.S. scientists declare they have gone their own route to corral the elusive element.

UPDATE: Chemists in the United States and Soviet Union bickered for decades over who deserved discovery credit for certain elements beyond fermium, element 100 on the periodic table, with each side assigning the elements different names. Known as the Transfermium Wars, the Cold War–era dispute wasn't settled until the International Union of Pure and Applied Chemistry stepped in and assigned names in the 1990s. Recently, U.S. and Russian scientists combined forces to discover three of the periodic table's four newest elements (*SN: 3/2/19, p. 16*). The table now stretches past element 104, rutherfordium, to element 118, oganesson, at the end of the table's seventh row (*SN Online: 2/12/18*).



Some dust in Earth's atmosphere may come from the Kuiper Belt (illustrated), a region of icy objects in a faraway orbit.

RETHINK

Kuiper Belt dust may be sprinkled in our atmosphere

THE WOODLANDS, TEXAS — Grains of dust from the edge of the solar system could be finding their way to Earth. And NASA may already have a handful of the debris.

With an estimated 40,000 tons of space dust settling in Earth's stratosphere every year, the U.S. space agency has been flying balloon and aircraft missions since the 1970s to collect samples.

The particles, some just a few tens of micrometers wide, had long been thought to come mostly from comets

–EST

This 15th century astrolabe came off a wrecked ship

While searching for shipwrecks in the Arabian Sea near Oman in 2014, divers found the world's oldest known mariner's astrolabe.

The navigation device was with the wreckage of a Portuguese ship that had been part of explorer Vasco da Gama's second trip to India from 1502 to 1503. Decorations on the disk led researchers to suggest that it was used as early as 1496. The device, a bit wider than a dollar bill's length, is marked with Portugal's royal coat of arms and a depiction of a ringed Earth or sun associated with a Portuguese king who ruled from 1495 to 1521.

A metal disk found in a shipwreck near Oman is the oldest known mariner's astrolabe, a device for navigating at sea.

Laser imaging of the metal disk revealed 18 scale marks separated at 5-degree intervals. The device could have measured altitudes from 0 degrees (when the sun is at the horizon) to 90 degrees (when the sun is directly overhead), researchers report online March 16 in the *International Journal of Nautical Archaeology*.

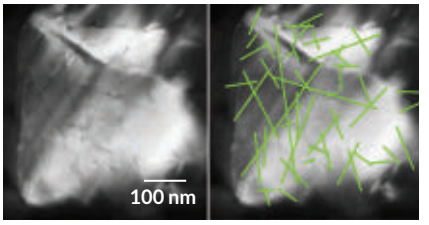
Only one other solid disk mariner's astrolabe has been found, though its age and authenticity are uncertain, says coauthor David Mearns, an oceanographer who directs the shipwreck recovery company Blue Water Recoveries in Midhurst, England. Of 104 artifacts known to have been used as mariner's astrolabes, the new find is the oldest and the only one decorated with a national symbol. By the early 1500s, most navigators had adopted more precise, open-wheeled astrolabes. — *Bruce Bower*

FROM TOP: NASA; D. MEARNS

and asteroids closer to the sun than to Jupiter (*SN: 4/13/19, p. 10*). But some of the particles may have come from as far out as the Kuiper Belt — a region of icy objects orbiting beyond Neptune, NASA planetary scientist Lindsay Keller said March 21 at the Lunar and Planetary Science Conference.

Studying those particles could reveal what Kuiper Belt objects are made of (*SN: 4/13/19, p. 11*). "We're not going to get a mission out to a Kuiper Belt object to actually collect samples anytime soon," Keller said. "But we have samples of these things in the stratospheric dust collections here at NASA."

One way to find a dust grain's home is to probe it for microscopic tracks where heavy charged particles from solar flares punched through. The more tracks a grain has, the longer it has wandered in space — and the more likely it originated far from Earth, said Keller, who works at the Johnson Space Center in Houston. To measure how many tracks a typical grain of space dust picks up per year, Keller needed a sample with a known age and known track density — criteria met only by moon rocks brought back on Apollo missions. And the last track-rate estimate was done with one moon rock in 1975, using instruments less precise than what's available today.



A dust grain from space shows tracks (green) where solar flare particles punched through.

So Keller and planetary scientist George Flynn of the State University of New York College at Plattsburgh looked at that same Apollo rock with an electron microscope and found that the rate at which rocks pick up flare tracks is about one-twentieth of the rate estimated in 1975. That means it takes longer for dust to pick up tracks than astronomers had assumed.

Counting flare tracks in 14 grains, the team found that some grains had spent millions of years in space — far too long to have come from between Mars and Jupiter. Grains from the Kuiper Belt would have taken 10 million years to reach Earth, the researchers calculated.

That's "pretty solid evidence that we're collecting Kuiper Belt dust right here," Keller said. Four of the well-traveled grains have minerals that form through interactions with liquid water — surprising, as the Kuiper Belt is thought too cold for liquid water. Keller suggests that heat from Kuiper Belt collisions may have melted ice.

More work is needed to confirm the dust wasn't just sitting on an asteroid for millions of years, says Carey Lisse, a planetary scientist at Johns Hopkins University Applied Physics Laboratory in Laurel, Md. — *Lisa Grossman*

TEASER

A new opioid antidote lasts longer

Synthetic opioids such as fentanyl outlast the antidotes, but a nanoparticle-based alternative could fix that. The single-dose antidote works in the bodies of mice for days, a study shows. If the results can be duplicated in humans, the treatment could one day help prevent overdoses from these deadly drugs.

Normally, a dose of the opioid antidote naloxone passes through a person's body in about 30 minutes — way too fast to counteract the effects of fentanyl, carfentanil and other synthetic opioids (*SN Online: 5/1/18*). These drugs, which are far stronger than morphine, can linger in a person's system for hours or days (*SN: 6/10/17, p. 22*). That retention time requires multiple doses of naloxone to prevent an overdose.

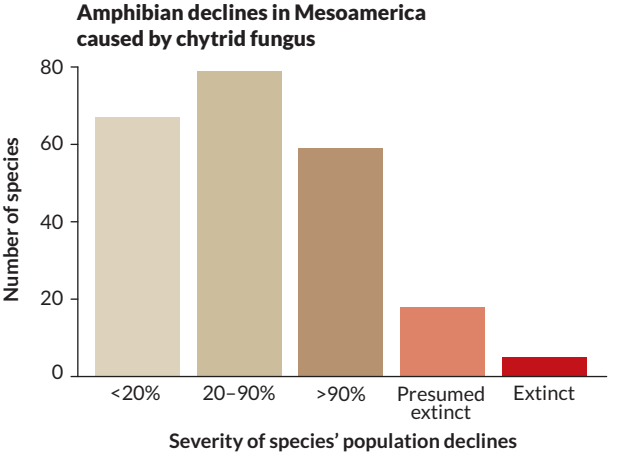
So researchers developed the longer-lasting alternative using nanoparticles in which naloxone molecules are tangled with polylactic acid, a biodegradable polymer. Water and enzymes in the body break down these nano-sized tangles to gradually release the naloxone. In mice, a single dose counteracted the pain-relieving effects of morphine for up to 96 hours, according to research presented March 31 at an American Chemical Society meeting in Orlando, Fla.

The team is planning tests at higher opioid levels to see if the antidote can prevent mice from overdosing, says Saadyah Averick, a biomaterials researcher at the Allegheny Health Network Research Institute in Pittsburgh. — *Maria Temming*

SCIENCE STATS

Chytrid drives frog deaths globally

A skin fungus plaguing frogs and toads is now the world's worst invasive killer, displacing cats and rodents. The first global tally, reported in the March 29 *Science*, shows the chytrid *Batrachochytrium dendrobatidis*, or *Bd*, has caused population declines in at least 500 amphibian species, including 90 presumed extinctions. By comparison, cats threaten 430 amphibian species, and rodents 420. Mexico, Central America and the Caribbean — or Mesoamerica — is the world's hardest hit region. — *Kathleen O'Neil*



FROM TOP: L. KELLER/ARES/JSC/NASA; B.C. SCHEELE *ET AL*/*SCIENCE* 2019

ATOM & COSMOS

First picture of a black hole wows

Image of M87's behemoth matches general relativity

BY LISA GROSSMAN AND EMILY CONOVER

WASHINGTON — This is what a black hole looks like.

A world-spanning telescope network called the Event Horizon Telescope, or EHT, has zoomed in on the supermassive monster in the galaxy M87 to create the first picture of a black hole.

"We have seen what we thought was unseeable," Sheperd Doeleman, an astrophysicist at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass., and director of the EHT, said April 10 at one of seven concurrent news conferences. The results were also published in six papers in the *Astrophysical Journal Letters*.

Black holes are notoriously hard to see. Their gravity is so extreme that nothing, not even light, can escape across the boundary at a black hole's edge, known as the event horizon. But some black holes, especially supermassive ones dwelling in galaxies' centers, stand out by voraciously accumulating gas and other material into a bright disk. The EHT image appears as a fuzzy, asymmetrical ring with a dark void in the center — the shadow of M87's black hole on its accretion disk. The image unveils the dark abyss of one of the universe's most mysterious objects.

"For me, the reveal lives up to the hype," says theoretical astrophysicist Priyamvada Natarajan of Yale University, who is not a member of the EHT team.

The image aligns with expectations of what a black hole should look like based on Einstein's general theory of relativity, which predicts how spacetime is warped by a black hole's extreme mass.

The first image of a black hole shows a bright ring with a dark, central spot. That ring is a disk of gas orbiting the supermassive black hole in galaxy M87, and the dark spot is the monster's shadow.

The picture is "one more strong piece of evidence supporting the existence of black holes. And that, of course, helps verify general relativity," says Clifford Will, a physicist at the University of Florida in Gainesville who is not on the EHT team.

Earlier studies have tested general relativity by looking at the motions of stars (*SN: 8/18/18, p. 12*) or gas clouds (*SN: 11/24/18, p. 16*) near a black hole, but never at its edge. "It's as good as it gets," Will says. Tiptoe any closer and you're inside the black hole — unable to report back on the results of any experiments.

The result "doesn't mean general relativity is completely fine," says EHT team member Feryal Özel, an astrophysicist at the University of Arizona in Tucson. If general relativity were to break down, "black hole environments are a likely place." Many physicists think that general relativity won't be the last word on gravity because it's incompatible with quantum mechanics, which describes physics on very small scales.

The image also provides new measurements of the black hole's heft. Estimates have ranged between 3.5 billion and 7.22 billion times the mass of the sun, but new EHT measurements show that the black hole is about 6.5 billion solar masses. The team also determined that the black hole's diameter is 38 billion kilometers, and that the black hole spins clockwise. "M87 is a monster even by supermassive black hole standards," said Sera Markoff, a theoretical astrophysicist at the University of Amsterdam and EHT team member.

EHT trained its sights on both M87's black hole and Sagittarius A*, the supermassive black hole at the center of the Milky Way. It turns out it was easier to image M87's black hole. That beast is 55 million light-years from Earth in the constellation Virgo, about 2,000 times as far away as Sgr A*. But it's also about 1,000 times as massive as the Milky Way's giant, which weighs the equivalent of roughly 4 million suns. The extra heft nearly balances out M87's distance.

Due to its gravitational oomph, gases swirling around M87's black hole move and vary in brightness more slowly than those around the Milky Way's. "During a single observation, Sgr A* doesn't sit still," Özel says. "We knew M87 would cooperate more."

With more data and analysis, the team hopes to solve some long-standing mysteries, such as how M87's behemoth spews a bright jet of charged particles many thousands of light-years into space. And hopes are still high for a view of Sgr A*. Studying such different environments could reveal more details of how black holes behave.

The new image "gives a glimpse of what the future might hold, but it doesn't give us all the information that we want," says Harvard University astrophysicist Avi Loeb, who isn't on the EHT team.

The next look at the M87 and Milky Way behemoths will have to wait. Scientists got a lucky stretch of good weather at all eight observatories that made up the EHT in 2017. Bad weather in 2018 and technical difficulties, which canceled the 2019 observing run, stymied the team. But by 2020, there will be 11 observatories, including additions in Greenland, Arizona and the French Alps. That should provide the extra eyes needed to bring black holes into even greater focus. ■

Staff writer Maria Temming contributed to this story.

EVENT HORIZON TELESCOPE COLLABORATION *ET AL*

For extended coverage of the Event Horizon Telescope, visit **www.sciencenews.org/eht**

How to take a picture of a black hole

Scientists crunched data from a global network of telescopes

BY MARIA TEMMING

Black holes are camera shy. Supermassive black holes, ensconced in the centers of galaxies, reveal themselves by spewing jets of charged particles or by flinging away or ripping up nearby stars. Up close, these behemoths are surrounded by glowing accretion disks of infalling material. But because a black hole's extreme gravity prevents light from escaping, the dark hearts of these cosmic heavy hitters remain invisible.

Luckily, there's a way to "see" a black hole without peering into the abyss itself. Telescopes can look for the silhouette of a black hole's event horizon — the perimeter inside which nothing can be seen or escape — against the black hole's accretion disk. That's what the Event Horizon Telescope, or EHT, has done; data collected in April 2017 has now yielded the first image of a black hole, the supermassive one inside galaxy M87.

"There is nothing better than having an image," says Harvard University astrophysicist Avi Loeb. Though scientists have plenty of indirect evidence for black holes, "seeing is believing," he says.

Weighing about 6.5 billion times the mass of our sun, M87's supermassive black hole is no small fry. But viewed from 55 million light-years away on Earth, it is only about 42 microarcseconds across on the sky. Still, besides the black hole at the center of our galaxy, M87's is the largest one on the sky.

Only a telescope with unprecedented resolution could pick out something so tiny. (The Hubble Space Telescope can distinguish objects only about as small as 50,000 microarcseconds.) A telescope's resolution depends on its diameter: Getting a crisp image of a supermassive black hole required a planet-sized radio dish.

"The trick is that you don't cover the entire Earth with an observatory," says Loeb, who is not involved with EHT.

Instead, EHT used very long baseline interferometry, which combines radio waves seen by many telescopes at once, so that the telescopes work together like one giant dish. The diameter of that virtual dish is equal to the length of the longest distance, or baseline, between two telescopes in the network.

In 2017, EHT had eight observatories in North America, Hawaii, Europe, South America and at the South Pole working in tandem. All but the South Pole Telescope could see M87, which is in the northern sky. On their own, the data from each station looked like nonsense. But together, they revealed M87's black hole.

Here's how it worked. Picture a pair of radio dishes aimed at the black hole's ring-shaped silhouette. Radio waves emanating from each bit of that ring traveled slightly different paths to each telescope. These waves interfered with each other, sometimes reinforcing one another and sometimes canceling each other out. The interference pattern seen by each telescope depended on how the waves from different parts of the ring were interacting when they reached that telescope.

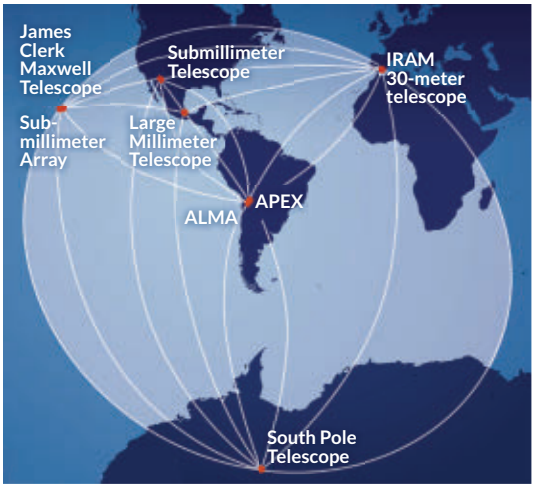
For simple targets, radio wave patterns picked up by a pair of telescopes provide enough info for scientists to work backward and figure out what distribution of light must have produced the data. But for a source with a complex structure like a black hole, there are too many possible solutions for what the image could be.

So an array for seeing a black hole needs as many baselines of different lengths and orientations as possible. Telescope pairs that are farther apart see finer details, because there's a bigger difference between the paths that waves take from the black hole to each telescope.

To braid together the observations, researchers used atomic clocks to record times for the data with exquisite precision. These data were sent to the MIT Haystack Observatory in Massachusetts and the Max Planck Institute for Radio Astronomy in Bonn, Germany, for processing in a supercomputer. Each observatory amassed hundreds of terabytes of information — far too much to send over the internet. So the team used snail mail.

Combining the data still wasn't enough to render a vivid picture of M87's black hole. If it were a song, then imaging it using only the combined data would be like listening to the piece played on a piano with some broken keys. The more working keys — or telescope baseline pairs — the easier it is to get the gist of the melody. "Even if you have some broken keys, if you're playing all the rest of them correctly, you can figure out the tune, and that's partly because we know what music sounds like," says Vincent Fish, an astronomer at Haystack. "We can reconstruct images, even though we don't have 100 percent of the information," he says, "because we know what images look like."

Mathematical rules govern how much randomness any given picture can contain, how bright it should be and how likely it is that neighboring pixels will look similar. Those guidelines informed how researchers decided which data interpretations made the most sense, creating the image of M87's black hole. ■



In 2017, eight observatories teamed up in the Event Horizon Telescope to peer at two supermassive black holes: one at the center of the Milky Way and one in galaxy M87. Combining data collected by pairs of telescopes allowed the network to act like one giant radio dish.

NRAO/AUI AND NSF

BODY & BRAIN

Lab-grown blood vessels show promise

Cells from dialysis patients integrated into bioengineered tubes

BY MARIA TEMMING

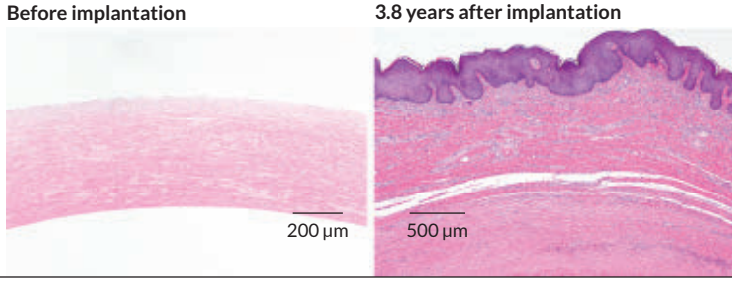
Bioengineered blood vessels are one step closer to being available for patients.

In clinical trials, these vessels were implanted in the arms of dialysis patients and successfully integrated into their circulatory systems, researchers report in the March 27 *Science Translational Medicine*. The new blood vessels, which eventually hosted the patient's own cells after implantation, are designed to be safer and more effective than current options. Traditional implants composed of synthetic polymers or donor tissue are liable to trigger inflammation or immune system rejection.

Hundreds of thousands of people in the United States alone require blood vessel implants for a type of dialysis called hemodyalisis that involves filtering a patient's blood through a machine. The procedure requires implanting a large extra vessel in the arm to serve as a circulatory detour, feeding blood into the dialysis machine.

The bioengineered vessels would not only help those dialysis patients but also patients who have lost blood vessels through tumor removal or injury, says Christopher Breuer, director of the Center for Regenerative Medicine at Nationwide Children's Hospital in Columbus, Ohio.

Heather Prichard, a biomedical engineer at the medical company Humacyte in Durham, N.C., and colleagues created each blood vessel by seeding a biodegradable polymer tube first with vascular cells from a deceased donor. The team placed the tube inside a bioreactor that supplied the vascular cells with nutrients, and then these cells multiplied and secreted proteins that formed an intercellular network (*SN: 2/26/11, p. 11*). After eight weeks, the polymer scaffold had broken down, and the researchers stripped the donor cells from the remaining protein tube, leaving no living material behind. The roughly 6-millimeter-wide vessel was then implanted into the patient, where the patient's own cells gradually migrated into the tube.



A bioengineered blood vessel grown in a lab is devoid of cells upon implantation (cross section of the tube stained pink, left). After almost four years, cells from the patient have moved into the blood vessel (cell nuclei stained purple, right) to build up mature blood vessel tissue (pink). Purple tissue on top is skin.

R.D. KIRKTON *ET AL/SCIENCE TRANSLATIONAL MEDICINE* 2019

MATTER & ENERGY

In an engine test, quantum wins

Tiny machine packs more power than a standard device

BY EMILY CONOVER

For the first time, a quantum engine has outperformed its traditional equivalent without any special tweaks to the environment.

The device harnesses the weird physics of very small objects to produce more power than a standard, or classical, engine under the same conditions, scientists report in a study published in the March 22 *Physical Review Letters*.

"They've shown very convincingly that the quantum machine performs better than the classical," says physicist Mark Mitchison of Trinity College Dublin. "It's a very important step forward."

The device is a type of engine called a heat engine. Traditional heat engines turn heat into motion. For instance, a car's internal combustion engine burns fuel to move pistons up and down, and the car moves forward.

Other heat engines have boasted power increases over normal limits. But those machines relied on tweaks to the environment outside the main machine — for example, the machine's heat source may have been imbued with beneficial properties — so the extra power wasn't entirely a feature of the machine itself.

In the new research, the quantum engine works not by igniting gasoline, but by using a laser to cause an electron within a tiny defect of a diamond crystal to jump between energy levels. And instead of moving pistons, the quantum machine outputs its power as electromagnetic waves.

Here's where the quantum part comes in: Objects that behave according to quantum mechanics are sometimes found in a limbo known as superposition, meaning they're caught in two places at once, or in two different configurations. The electron in the quantum engine can be in a superposition of two energy levels. It's as if a car engine's piston were simultaneously in the up and down positions.

Under certain conditions, that property, the scientists report, results in increased power output as compared with the maximum power possible in a traditional heat engine. "This is the first experiment where this kind of regime was reached," says physicist Roberto Serra of the Federal University of ABC in Santo André, Brazil.

But the researchers "don't have a complete characterization of the quantum engine," Serra says. The team estimated the engine's output power but not other qualities, such as efficiency. So future experiments should further investigate this type of machine, he says.

The quantum power boost shows

"Think of this as an apartment building without any tenants," says Laura Niklason, a biomedical engineer at Yale University. The protein tube is "an empty space for [the patient's] cells to come in and occupy."

The researchers tested the vessels in 60 people with kidney disease who needed hemodialysis.

The newly engineered blood vessels didn't trigger any significant immune reactions in any of the patients. Tissue samples from 13 participants revealed that the vessels had matured within one to two years after implantation. The patients' bodies had populated the new blood vessels with both smooth muscle cells like those that normally compose blood vessel walls as well as endothelial cells, which coat blood vessels' inner surfaces. The new vessels also became covered in microvessels that supplied oxygen and nutrients to the implants.

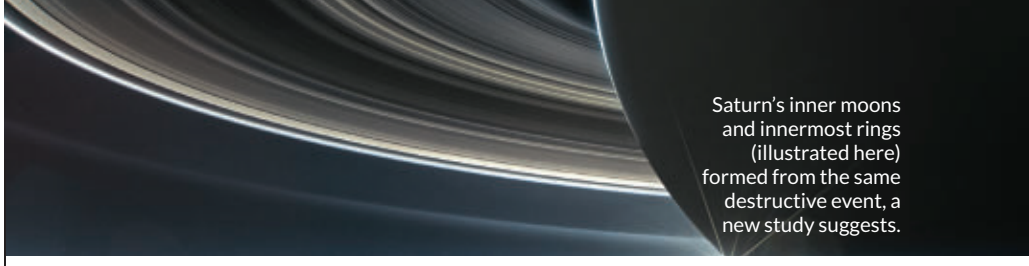
The researchers are now testing the effectiveness of their vessels compared with a synthetic alternative in a clinical trial involving hundreds of patients. ■

up only when the engine is operated extremely gently, like a car engine in which the pistons move only slightly during each cycle. That means the quantum machine doesn't blow all possible competitors out of the water, only those that are also operated in this gentle state — which most aren't.

So don't expect these quantum engines to be powering vehicles or devices anytime soon. "If you're trying to build a car or a jet engine ... it's absolutely useless," says study coauthor Ian Walmsley, a physicist at Imperial College London.

Instead, the study reveals new details of how quantum mechanics meshes with thermodynamics, the theory that governs heat, temperature and energy (*SN: 3/19/16, p. 18*). In this case, the new engine reveals a loophole to normal limits on power generation. "We haven't changed the structure of thermodynamics, but we've unlocked a new piece of it," Walmsley says. ■

FROM TOP: J. KIM ET AL/SCIENCE 2019



Saturn's inner moons and innermost rings (illustrated here) formed from the same destructive event, a new study suggests.

ATOM & COSMOS

Saturn's rings paint inner moons

Satellites show color variation based on distance from planet

BY LISA GROSSMAN

Saturn's rings are painting the planet's innermost moons. Data from NASA's now-defunct Cassini spacecraft show that five moons embedded in Saturn's rings are different colors. The hues come from the rings themselves. That observation could help scientists figure out how the moons were born.

"The ring moons and the rings themselves are kind of one and the same," says planetary scientist Bonnie Buratti of NASA's Jet Propulsion Laboratory in Pasadena, Calif. "For as long as the moons have existed, they've been accreting particles from the rings."

Saturn has more than 60 moons, but those nearest to the planet interact closely with its main band of rings. Between December 2016 and April 2017, Cassini passed by five of these ring-dwelling moons: Pan (*SN: 4/15/17, p. 10*), Atlas, Daphnis (*SN: 9/2/17, p. 16*), Pandora and Epimetheus. The flybys brought Cassini between two and 10 times closer to those moons than it had ever been, before the NASA spacecraft deliberately crashed into Saturn in September 2017.

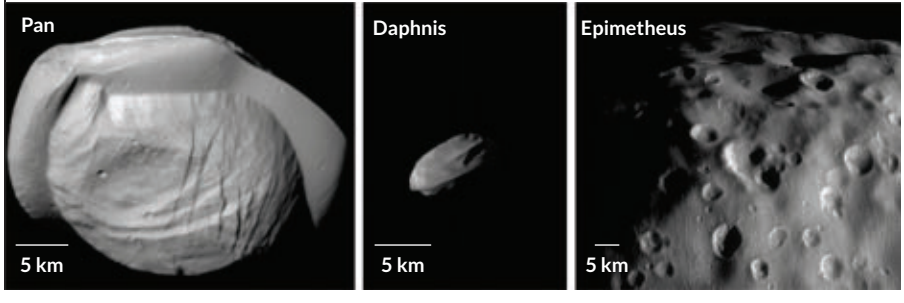
Examining those close-ups, Buratti and colleagues noticed that the moons' colors vary depending on the objects' distances from Saturn. And the moon hues are similar to the colors of the rings that the objects are closest to, the team reports online March 28 in *Science*.

Close-in Pan is the reddest moon, and farthest-out Epimetheus is the bluest. The researchers think the red material comes from Saturn's main rings and mostly consists of organics and iron. The blue material is probably water ice from Saturn's more distant E ring, which is created by plumes erupting from the larger icy moon Enceladus.

The team thinks that the rings are continually depositing material onto the moons. "It's an ongoing process," Buratti says. She notes that "skirts" of material at Atlas' and Pan's equators are probably made of accreted ring debris, too.

The overall similarity between the moons and rings led the researchers to conclude that the moons are leftover shards of a destructive event that created the rings. But whether that event was a collision between long-gone, larger moons, the shredding of one moon by Saturn's gravity or some other occurrence is unknown (*SN: 1/20/18, p. 7*).

The idea that the rings are still shedding material onto the moons "sounds perfectly reasonable," says planetary scientist Matija Ćuk of the SETI Institute in Mountain View, Calif. But he isn't sure the moons formed at the same time as the rings. It's possible, he says, "they formed from the rings since that catastrophic event." ■



Five of Saturn's ring-dwelling moons (three shown here in gray-scale images) appear to be picking up debris from the rings.

LIFE & EVOLUTION

Fossils may reveal asteroid's aftermath

Scientists claim site dates to the day of the dino-killing impact

BY CAROLYN GRAMLING

About 66 million years ago, an asteroid smashed into Earth off the coast of what's now Mexico. Less than an hour later, a riverbed 3,000 kilometers away sloshed violently back and forth, swiftly burying fish, plants and other organisms in the sediment, a study suggests. Signs of those surges, and traces of the impact itself, appear to be preserved in a thick layer of rock in North Dakota.

Set off by the impact, a giant earthquake — equivalent to a magnitude 10 or even 11.5 — sent seismic waves through Earth's crust, triggering the sloshing, researchers argue online April 1 in the *Proceedings of the National Academy of Sciences*. If true, the scenario would add a new kill mechanism to the extinction event that marks the boundary between the Cretaceous and Paleogene periods, often called the K-Pg. At least 75 percent of species, including all nonbird dinosaurs, died out (*SN: 2/4/17, p. 16*).

The site, dubbed Tanis, offers a unique snapshot of what happened in the immediate aftermath of the impact, says paleontologist Robert DePalma of the University of Kansas in Lawrence.

"It's a critical moment in time," he says. "We have a high-resolution image of the first couple of hours after the impact. That level of detail is not really known elsewhere."

Yet the publication of the paper was overshadowed by a profile of DePalma published online March 29 in the *New Yorker*, just a few days before the study's planned release. The profile included tantalizing hints of fossilized dinosaurs and pterosaurs and even rarely preserved feathers that the researchers say they found at Tanis. If so, the site could hold the answer to a much larger question: Was it really the asteroid strike that killed dinosaurs, or were they already dying out? The new paper doesn't discuss those fossils, and paleontologists have expressed skepticism and frustration over how to evaluate the claims.

The paper in *PNAS* does provide evidence that the fossil site opens a window on a key time in Earth's history. At Tanis, a river once drained eastward from a vast inland sea. Sandy deposits reveal where the meandering river carved a deep channel into the rock. Above that channel lies an unusual rock sequence that DePalma and colleagues call the "event deposit." That 1.3-meter-thick layer has two distinct sublayers. The bottom layer has large pebbles at its base and finer-grained sediment toward the top, ending in fine silt. Overlying that is another layer that starts with large sand grains and then gets finer toward the surface. This pattern, along with the direction of water flow preserved by the grains, points to a massive inundation, DePalma says.

The deposit also contains tiny glass spheres, remnants of vaporized rock cast into the atmosphere from the impact that then rained back down potentially thousands of kilometers away. Fossils are also abundant in the deposit, particularly bits of logs and groups of fish skeletons. The fish, the researchers say, may have died en masse after becoming rapidly buried by mud displaced during the inundation. Some of the fish's gills contain the tiny spherules, possibly snagged from the water just before death.

Above the event deposit is a thin layer of volcanic ash–turned–clay that also is found in other parts of the central United States. The layer contains impact spherules and dates to the K-Pg, helping connect Tanis to the extinction event.

The spherules embedded in the event deposit indicate that the powerful wave action must have occurred nearly instantly after the impact, DePalma says. Strong seismic waves might have shaken up a local body of water, such as a river or lake, producing the deposits.

The team convincingly argues that the whole sequence of events took only a few hours, says Paul Olsen, a paleontologist at Columbia University's Lamont-Doherty Earth Observatory in Palisades, N.Y. Fish consumed the spherules that rained into the water, became entombed in sediment displaced during the sloshing of the water, and were then covered by a second layer of sediment bearing iridium, an element found in asteroids. "They've got that nailed. It's hard to imagine how that would occur any other way," Olsen says.

Jessica Whiteside, a geochemist at the University of Southampton in England, agrees that the sedimentary evidence supports the idea that the impact produced violent sloshing. And the possibility that a massive quake provoked those waves is plausible, she adds.

"But it's not the only plausible sequence of events that could have happened," she says. And there may be no

These fossil fish, found in North Dakota, were buried in mud 66 million years ago when an asteroid hit Earth and caused violent shaking, researchers say.

R. DEPALMA/UNIV. OF KANSAS

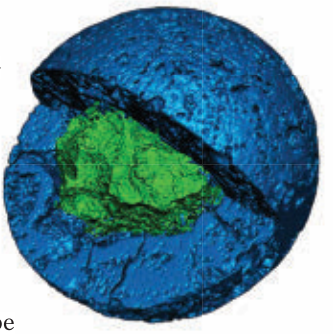
way to know for sure if the scenario is the right one, or the exact timing of the seismic waves' arrival, because there are so many unknowns about the lay of the land 66 million years ago.

"That said, I find it really exciting work," Whiteside says.

Antoine Bercovici, a paleobotanist and sedimentologist at the Smithsonian Institution in Washington, D.C., says the fish fossils are "pretty amazing." Yet, he's a bit skeptical that the fossils' haphazard orientation definitively represents a snapshot of mass death right as the waves impacted the animals, spherules still held in their mouths. "It's a bit dramatic and hard to verify," he says.

But the drama of a mass fish grave is minimal compared with the reaction to some of the other fossils DePalma says that he has found, as described in the *New Yorker* profile: a mammal burrow, dinosaur feathers, the hip bone of a horned dinosaur with a skin impression.

A general dearth of dinosaur fossils dating to just before the impact has led some scientists to speculate that the animals were already vanishing before the asteroid hit. So the discovery of dino fossils at Tanis could help prove the impact was the culprit after all.



As an asteroid hit Earth, it vaporized rock, sending spherical particles into the air that rained down far from the impact. One such spherule is shown here in a micro-CT image (green is a silicate glass core; blue is a layer that has weathered to clay).

That wouldn't, in itself, be that surprising. Most paleontologists think that the dinosaurs survived up to the K-Pg impact. Still, such extraordinary claims for what Tanis holds require extraordinary evidence, says Thomas Holtz, a paleontologist at the University of Maryland in College Park. "A lot of the reaction to this stems from the particulars of how the announcement came out," Holtz says, referring to the publication of the *New Yorker* article ahead of the journal article. Either the findings should have been included in the paper, or they shouldn't have been reported in advance if the researchers weren't ready to reveal the data, Holtz says.

And for now, DePalma and colleagues' data on those tantalizing dinosaur fossils remain unpublished. DePalma says he didn't want the information about the dinosaurs to appear in the *New Yorker*. "Of course we'd seek to keep that under wraps; we want to publish it later."

Whether Tanis contains dinosaur fossils, the site is still interesting, Bercovici says. "Tanis is the first unequivocal site of this kind," in that it represents the first minutes of impact. Furthermore, he adds, although dinosaurs tend to take center stage in the popular imagination, "the K-Pg extinction is not a nonavian dinosaur story. It involved the demise of entire and complex ecosystems." ■

R. DEPALMA/UNIV. OF KANSAS

BODY & BRAIN

Young testicle grafts preserve fertility

Tests in monkeys show promise for childhood cancer patients

BY AIMEE CUNNINGHAM

A technique with the potential to preserve fertility for prepubescent boys with cancer has passed a key test in monkeys: the birth of a healthy infant.

Testicle tissue from rhesus macaques that had not yet reached puberty was removed, frozen and then grafted back onto the monkeys. Over the following year, as the monkeys went through puberty, immature sperm cells in the grafts developed into sperm. In vitro fertilization with sperm from one monkey led to a successful pregnancy and the birth of a female named Grady, researchers report in the March 22 *Science*.

The work is an encouraging step toward one day preserving the fertility of prepubescent boys who undergo chemotherapy and radiation for cancer, which can affect the ability to produce sperm, says Robert Brannigan, a reproductive urologist at Northwestern University Feinberg School of Medicine in Chicago who was not involved in the study.

This rhesus macaque was conceived with sperm from frozen, immature testicle tissue that was later grafted back onto the donor.

Survival rates of at least five years for children with cancer in the United States are about 80 percent. But unlike teens or adults, younger boys haven't yet developed sperm that can be frozen for future use. The new work provides "a potential pathway to solving this very real clinical problem," Brannigan says.

At some hospitals, young male cancer patients already have the option to preserve tissue from one of their immature testicles before undergoing treatment. "We tell patients that we have something in the research pipeline ... but we have no guarantees," says reproductive biologist Kyle Orwig of the University of Pittsburgh School of Medicine.

Orwig and his colleagues removed testicle tissue from five prepubescent monkeys and froze samples for up to five months. The researchers then grafted the tissue back onto each monkey, under the skin on both the back and scrotum. Over the next eight to 12 months, the grafted tissue grew, produced testosterone and developed sperm in all five monkeys. One monkey's sperm was used to create embryos and impregnate a female, resulting in Grady.

This study provides evidence of functional sperm — and the first birth of a healthy baby — from frozen, immature testicle tissue grafted back to the donor monkey. The work supports further testing to explore whether the procedure might work for people, researchers say. ■

GENES & CELLS

Sperm DNA gets closer scrutiny

Dad's health contributes to miscarriages, study hints

BY AIMEE CUNNINGHAM

NEW ORLEANS — For couples who have suffered repeated miscarriages, it may be useful to scrutinize the man's reproductive health as closely as the woman's. Some miscarriages may be linked to abnormalities in semen, a study finds.

Researchers analyzed semen from 49 men whose partners had lost three or more consecutive pregnancies before the 20-week mark. The men had sperm with more than twice as much DNA damage and semen with more than four times the amount of potentially harmful molecules called reactive oxygen species as samples from healthy men screened for fertility issues, the team reported March 24 at the Endocrine Society's annual meeting.

After repeated miscarriages, "historically, clinicians have focused on the woman having some health problem," says endocrinologist Bradley Anawalt of the University of Washington School of Medicine in Seattle, who was not involved in the study. The new research suggests that "perhaps the man is contributing something that is leading to early pregnancy loss on a regular basis," he says.

Roughly 1 to 2 percent of couples experience recurrent pregnancy loss, traditionally defined as the loss of three or more pregnancies in a row before the 20th week. But this estimate is based on limited epidemiological evidence.

Cases of recurrent pregnancy loss can be traced to chromosomal abnormalities in the embryo or health issues in the mother. But in up to 50 percent of cases, no explanation can be found. Previous studies have pointed to unhealthy sperm as possibly being behind some unexplained cases.

Past research also has suggested that sperm play a role in the development of the placenta, the proper functioning of which "is absolutely critical in preventing miscarriage," says reproductive endocrinologist Channa Jayasena of Imperial College London.

But in terms of measuring sperm quality, "traditionally we've looked down our microscope and we've said how many sperm are there, how many of the sperm are moving and how many of them look really good — and that is very subjective," Jayasena says. To identify more objective markers, he and colleagues measured the amount of reactive oxygen species in the semen samples — high levels can damage DNA — and breaks in sperm DNA.

The next steps are to study how some men develop these abnormalities and figure out how the defects might cause miscarriages, Jayasena says. ■

A. P. FAYOMI *ET AL*/*SCIENCE* 2019

BODY & BRAIN

Exercise boosts memory, but not for all

A single workout may predict long-term benefits in older people

BY LAURA SANDERS

For some older people, the brain boosts from exercise can be almost immediate.

Improvements in thinking abilities after a single 20-minute bout of pedaling a stationary bike mirrored those produced by three months of regular exercise, according to a preliminary study presented March 24 at the annual meeting of the Cognitive Neuroscience Society.

The results suggest that short-term gains may predict who will benefit from long-term exercise.

The similarity between a single bout of exercise and months of training "suggests we don't have to wait three months to see an improvement," said Michelle Voss, a cognitive neuroscientist at the University of Iowa in Iowa City. "We can get a day-by-day boost."

Voss and her colleagues enlisted 34 people with an average age of 67 to undergo brain scans and memory tests and to exercise. In the first part of the investigation, she and colleagues were looking for effects of a single 20-minute bout of exercise on a stationary bike, designed to be rigorous enough to make people sweat. Participants were huffing and puffing but could still talk during the workout.

Before and after exercising, participants underwent functional MRI brain scans and took memory tests that involved remembering previously seen faces. On a different day, participants had similar brain tests after spending 20 minutes on a bike that pedaled for them.

On average, people were better at remembering the faces, especially when the memory task was difficult, after 20 minutes of intense exercise than after sitting on the self-pedaling bike. In addition, certain connections between different brain areas got stronger after the rigorous exercising, the fMRI scans showed.

Participants then were divided into two groups — one that spent the next three months exercising on a stationary bike three times a week for 50 minutes and one that spent just four minutes exercising three times a week. Overall, people who did the longer workouts performed better on the memory task than participants who exercised for 12 minutes a week.

But within that average, people's responses varied. To Voss' surprise, the people who improved a lot after 20 minutes had similar memory improvements and similar brain changes after the three months. And those who didn't improve after the 20 minutes were less likely to have improved after three months.

> Certain connections between brain areas got stronger after rigorous exercise.

"If it's not working for some people, that's good to know," Voss says. "But you can go one step further and ask, 'Are the reasons it's not working modifiable? And can we learn that quickly? Can we fail fast?' "

Teasing apart the individual variation among exercise effects is "really exciting," says cognitive neuroscientist Wendy Suzuki of New York University. She cautions that the study is preliminary. Still, she says, "this is exactly the right question to ask."

Suzuki likes to think of exercise as medicine. "The key word is 'personalized' medicine," she says. "Can it be designed for you at your age and fitness level and gender and genetic background?"

The answer, Suzuki says, is theoretically yes, though scientists still have much more research to do to understand how working out affects people differently. ■

MEETING NOTE

Epileptic seizures may disrupt memories during sleep

Seizures during sleep can scramble memories — a preliminary finding that may help explain why people with epilepsy sometimes have trouble remembering.

The sleeping brain normally rehashes newly learned material, a nocturnal rehearsal that strengthens those memories. Neuroscientist Jessica Creery and colleagues forced this rehearsal by playing certain sounds while nine people with epilepsy learned where on a screen certain pictures of common objects were located. Then, while the subjects later slept, the researchers played the sounds to call up some of the associated memories.

This method of strengthening memories, called targeted memory reactivation, worked as expected for five people who didn't have seizures while sleeping. When these people woke up, they remembered the picture locations reactivated by a tone better than those that weren't reactivated during sleep, said Creery, of Northwestern University in Evanston, Ill. She presented the research March 25 at the annual meeting of the Cognitive Neuroscience Society.

The opposite was true, however, for four people who had mild seizures while they slept, detected only by electrodes implanted deep in the brain. For these people, memory reactivation during sleep worsened those reactivated memories, making them weaker than the memories that weren't reactivated during sleep. The combination of seizures and memory reactivation "seems like it's actually scrambling the memory," Creery said, a finding that suggests that seizures somehow accelerate forgetting.

— Laura Sanders

LIFE & EVOLUTION

Fossils expand variety of early life

Site in China offers a new look at the Cambrian explosion

BY CAROLYN GRAMLING

China's Qingjiang fossils, dating to about 518 million years ago, help document the Cambrian explosion. Fossils shown here, from left, are a jellyfish, a segmented animal and a branched alga.

Along the banks of China's Danshui River lies a treasure trove of fossils that may rival the most famous Cambrian fossil assemblage, Canada's Burgess Shale. The roughly 518-million-year-old Chinese fossils, known as the Qingjiang biota, include a dizzying abundance of beautifully preserved life-forms, from jellyfish and comb jellies to arthropods and algae.

So far, scientists led by paleontologist Dongjing Fu of Northwest University in Xi'an, China, have collected 4,351 specimens, representing 101 different taxa, or groups of organisms. Of those taxa, about 53 percent have never before been observed, Fu and her colleagues report in the March 22 *Science* — not even at other well-known Cambrian sites such as the 508-million-year-old Burgess Shale or the 518-million-year-old Chengjiang site in China (see Page 32).

"It's an exciting discovery," says paleontologist Jean-Bernard Caron of the Royal Ontario Museum in Toronto, who wasn't involved in the research. During the Cambrian Period, which began about 541 million years ago, life diversified extremely rapidly in an event known as the Cambrian explosion. The new find "shows that there's hope for new discoveries" of other Cambrian sites, Caron says.

Such sites represent snapshots of life long ago, and no one site can portray the true diversity of life at any given time, Caron says. "It's a giant jigsaw puzzle, and we only have a few pieces.... But the more pieces we have, the better chance we have to understand life during that time."

The new fossil trove was first spotted in 2007, says coauthor Xingliang Zhang, a paleontologist also at Northwest University. During a field expedition, he and his students were investigating a different Cambrian-aged rock layer. At lunchtime, he happened to sit on the next lower rock layer as it was being lapped by water from the Danshui River. He recognized that the fine clay layer was the perfect preservation setting for fossils. "We split the clay stone, and I found a *Leanchoilia* quickly," he says. After the discovery of that segmented arthropod, more finds soon followed.

The site is remarkable for the quality of the preservation, says Allison Daley, a paleontologist at the University of Lausanne in Switzerland who wrote a commentary accompanying the report in *Science*. Unlike at some Cambrian fossil sites, including Burgess and Chengjiang, there is little metamorphism or weathering with the Qingjiang biota, she says. "We see almost pristine fossils at this site." She mentions one startlingly clear image of a jellyfish. "I mean, if you were going to smack a jellyfish on a rock, that's how it would look."

The Qingjiang fossils appear to have a high proportion of jellyfish and comb jellies. These species, particularly the comb jellies, are extremely rare at other Cambrian sites.

The opportunity to study so many well-preserved comb jelly fossils may help answer a long-standing debate, Daley says: whether comb jellies or sponges are the most primitive animal on their family tree. Scientists have thought that sponges were closer to the base of the tree, based on their very simple shapes. But some molecular analyses have hinted that comb jellies may be at the tree's base (*SN: 1/25/14, p. 16*).

"It's hard to disentangle the exact relationships of these [creatures]," Daley says. "Getting more info on [them] at this new site, where the preservation is really amazing, is really going to fill a gap."

The Burgess Shale, discovered in the Canadian Rockies in 1909, gave scientists their first glimpse at the Cambrian explosion. The Burgess and Chengjiang sites, separated by 10 million years and half a world today, share only about 15 percent of the same taxa.

The lack of overlap might be expected, Daley says, given the differences in both space and time. But the Qingjiang and Chengjiang sites, which date to the same time and are separated by only 1,050 kilometers today, share just 8 percent of their taxa, she says. The researchers suggest that the Qingjiang site may have been a slightly deeper marine environment. That difference in ancient environments may explain why the assemblage of creatures is so different, Daley says.

The new work represents just the first of what is likely to be a deluge of Qingjiang studies, Zhang says. "We're just beginning."

Even after 110 years of digging in the Burgess Shale, paleontologists there are still turning up bizarre new creatures, Caron adds. ■

D. FU ET AL/SCIENCE 2019

HUMANS & SOCIETY

Denisovan skull fossil ID'd for first time

The hominids may have lived as recently as 15,000 years ago

BY BRUCE BOWER

A palm-sized section of a braincase is the first Denisovan skull fossil ever found.

Discovered in two pieces in Siberia's Denisova Cave in 2016, the find joins only a handful of fragmentary fossils from these mysterious, extinct hominids. Mitochondrial DNA, a type of DNA typically inherited from the mother, extracted from the skull pegged it as Denisovan, paleoanthropologist Bence Viola said March 28 at a meeting of the American Association of Physical Anthropologists.

Viola's presentation was one of several that raised new questions about these Neandertal relatives, including how recently they existed. The population is known only from discoveries in Denisova Cave. A decade ago, a finger bone yielded DNA that helped identify the population. Sediment analyses indicate that Denisovans periodically inhabited the cave from about 300,000 to 50,000 years ago, with Neandertals reaching the cave after about 200,000 years ago (*SN: 3/2/19, p. 11*).

But little else is known about the evolutionary history or identity of Denisovans. It's unclear, for instance, if they belonged to a distinct *Homo* species. Most researchers say the new evidence is not enough to resolve that mystery.

"We're a long way from solving the species question about Denisovans," paleoanthropologist Chris Stringer of the Natural History Museum in London said at the meeting.

Viola, of the University of Toronto, and colleagues compared a digital reconstruction of the skull fragment with corresponding parts of 112 present-day human skulls and 30 Stone Age *Homo* skulls, including *Homo sapiens* and Neandertals. The Denisovan find doesn't fit neatly into any known species. Some features link the fossil to Neandertals and to a 430,000-year-old Spanish *Homo* species that had Denisovan ancestry (*SN: 12/28/13, p. 8*). The Denisovan skull fragment is surprisingly thick, like cranial bones of *Homo erectus*, Viola said.

Such evidence is tough to interpret, paleoanthropologist María Martinón-Torres of University College London said. Interbreeding of closely related populations, such as Denisovans, Neandertals and *H. sapiens*, generates novel features that can obscure what started out as, say, a distinctive Denisovan look, she said.

Whatever evolutionary niche these hominids occupied, at least three separate Denisovan populations interbred with ancient humans, reported population geneticist Murray Cox of Massey University in Palmerston North, New Zealand. Genetic remnants of two of those populations appear in modern aboriginal groups in Papua New Guinea, Cox and colleagues found.

People in Papua New Guinea interbred with one genetically distinct Denisovan population about 46,000 years ago, the team estimates. Interbreeding with a second Denisovan line took place by about 30,000 years ago and possibly as recently as 15,000 years ago.

If that recent estimate is correct, "Denisovans were the last surviving hominids who were not *Homo sapiens*," Cox said. Those survivors probably inhabited Papua New Guinea or a nearby island.

His team probed about 3,000 DNA samples from about 100 communities in Papua New Guinea and other Southeast Asian islands for signs of Denisovan ancestry. The analyses suggest that some people now living in Papua New Guinea and nearby islands carry about 400 Denisovan genes involved in immune and dietary functions. Denisovan DNA previously identified in Siberians, East Asians and Native Americans does not occur in people from islands in Southeast Asia and thus represents a third Denisovan line.

"We had no idea there were different Denisovan populations on Southeast Asian islands until now," said paleoanthropologist John Hawks of the University of Wisconsin–Madison. ■

M. BIETAK © ÖAI/OREA

MEETING NOTE

Foreigners in ancient Egypt married into power

A foreign dynasty that ruled ancient Egypt for about a century gained power not by force but by marrying into royalty, a new study suggests.

Hyksos people, thought to have come from West Asia, reigned in Egypt from about 3,650 to 3,540 years ago. Later Egyptian pharaohs called the Hyksos invaders, but no evidence of battles has been found.

An influx of mostly female immigrants may have occurred at Tell el-Dab'a, which became the Hyksos capital, shortly before the foreigners took over. "Hyksos people … appear to have been an elite group that gained power from within," Christina Stantis of Bournemouth University in Poole, England, said March 29 at a meeting of the American Association of Physical Anthropologists.

She and Bournemouth colleague Holger Schutkowski looked at strontium in teeth from people excavated at Tell el-Dab'a. Measures of strontium are geographically distinct, indicating regions where people have lived. Twenty-one of 27 females interred in elite graves dating to shortly before Hyksos rule came from outside the Nile Valley. Only a few nonlocal elite males came from that period. Female-skewed immigration fits a scenario in which Hyksos women married into Egyptian royal families. — *Bruce Bower*

An analysis of teeth hint that the Hyksos dynasty, represented here by palace remnants, married into power.

LIFE & EVOLUTION

Pumpkin toadlets sport bones that glow through the skin

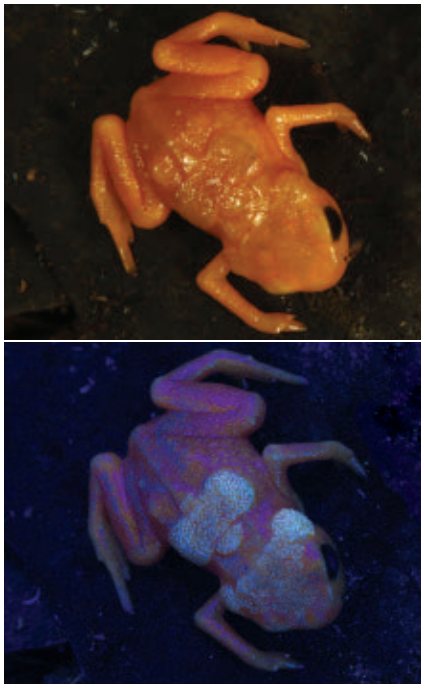
When a group of biologists realized that pumpkin toadlets have no middle ear bone, the team was stumped. That meant that these tiny toxic frogs native to southeastern Brazil couldn't hear each other's high-pitched chirps, which is how most frogs attract mates.

Suspecting that the frogs use a less obvious form of communication, similar to parrots attracting mates with feathers that fluoresce, the team aimed an ultraviolet lamp at the orange frogs. Bony plates just beneath the skin on the frogs' heads and backs glowed blue.

The frogs join chameleons as the only land vertebrates known to show bone fluorescence, the scientists report online March 29 in *Scientific Reports*.

All bone fluoresces under UV light, but usually layers of skin, muscle and fat block that light from getting out. The skin covering the toadlets' plates, however, is thin and lacks the pigmented cells that block UV light from getting through skin.

These traits may allow the frogs to communicate using fluorescence, possibly for luring potential mates or warning would-be predators, evolutionary biologist Sandra Goutte of New York University Abu Dhabi in the United Arab Emirates and colleagues speculate. — *Jeremy Rehm*



Pumpkin toadlets have bony plates that glow through the skin when under ultraviolet light.

S. GOUTTE, CARLOS JARED

GENES & CELLS

Geneticists close in on how mosquitoes sniff out humans

Geneticists have found a scent-sniffer protein in mosquito antennae that — if somehow jammed — might leave a blood-sucker confused about whether we're human enough to bite.

Aedes aegypti mosquitoes, which can spread Zika and dengue, prefer human blood to the blood of other animals. New experiments show that the protein IR8a, found in the antennae, is necessary for detecting lactic acid in human sweat. Intense lactic acid may help ID humans.

IR8a's role was revealed in part by how mutant *Ae. aegypti* mosquitoes behave. Mutants with nonworking IR8a were about half as likely to settle on a human arm or sweat-stained sleeve as normal mosquitoes, geneticist Matthew DeGennaro of Florida International University in Miami and colleagues say online March 28 in *Current Biology*.

Mosquitoes rely on three families of odor-sniffing proteins that have overlapping abilities. Proteins called ionotropic receptors, which include IR8a, target acids among other compounds. Floating chemical cues get combined with other information such as the sight of something bitable. — *Susan Milius*

EARTH & ENVIRONMENT

One Antarctic ice shelf gets half its annual snowfall in just 10 days

Just a few powerful storms in Antarctica can have an outsize effect on how much snow parts of the continent get. Ice cores, which preserve these storms, might give a skewed view of how quickly Antarctica's ice sheet has grown or shrunk over time.

Relatively rare extreme precipitation events are responsible for more than 40 percent of the total annual snowfall across most of the continent — and in some places, for more than 60 percent, researchers report online March 22 in *Geophysical Research Letters*.

Climatologist John Turner of the British Antarctic Survey and colleagues used climate simulations to estimate daily precipitation across the continent from 1979 to 2016. The team zoomed in on 10 locations to find regional snowfall differences. Extreme events packed the biggest wallop along the coasts. For instance, the Amery ice shelf in East Antarctica gets about half of its annual precipitation — which typically totals about half a meter of snow — in just 10 days, on average. — *Carolyn Gramling*

MATTER & ENERGY

How a proton gets its spin is surprisingly complicated

Like a quantum version of a whirling top, protons have angular momentum, known as spin. Now scientists confirm that some of that spin comes from a frothing sea of particles known as quarks and their antimatter partners, antiquarks, found inside the proton.

Surprisingly, a less common type of antiquark contributes more spin than a more plentiful variety, scientists report online March 14 in *Physical Review D*.

Protons are made up of three main quarks: two up quarks and one down quark. Protons also have a "sea" of transient quarks and antiquarks of different types, including up, down and other varieties (*SN: 4/29/17, p. 22*).

Previous measurements suggested that the spins of the quarks and antiquarks within this sea contribute to a proton's overall spin. The new result — made by slamming protons together at the Relativistic Heavy Ion Collider, or RHIC — clinches that idea, says physicist Elke-Caroline Aschenauer of Brookhaven National Lab in Upton, N.Y., where the RHIC is located.

A proton's sea has more down antiquarks than up antiquarks. But, counterintuitively, more of the proton's spin comes from up than down antiquarks, the researchers found. In fact, the down antiquarks actually spin in the opposite direction from the up antiquarks, slightly subtracting from the proton's total spin. — *Emily Conover*

Young and Anxious

Seeking ways to break the link between preschool worries and adult anxiety

By Sujata Gupta

When Molly was 10 months old, her parents took her to a Halloween party with other young families. While the other babies explored their surroundings, Molly sat and watched. She's always been cautious, says Molly's mom, Rachel. Early on, though, the little girl's shyness didn't raise red flags.

By the time Molly turned 4, however, life was getting harder — for everyone. Even though she loved to dance, Molly refused to engage in class without her parents nearby. She clung to her mom in public and became whiny and upset. The family began avoiding outings. Dance classes ceased, as did gymnastics. Playdates were rare and had to be held in Molly's home. "Our world was getting smaller," says Rachel, who asked to use only first names to protect her daughter's privacy.

In kindergarten, Molly's anxiety escalated. Parents were supposed to drop their children off in front of the school so a teacher could walk them inside, but Molly struggled. "She would ... chase us into the road," Rachel says. Concerned for Molly's safety, school administrators eventually gave the family permission to escort her inside. Once at school, Molly latched onto another girl, trying hard to dress exactly like her. It seemed to Rachel that Molly "wanted to be invisible."

Fears about going to school consumed Molly, who felt sick every night before school. "She had stomachaches," Rachel says. "She was constipated."

Molly's issues may appear extreme, but anxiety is surprisingly common among young children. Estimates vary widely, but most studies indicate that 10 to 20 percent of U.S. preschoolers suffer from one of several anxiety disorders. When anxiety hits young, it often holds on into adolescence and adulthood. Children diagnosed with clinical anxiety early have double the risk of anxiety and substance abuse in their teen years, compared with children who don't have an anxiety disorder. That later anxiety has been linked to missed school, drug abuse, depression and even suicide.

So for decades, researchers have been trying to decipher the biological roots of the young, anxious mind in hopes of sorting out how to intervene before worries become debilitating. It now seems that all forms of anxiety are linked to abnormalities in how the brain processes fear. So sometimes, when symptoms are particularly severe and very young children struggle to do typical things like start school or go to the playground, psychiatrists turn to antidepressants.

But studies of antidepressants in children tend to be small and shorter than a year in duration, with sparse studies looking at medicating children under age 5. Anecdotally, researchers know that antidepressants can cause hyperactivity in young children, in the form of uncontrolled outbursts, restlessness and disrupted sleep. Not surprisingly, Prozac for the preschool set remains controversial. Some psychiatrists say that a short-term dose can help an anxious child find the courage to talk to a therapist. Therapy can be a form of training that helps the brain develop along a less anxious path. To that end, researchers are trying to modify therapies that work for adults or develop new approaches to meet the needs of young children.

ALL ILLUSTRATIONS: GRACIA LAM

One of the most promising strands of research involves individuals like Molly, as researchers have identified a clear link between shyness in infancy and later anxiety, namely social anxiety.

Born cautious

To experience fears about the future or social belonging is human, says Jerome Kagan, a retired Harvard University psychologist and a leading researcher in the field. It's normal for children to fear big, barking dogs, or to worry about losing a parent or how to respond when a classmate is being bullied. Only when such anxieties become all encompassing, when they interfere with overall happiness or the ability to interact in society, does the condition become pathological, meriting the name "anxiety disorder."

But what enables some individuals to confront their fears while others are left reeling? That question has consumed Kagan ever since he began interviewing participants in a longitudinal study that began back in 1929. By the time Kagan joined the project in the late 1950s, the first participants were adults. Kagan soon noticed that those who had been wary babies — marked by caution, inhibition around strangers and a tendency to stick close to a trusted adult — remained shy and withdrawn as adults. What's more, being wary in new situations was the only temperament Kagan observed that stayed constant throughout life.

In 1989, Kagan began recruiting mothers and infants to build his own longitudinal study. Soon, he had 500 mothers, all of whom came to his laboratory when their babies were 4 months old. The babies were exposed to various stimuli, such as swaying mobiles or tape recordings intoning statements like, "Hello baby. How are you today?"

Most babies responded to the objects and recordings with stares, babbles and grunts. But about one-fifth of the babies cried or thrashed their legs, signs of distress that marked them as highly reactive, or inhibited. (Researchers used the term "behavioral inhibition" to describe this tendency.)

Kagan continued to observe the boys and girls throughout childhood. By age 7, about half of those who were babies in the reactive group remained cautious as children. "They needed a night-light at home, they wouldn't sleep over at a friend's house, they were afraid of dogs," Kagan recalls. "And they were quiet and shy in the classroom."

By age 18, about 40 percent of those formerly reactive babies met the criteria for an anxiety disorder — double the risk of those who were not

reactive as babies and of the general population. Kagan was floored. These are kids "that come from middle-class homes. They have a protective environment," Kagan says. "They're not in a war zone."

Equally intriguing to Kagan and, later, his protégé, Nathan Fox, were the 60 percent of reactive babies who did not go on to develop an anxiety disorder. Fox, a developmental neuroscientist at the University of Maryland in College Park, has

Anxiety in children

The four most common anxiety disorders in preschool children are:

Separation anxiety — excessive fear surrounding separation from caregivers. Tots sobbing at day care drop-off is a common example. The behavior is normal in the first year or two of life.

Social anxiety — excessive fear of negative social evaluation, essentially a fear of judgment from others.

Generalized anxiety — excessive anxious anticipation of future events. Children worrying about the house burning down, for example, or about mom dying while the child's at school.

Specific phobias — excessive fear of specific things, for example, dogs, spiders or heights.

10 to 20 percent

Estimated share of U.S. preschoolers who suffer from one of several anxiety disorders

followed two similar study groups of his own for decades. The wary, reactive babies who manage to avoid becoming anxious adults don't undergo a 180-degree temperament change, Fox says. "There is a core temperament in there. Our kids may not have a social anxiety disorder, but they're not the captains of football teams, and they're not the exuberant, outgoing [ones]."

That realization led researchers to focus on a key question: Is there a way to help shy, anxious kids become shy, well-adjusted adults?

Feeling the fear

Two months into Molly's kindergarten year, her parents were growing desperate. They put their daughter in therapy, which was its own ordeal. "At the first therapy appointment, I couldn't leave the room," Rachel says. "She was hysterical."

Molly slowly adjusted to visits to the therapist, who had her draw a "worry bully." (Molly named him Otis.) If Molly was worried that people would laugh at her, Rachel says, the therapist would say things like, "Oh, you think Otis is going to laugh at you? But Otis doesn't know that." Transferring her fears to Otis let Molly label the source of her angst. Molly also began to practice doing things that scared her. She would get prizes for going to a friend's house without mom for just 20 minutes.

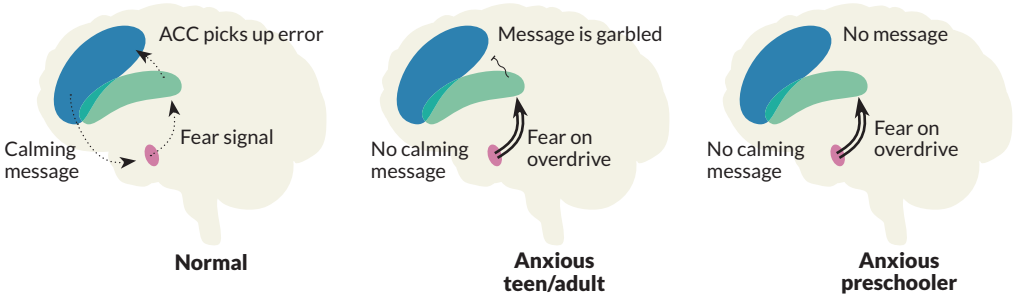
Molly's therapist was employing classic cognitive behavioral therapy, a hands-on approach to changing patterns of thinking or behavior and the current gold standard for treating anxiety in adults. Another promising therapy for treating anxiety in young children is a modification of a program geared at strengthening the parent-child relationship. In that approach, known as Parent-Child Interaction Therapy, or PCIT, a therapist sits behind a one-way mirror and directs parents in their interactions with a child through earphones. The thinking is that, rather than deal with their child's anxieties by avoiding scary situations — a common survival strategy — parents can learn with the child how to manage those fears.

Cognitive behavioral therapy — which also will include parents when used for young children — is thought to work by aligning the feeling and thinking parts of the brain, the amygdala and the prefrontal cortex. In scary or new situations, the amygdala sends a fear signal to the prefrontal cortex. When things are working well, the prefrontal cortex deciphers the situation and sends a message back to the amygdala along the lines of, "Hey, chill out." But when anxiety strikes, communication between the amygdala and the prefrontal cortex breaks down, and the "chill" message never reaches the amygdala. The feedback loop breaks down.

So cognitive behavioral therapy aims to tamp down the amygdala's panic response — by making a scary situation, like going to a friend's house, routine — and amp up the prefrontal cortex's calming effect. Knocking the amygdala down a notch should in theory help it sync better with the prefrontal cortex. Essentially, says Kate Fitzgerald, a child psychiatrist at the University of Michigan in Ann Arbor, the brain learns "to feel the fear and [go ahead] anyway."

For more than half of preschoolers, however, cognitive behavioral therapy fails or its positive effects wane over time. For Molly, therapy was imperfect, but it helped. After six months, she was doing better at school and making friends. But she still struggled to separate from her parents, and she remained overly concerned about what other children would be wearing. She much preferred if nobody looked at her.

To Rachel, Molly's progress felt tenuous. Then Rachel heard about a research program Fitzgerald runs, called Camp Kid Power, for 4- to 6-year-olds with anxiety. The camp was designed to address



Feedback loop The amygdala (pink) sends fear signals that the ACC (green) detects as errors when the fear is unwarranted. This error signal goes to the rational part of the prefrontal cortex (blue), which sends a "chill out" message. In anxious adults, the error signal gets garbled leaving the ACC. In anxious preschoolers, the immature ACC doesn't trigger the rational brain to calm things down.

the notion that a child's brain may not be mature enough to fully benefit from standard cognitive behavioral therapy. Rachel was intrigued.

Stuck in the fear

By early 2018, Molly was registered for the next round of Camp Kid Power. Before camp, which was to take place over two consecutive weekends, Rachel took Molly in for an initial assessment.

At the lab, Molly was hooked up to an electroencephalograph, or EEG, a contraption like a shower cap with electrodes that rest on different spots along the skull. Then, sitting in front of a computer screen, Molly was introduced to Melissa, a virtual zookeeper. Melissa told Molly that all the animals had escaped from the zoo. Molly could help return the animals to their cages by pressing a button every time an animal popped up on the screen. But she shouldn't push the button when an orangutan appeared, because those animals were Melissa's helpers.

When Molly and other participants in Camp Kid Power accidentally pressed the button for the orangutans, Fitzgerald and her team measured the electrical impulse from an electrode atop the middle of the skull. The region of the brain under that electrode houses a part of the prefrontal cortex known as the anterior cingulate cortex, or ACC. The ACC responds to mistakes and other errors in thinking, such as "No one will like me!" or "I am too stupid to understand this lesson."

It turns out that the ACC reacts differently in anxious preschoolers than in anxious teens and adults, Fitzgerald is finding. And those differences might matter for therapy.

In anxious teens and adults, the ACC overreacts, researchers suspect, producing fear in situations that are relatively safe. Going back to the feedback loop, the amygdala issues an alert, which travels to the ACC. But instead of identifying those negative thoughts as nonsense and communicating that to other parts of the prefrontal cortex, the ACC's safety message is garbled and doesn't get through. As a result, the amygdala keeps right on freaking out.

For these older age groups, the aim of cognitive behavioral therapy is to sort out how to allow the ACC to do its job, responding to fear so that the "calm down" message gets through.

In children younger than age 10 or so, the ACC response is too weak, perhaps because that part of the brain is underdeveloped, Fitzgerald's team reported in March in Chicago at a meeting of the Anxiety Disorders Association of America. When a child accidentally pushes the button for an orangutan, for example, the amygdala responds with fear, but the ACC under-responds and never makes sense of the flawed fear message.

That communication breakdown could explain why cognitive behavioral therapy isn't enough for

E. OTWELL

so many young children. They cannot call upon the ACC or the rest of the prefrontal cortex to will their bodies into doing something fearful. Imagine a child who's afraid of dogs. A neighbor's dog approaches, the child clings to a parent and the parent says, "Don't worry. You know this dog." But the thinking part of the child's brain isn't getting the message. The terrified child stays terrified.

What if, Fitzgerald wondered, she could expedite development in the ACC just enough so that preschoolers with various types of anxiety could keep their cool? Enter Camp Kid Power.

At camp, Molly played familiar games — Simon Says and Red Light/Green Light — but with a twist. She had to remember four things Simon said before acting on them. Or she had to stop, rather than go, on green. Fitzgerald's goal was to force anxious children to make mistakes. And then when the children responded with distress — refusing to play, crying, whining — a counselor would intervene, have them run through the rules of the game and talk through how to do it better. In this way, Fitzgerald was trying to train the children's ACC to receive the message from the amygdala and then recruit other parts of the prefrontal cortex that help with slowing down and persevering.

Preliminary EEG results show that the ACC gets stronger in children after the camp. In other words, their brains mature ever so slightly. Fitzgerald thinks the Camp Kid Power protocol could one day work in tandem with behavioral therapy.

But it's a pilot program, and Fitzgerald doesn't expect Camp Kid Power alone to alleviate anxiety in preschoolers over the long haul — at least not yet. "It would be amazing if four days in Camp Kid Power really altered [an anxious child's] trajectory," she says.

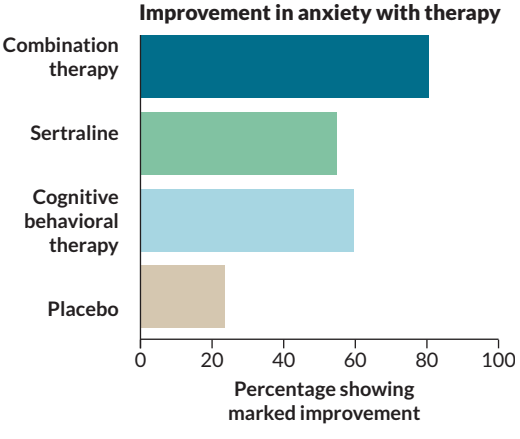
Too fearful for therapy

With cognitive behavioral therapy plus Camp Kid Power, Molly survived kindergarten. But then summer hit and, like many working parents, Rachel cobbled Molly's child care together through weekly summer camps in dance, gymnastics and art. With her world again thrown into flux, Molly's old clinginess and whininess came back stronger than ever. Her fears even spilled over to the times when Molly felt safe, such as weekly family dinners with her cousins, where she stopped talking completely. "It felt like we were slipping back completely," Rachel says.

Molly resumed therapy when she started first grade, but this time made little progress. So in November 2018, with her doctor's blessing, Molly went on Prozac. The little girl's response to the antidepressant was miraculous, Rachel says. "Now you can have conversations. She can understand. She can use those skills she learned."

Molly's experience on Prozac squares with a seminal study from 2008 of 488 children with an anxiety disorder, ages 7 to 17, who were divided into groups. Some received an antidepressant

Better together In 488 children, ages 7 to 17, the most effective treatment for anxiety was a combination of the antidepressant, sertraline, or Zoloft, and cognitive behavioral therapy. SOURCE: J.T. WALKUP *ET AL*/*NEJM* 2008



E. OTWELL

alone, others received cognitive behavioral therapy alone and another group received both. A fourth group took a placebo drug.

After 12 weeks, 80 percent of the children on the combination therapy showed marked improvement in anxiety as measured by a standard scale. Sixty percent in the behavioral therapy group showed improvement, and about 55 percent in the medication group improved. All therapies outperformed the placebo group, which showed only 24 percent responding.

The success in the therapy plus antidepressant group suggests that medication enabled children to get more from psychotherapy, says Jeffrey Strawn, a child and adolescent psychiatrist at the University of Cincinnati. Even though the study evaluated children ages 7 or older, Strawn says in difficult cases, medication can be appropriate for even younger children. The key, says Fitzgerald, is to watch for signs of hyperactivity and lower the dose as needed.

Still, some practitioners remain skeptical about medicating or even offering therapy to children who are so young. For Kagan, wait and see is almost always the preferred approach. If 40 percent of shy preschoolers go on to develop anxiety, that means 60 percent do not. That's why Kagan is willing to suggest treatment for anxious 18-year-olds, but is reluctant to do so for 4- to 5-year-olds.

Strawn says he's not advocating that all anxious kids take medications or even get therapy. If a child's fears are singular, such as a fear of sleeping alone at night or of dogs, and life is otherwise fairly typical, then simply exposing children to their fears slowly might suffice.

What's more, Strawn says, the goal is not to remain in therapy or on meds in perpetuity.

But stopping therapies, whether pharmaceutical or behavioral, has proved challenging. A follow-up to the study of those 488 anxious children four to 12 years after the 12-week treatment showed that anxiety disorders tend to persist over the years. About 22 percent of the children who received the 12 weeks of treatment — whether behavioral, pharmaceutical or the combination — remained free of the disorder every year for four years. Half of the participants reported periodic anxiety and 30 percent reported being anxious at every checkup, the researchers reported last July in the *Journal of the American Academy of Child & Adolescent Psychiatry*.

It's possible that interventions like Camp Kid Power will ultimately put an anxious child on a healthier developmental path and, in turn, void the need for therapy or medication throughout life. But nobody knows yet.

For Rachel, the move to start Molly on an antidepressant did not come easy. She recalls meeting a mom at the first day of Camp Kid Power who mentioned that her child was on Prozac. The idea of medicating a child so young made Rachel uncomfortable. Yet six months later, at a breaking point, she went ahead with the medication anyway, and, in so doing, feels that she unearthed her daughter's potential.

"The idea is to get her a year where she isn't fighting that crippling anxiety, where she can use these skills and practice not being anxious. The plan is to get her off these medicines," Rachel says.

In pictures taken before Prozac, Molly is crying or biting her nails. She appears distant and withdrawn. But in pictures taken after she started the drug, her face is calm, she's smiling and often arm in arm with her friends. So for now, Rachel says, she's taking the psychiatrist's advice and letting the family enjoy a still-cautious, but happy, Molly. ■

Explore more

- Diana Whalen, Chad Sylvester and Joan Luby. "Depression and anxiety in preschoolers: a review of the past 7 years." *Child and Adolescent Psychiatric Clinics of North America*. July 2017.

A Tricky Parasite

Trichomonas vaginalis has a funny shape and some clever ways of infecting people.

DAVID M. PHILLIPS/SCIENCE SOURCE

Trichomonas vaginalis enlists helpers to battle the immune system

By Amber Dance

Frances Mercer runs a fight club.

In one corner, the parasite *Trichomonas vaginalis*, which causes a widespread sexually transmitted infection that many people have never heard of. In the other corner are neutrophils, the immune system cells best equipped to take down the aggressor.

Watching the two battle it out, Mercer, an immunoparasitologist at California State Polytechnic University in Pomona, has learned a lot about the parasite. And she's shown exactly how neutrophils manage to take down *T. vaginalis* — using a maneuver that scientists didn't even know the immune cells possessed.

A focus on *T. vaginalis* has been a long time coming. In 2016, the parasite was responsible for about 156 million worldwide cases of the sexually transmitted infection called trichomoniasis in men and women. In the United States, trichomoniasis is the third most common sexually transmitted infection after HPV, or human papillomavirus, and herpes.

Today, scientists are just beginning to get a handle on how the parasite causes trouble — including increasing risk for HIV infection, infertility and preterm delivery — and how the human immune system fights back. Complicating the picture is the fact that *T. vaginalis* doesn't work alone. Other microbes living inside the vagina, and some inside the parasite itself, get into the fray.

Not just a nuisance

The infection "is not taken very seriously; it's thought of as making women a bit itchy down there," says Jane Carlton, a parasitologist at the New York University Center for Genomics and Systems Biology. As its name suggests, *T. vaginalis* colonizes the vagina, but it can also find a home in the urethra, which carries urine, in both men and women.

"One person's nuisance infection is another person's raving, itchy, hot, burning infection," Carlton adds. About one-third or more of women who have an infection will have itch, discomfort or discharge — probably due to the action of the immune cells fighting the parasite, Mercer says.

About 5 to 10 percent of infected men suffer

similar symptoms. The infection can be treated with metronidazole, a parasite-killing antibiotic, but about 5 percent of parasites are resistant to the drug.

Left untreated, trichomoniasis can have long-term consequences. The infection about doubles a woman's chances of acquiring HIV. The risk might go up, Mercer says, because the parasite damages the barrier between the vaginal wall and the rest of the body, or because it causes an influx of the immune system's T cells, which are the target of HIV infections. The parasite also interferes with female fertility and pregnancy. In men, *T. vaginalis* has been tentatively linked to infertility and prostate cancer.

Plus, the parasite can infect the same person more than once. Unlike with many other microbes, the immune system seems to be lousy at remembering how to fight *T. vaginalis*. The invader may even manipulate the immune response to block that memory, speculates Daniele Dessì, a microbiologist at the University of Sassari in Italy, with a touch of awe: "This is quite amazing for such a primitive organism."

T. vaginalis is one of three species of trichomonad that infect humans. Scientists think trichomonads, single-celled protozoans, may have been among the first organisms to branch off the evolutionary tree after the rise of the original eukaryote, the ancestor of all animals, plants, fungi and protozoans.

"Learning about *Trichomonas vaginalis* is like learning about our own origins — who we were at the beginning," says parasitologist Augusto Simoes-Barbosa of the University of Auckland in New Zealand. "Probably our ancestor was a very complex organism."

At some point in its history — scientists don't know when — *T. vaginalis* found the vagina a suitable place to live. It's a good choice, points out Carlton: warm, moist, with plentiful sources of nutrition. Plus, men provide a convenient shuttle service to the next vagina.

Transmitted by sexual contact, the pear-shaped parasite swims into the vagina, paddling with tail-like flagella. *T. vaginalis* then sprawls out, amoeba-like, among the cells lining the vagina and cervix, rupturing them and eating the pieces.

Duel in a dish

Mercer first began investigating the parasite in 2013, as a postdoc in the lab of Patricia Johnson, a parasitologist at UCLA. At the time, not much was known about how *T. vaginalis* interacted with the immune system.

So Mercer set up her fight club, pitting the parasite against various immune cells in laboratory dishes. The parasite killed T cells and B cells, she reported with Johnson and colleagues in *PLOS Neglected Tropical Diseases* in 2016. The parasite seems to poison the cells, Mercer says, and may also gobble them up. B cells help the body remember past infections. So their loss may help explain why a person can get trichomoniasis multiple times. *T. vaginalis* was less effective at killing another type of immune cell, monocytes, which have a variety of roles, including swallowing invaders and helping T cells learn about pathogens.

156 million
Estimate of worldwide cases of trichomoniasis in men and women in 2016

One type of immune cell stood out: Neutrophils slaughtered the parasite in just 10 minutes. Neutrophils are the body's first line of defense, so their action wasn't a big surprise. These cells, "the foot soldiers of the immune system," Mercer calls them, are drawn to infections when cells send out a distress call: the molecule interleukin-8, or IL-8.

The surprise came when Mercer, Johnson and colleagues learned how neutrophils fight the parasite. The team reported its findings in February 2018 in *PLOS Biology*. Neutrophils were known to kill invaders in three ways. The first, phagocytosis, involves swallowing pathogens whole. But Mercer didn't think that was happening with *T. vaginalis*. The parasites are about 20 percent bigger than the immune cells, so Mercer doubted the neutrophils could catch and guzzle the larger pathogen, especially one capable of swimming away.

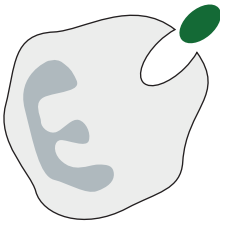
Second, neutrophils spew toxins. But Mercer found that the neutrophils needed to be touching *T. vaginalis* to kill it; the immune cells weren't just hurling chemical bombs from afar.

The third strategy, called NETosis, is the weirdest. A kamikaze neutrophil vomits its own DNA onto a parasite, entangling and killing its prey in the strands. Yet when Mercer added chemicals to destroy the vomited DNA in the lab dishes, neutrophils could still slay the parasites. No NETosis here.

At a dead end, Mercer took a second look at phagocytosis. And indeed, chemicals that prevent phagocytosis stopped neutrophils from killing

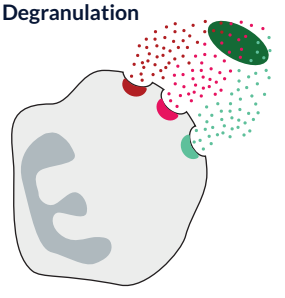
Four ways to kill Neutrophils are the body's first line of defense against invaders such as parasites. These immune cells tailor their attack to the specific pathogen they're after. Until 2018, scientists knew of three modes of attack. Then scientists reported witnessing a fourth method, trogocytosis, that kills the *T. vaginalis* parasite.
SOURCES: C. ROSALES/*FRONTIERS IN PHYSIOLOGY* 2018; F. MERCER *ET AL*/*PLOS BIOLOGY* 2018

Phagocytosis



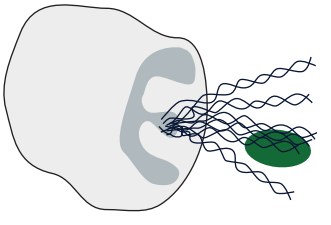
Neutrophils swallow an invader whole.

Degranulation



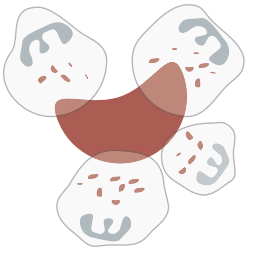
Neutrophils spew toxins to kill a pathogen from afar.

NETosis



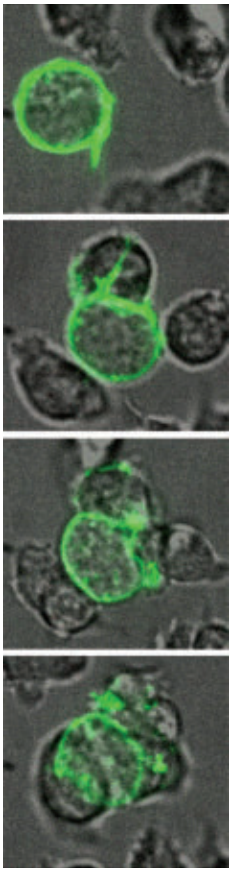
Neutrophils disgorge their own DNA and ensnare microbes in the strands.

Trogocytosis



Several neutrophils surround and nibble a parasite to death.

T. TIBBITTS



In a lab dish, a *T. vaginalis* (green) is surrounded by neutrophils (two middle panels), which nibble the parasite to death (last panel, green is seen inside the neutrophils).

T. vaginalis. "We were confused," Mercer recalls. "How is the neutrophil engulfing something that is bigger than it?"

She got her answer when she dyed neutrophils one color and parasites another, and put them together. She often found neutrophils containing a smidge of parasite coloring. When she looked under the microscope, she caught the neutrophils in the act. Three to six neutrophils surrounded a parasite and nibbled it to death, a process called trogocytosis. Within about three to eight bites, the parasites usually succumbed, Mercer, Johnson and colleagues found.

Discovering that neutrophils have a fourth weapon in their arsenal "was really exciting," says Katy Ralston, a microbiologist at the University of California, Davis, who studies trogocytosis. She's found that the gut parasite *Entamoeba histolytica* uses the same process to nibble cells lining the digestive system, causing sometimes-fatal diarrhea.

Scientists have also observed nonlethal trogocytosis between immune cells (though not neutrophils) as a form of communication. And the phenomenon occurs during animal development, as one cell nibbles another to shape body parts.

Since Mercer's work, scientists have discovered neutrophils gnawing cancer cells to death, too. Ralston suspects neutrophils might employ trogocytosis against other large parasites as well.

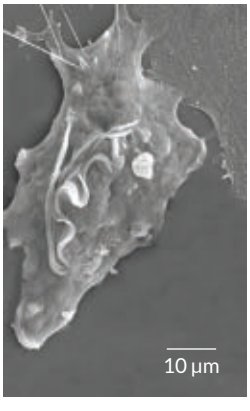
Throwing punches

T. vaginalis doesn't take this nibbling without a fight, of course. It has countermoves to survive in the vagina and to undermine the host immune response.

In a preemptive strike, for example, *T. vaginalis* expels tiny bubbles containing small RNAs and proteins, Johnson's group discovered. The bubbles attach to the cells lining the vagina, priming them for parasite attachment. The researchers aren't yet sure exactly how the bubbles, called extracellular vesicles, alter vaginal cells.

Simoes-Barbosa, who also trained with Johnson, is studying the genetic material inside those vesicles. It takes the form of small RNAs that Simoes-Barbosa thinks turn on or off certain genes within the cells of the vaginal wall. By changing which genes are active, the parasite seems to make those vaginal cells easier to grab onto, perhaps by altering the cell surface in some way.

While prepping the vaginal wall for landing, *T. vaginalis* vesicles also dampen the IL-8 distress call that summons the immune system, Johnson's team reported in 2013 in *PLOS Pathogens*.



As pear-shaped *T. vaginalis* settles in among the cells lining the vagina and cervix, it spreads out into an amoeba-like shape and pierces the cells.

Tag team

This host versus parasite battle rages amid the complex vaginal microbiome, which includes dozens of kinds of bacteria. Not just spectators, some of these bacteria seem to join the melee.

The human vaginal microbiome is dominated by *Lactobacillus* bacteria. The vagina contains glycogen, a carbohydrate that nourishes the lactobacilli. The bacteria, in return, excrete acid that prevents many disease-causing microorganisms from taking hold. "It's a very beautiful relationship," Simoes-Barbosa says. He reported in 2013 in *Sexually Transmitted Infections* that lactobacilli make it harder for *T. vaginalis* to stick to the cells that line the vagina.

But about a quarter of women have an especially diverse mix of vaginal microbes, with fewer lactobacilli, and that can be a bad thing. The diverse microbiome seems to make the vagina more hospitable to unwanted pathogens like *T. vaginalis* and to make the parasite better able to survive drug treatments. "There is a team — of bacteria and protozoa — promoting that disease," Simoes-Barbosa says.

In fact, in lab dishes containing vaginal and cervical cells alongside beneficial lactobacilli and bacteria associated with vaginal infections, *T. vaginalis* diminishes the numbers of certain lactobacilli by more than 99 percent. Dessì thinks that the parasite might be acting as a sort of microbe farmer, shaping a vaginal community to be more hospitable to its needs. The parasite might do so, he speculates, by simply eating lactobacilli and other protective bacteria.

T. vaginalis can also play host to its own helpful microbes: bacteria called *Mycoplasma hominis* and a handful of viruses called TVVs, for *Trichomonas vaginalis* virus. Exactly how these microbes influence infection in humans isn't fully understood, but the viruses seem to help the parasite stick to host cells and may also magnify inflammation and

FROM TOP: F. MERCER *ET AL/PLOS BIOLOGY* 2018; R.G. VANCINI *ET AL/ EUROPEAN JOURNAL OF CLINICAL MICROBIOLOGY & INFECTIOUS DISEASES* 2008

symptoms. Researchers know of at least four types of TVV and recently discovered another species of bacteria, *Mycoplasma girerdii*, hanging out with *T. vaginalis,* too.

"It is becoming like a zoo," Simoes-Barbosa jokes.

M. hominis can also work alone to cause sexually transmitted infections, accompanied by burning, pain and discharge like trichomoniasis. Dessì suspects the two microbes first met up in the reproductive tract and started cooperating, with the smaller bacterium either inside or alongside *T. vaginalis*. When inside, *M. hominis* gains a safe space to live, protected from the immune system and drug treatments.

But both may benefit from the partnership, Dessì says. "It's like having one more player on your team."

For example, Dessì and collaborators reported in *Frontiers in Microbiology* in 2016 that when *T. vaginalis* in the lab carries *M. hominis*, the *T. vaginalis* makes more energy and grows faster. Dessì thinks the pair cooperate to collect a nutrient called arginine from the environment. Immune cells need arginine to make nitric oxide, which kills microbes. By eating the arginine, the microbes may be thwarting the immune system. Dessì can't be sure that the same happens in a human infection, but he suspects *M. hominis* would make symptoms worse.

M. hominis, however, might not be entirely beneficial to *T. vaginalis*; the presence of *M. hominis* gets the attention of immune soldiers. Mercer and Johnson reported in their 2016 paper in *PLOS Neglected Tropical Diseases* that the parasite-bacterium pair together cause immune cells to spew more distress signals like IL-8, compared with *T. vaginalis* alone. Mercer thinks that *M. hominis* might help trigger the kind of immune response that remembers *T. vaginalis* and fights it off next time.

Stacking the deck

To devise new treatments for those who don't get relief from existing drugs, or to develop a preventive vaccine, Dessì says, researchers need a better understanding of the interactions among *T. vaginalis*, the immune system and the other microbes involved.

For example, a vaccine that promotes neutrophil trogocytosis might be beneficial.

Meanwhile, Simoes-Barbosa's work suggests that treating just *T. vaginalis* may not be enough. To keep the parasite from returning, some women may need treatments that promote a healthy, lactobacilli-heavy microbiome, too. Some might even need medicines that kill the *M. hominis* carried by the parasite.

That kind of therapy is far off, though, as there's still a lot to learn about *T. vaginalis*. For now, our protective neutrophils, the parasite and the microbial hangers-on remain locked in a nearly even match. No one seems to dominate, says Johnson: "There's just so many players." ■

Explore more

- Frances Mercer and Patricia J. Johnson. "*Trichomonas vaginalis*: pathogenesis, symbiont interactions and host cell immune responses." *Trends in Parasitology*. August 1, 2018.

Amber Dance is a freelance science writer based in the Los Angeles area.

A parasite's impact

T. vaginalis spreads by sexual contact. The infection, known as trichomoniasis, is usually treated with the antibiotic metronidazole. About 5 percent of infections are resistant to the drug.

In women Infects the vulva, vagina, cervix or urethra

Risks

- Nearly doubles the risk of HIV infection
- May increase the risk of transmitting HIV to sexual partners
- Nearly doubles the risk of infertility by damaging the reproductive system
- Raises a pregnant woman's risk for preterm delivery and low birth weight in her newborn by 30 percent or more; treatment doesn't always seem to reduce this risk
- Raises the risk of cervical cancer spreading in women with HPV

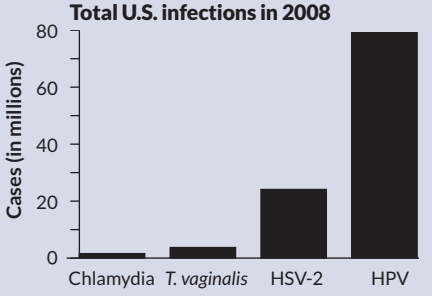
In men Infects the urethra, and sometimes the head of the penis, prostate or epididymis, where sperm mature and are stored

Risks

- May boost prostate cancer risk, though unconfirmed
- May damage sperm and interfere with fertility

Under the radar

T. vaginalis prevalence data are old and probably underestimates. In 2008, trichomoniasis was the third most common sexually transmitted infection, after HPV and herpes simplex virus type 2 (HSV-2). SOURCE: CDC



T. TIBBITTS

Patches of feathers adorn the head of this life-size model of *Tyrannosaurus rex*.

EXHIBIT

Tyrannosaurus rex exhibit takes a deep dive into the iconic dinosaur

Ultrafierce *Tyrannosaurus rex* is an icon. But the "tyrant lizard king," which lived between 68 million and 66 million years ago, is just the youngest member of a family of dinosaurs that went back to about 167 million years ago. The earliest tyrannosaurs were quick and small. So how did *T. rex* become so big and bad?

That's one of the questions at the heart of "*T. rex*: The Ultimate Predator," a new exhibit at the American Museum of Natural History in New York City. The exhibit takes a deep, multisensory dive into what we know about this most famous of dinosaurs. It is a fitting centerpiece for the museum's 150th anniversary. The very first *T. rex* specimen was described in 1905 by Barnum Brown, a paleontologist at the museum.

"*T. rex*: The Ultimate Predator"
THROUGH AUGUST 2020
AMERICAN MUSEUM OF NATURAL HISTORY
New York City

In 1908, Brown and his team dug up a second *T. rex* skeleton — this one nearly complete. The new exhibit includes a reproduction of this skeleton but goes beyond that static representation, drawing on research over the last 10 years or so to illustrate how scientists now think the animal grew, moved, ate and perceived the world.

For instance, cranial analyses suggest that *T. rex* had excellent vision and a very good sense of smell. The dinosaur also had a bone-crushing bite force (*SN: 11/10/18, p. 13*). Perhaps reassuringly, the exhibit also notes that while a juvenile *T. rex* could run — defined as lifting one foot fully off the ground followed by the other — an adult *T. rex* was too heavy for a running gait. The skeleton would have buckled under such a weighty load.

A baby *T. rex* was about the size of a chicken. Most hatchlings didn't survive their first year.

Life-size models of *T. rex* at various life stages help illustrate the animal's astoundingly rapid rate of growth. Fluffy hatchlings were perhaps the size of chickens, and only about 40 percent of them survived their first year. By age 4, the animals were already 4 meters long, and by age 20, they had reached their full length, about 13 meters. A *T. rex* that lived to age 28 was essentially a senior citizen; no known *T. rex* is thought to have lived longer than that.

There's a lot we still don't know about *T. rex*: what it sounded like, how to tell apart males from females and how the species got to be so giant (*SN: 3/16/19, p. 11*). For clues to lingering puzzles, researchers have often turned to the other known members of the tyrannosaur family. As described in the exhibit, fossilized feathers found with several of *T. rex*'s close relatives are the reason scientists suspect the king had feathers, too. And tyrannosaurs with sensitive facial skin could mean that *T. rex* was similarly sensitive to touch and temperature (*SN: 4/29/17, p. 5*).

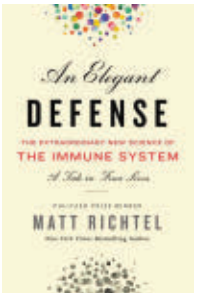
To this reviewer's delight, the exhibit gives some of these other members of the tyrannosaur family tree a moment in the spotlight. These dinos include little-yet-fierce tyrannosaurs such as the wolf-sized *Proceratosaurus bradleyi*, which lived about 167 million years ago, and the hollow-boned, long-armed and feathered *Dilong paradoxus*, which lived about 126 million years ago.

There's a lot of information to take in, but the exhibit also aims to be highly interactive. There are touchable fossils and fossil casts, a "roar mixer" that allows people to imagine the voice of a *T. rex* by blending other animal sounds, and a virtual reality station where visitors can piece together a skeleton. The pièce de résistance comes at the end of the exhibit: a life-size animated *T. rex* projected onto a screen that tracks passersby. Stand in front of it long enough and it might snap at you. — *Carolyn Gramling*

BOTH: D. FINNIN/© AMNH

BOOKSHELF

The immune system's softer side



An Elegant Defense
Matt Richtel
WILLIAM MORROW, $28.99

We like to think of the immune system as our own personal military, ready to attack foreign invaders. Slice your finger, and immune cells rush in to destroy rogue pathogens.

But it's misleading to think of the immune system as solely a war machine. It must also keep the peace, assessing each threat and, in many cases, deciding to stand down. (This often-overlooked peacekeeping role is what allows the microbiome, the collection of microorganisms that live in and on the body, to thrive.) In *An Elegant Defense*, Pulitzer Prize–winning journalist Matt Richtel argues that it is this ability — to differentiate friend from foe (or neutral party) and act accordingly — that makes the immune system so powerful and so elegant.

"It is a system precisely and delicately tailored to stay in balance, keep the peace and do as little damage as possible to us and our surroundings," he writes. And that balance is central to our health.

An Elegant Defense offers a sweeping overview of immunology's history, from Élie Metchnikoff's observations in the 1800s of immune cells swarming splinters in starfish larvae to recent discoveries underpinning cancer immunotherapy. Richtel explains all of this science through the stories of four individuals deeply affected by their immune systems. Richtel's childhood friend Jason Greenstein is battling a stubborn form of Hodgkin's disease that seems to be invisible to his immune response. Bob Hoff contracted HIV in 1977, but his immune system managed to keep the virus in check. And the lives of Linda Segre and Merredith Branscombe have been radically altered by their overactive immune systems.

Richtel, who covers science and technology for the *New York Times*, once joked that the paper's writing will always remain "dry and lifeless." But that's not Richtel's style. The prose in *An Elegant Defense* is vibrant, conversational, direct and often funny. He introduces one story like this: "A Dane, an Argentinian Jew and a German walk into a research lab..."

But Richtel seems to presume that readers will find too much science tedious. Describing how the body can make hundreds of millions of different antibodies, he offers readers a "pep talk" and implores them to "Soldier on!"

At times he glosses over experimental details in ways guaranteed to make scientists cringe. "This is one of those experiments that is too technical to describe," he writes, adding "first there were some mixtures, or assays, and then the data was crunched digitally and the results came over the computer." Even more frustrating, the book fails to provide references, an omission that makes it difficult for readers who *do* care about technical details to do their own research.

Yet Richtel's refusal to get bogged down in minutiae also helps the book feel lighter than it otherwise might. The science isn't a slog. And although it seems to jump haphazardly through time — Richtel returns to the 1950s, '60s and '70s again and again — the content is captivating and useful. For example, Richtel examines how we're sabotaging our immune systems with too little sleep and too much stress, and explains why supplements designed to boost immunity are a waste of money.

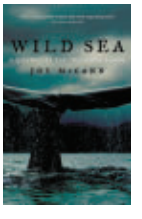
But it's when Richtel delves into the lives of Bob, Linda, Merredith and especially Jason that the writing shines. "Never was he happier than when he was driving, a dip of Skoal Fine Cut packed in his lip, rocking out to Springsteen or to a local station on the dial with some new town on the horizon," Richtel writes about Jason. "He was a genuine American dreamer and the van his covered wagon." — *Cassandra Willyard*

BOOKSHELF

The Human Swarm
Mark W. Moffett
A biologist argues that humans have been able to develop such complex civilizations because of our ability to be comfortable with strangers.
Basic Books, $32

Einstein's Wife
Allen Esterson and David C. Cassidy, with a contribution by Ruth Lewin Sime
A biography explores the challenging life of Albert Einstein's first wife, Mileva Einstein-Marić. *MIT Press, $29.95*

The Pandemic Century
Mark Honigsbaum
From polio and Legionnaires' disease to HIV and Ebola, a medical historian examines 100 years of disease epidemics and the role human behavior plays in the spread of infections.
W.W. Norton & Co., $29.95



Wild Sea
Joy McCann
Sea captains' journals, maps, letters and other historical records illuminate the natural and cultural history of the Southern Ocean.
Univ. of Chicago, $28

The Earth Book
Jim Bell
Earth's history and predicted future, from the planet's birth to its ultimate demise billions of years from now, are told through short, illustrated stories of 250 milestones.
Sterling, $29.95

Grant to the Society creates the Lemelson Early Inventor Prize and increases funding for a Broadcom MASTERS award

The Lemelson Foundation has awarded Society for Science & the Public a three-year grant of nearly $445,000 to celebrate outstanding middle school inventors and to inspire young people to pursue inventive careers.

The funding includes the launch of the new Lemelson Early Inventor Prize program and expands support for the Lemelson Award for Invention at the Broadcom MASTERS event, the premier U.S. science and engineering competition for middle school students. The competition inspires and encourages the nation's brightest minds to become leading scientists, engineers and innovators.

Over three years, the Foundation will fund the Lemelson Early Inventor Prize program by giving a total of $81,000 to support a $100 award for an outstanding inventor at each of 270 Society-affiliated middle school science fairs around the United States. Each science fair will select its own Lemelson Early Inventor Prize winner.

The Foundation is also increasing its existing Lemelson Award for Invention from $7,500 to $10,000, awarded at the Broadcom MASTERS to a young inventor creating promising solutions to real-world problems. The most recent recipient of the award was John Madland (above, standing with Pam Kahl of the Lemelson Foundation). He won the prize in 2018 for creating a model showing that a magnetic shield placed above the surface of Mars might protect people on the planet's surface from harmful radiation.

Additionally, the grant will continue the Foundation's support of an annual 18-article series — focused on important invention, technology and innovation news — published in the award-winning, free online magazine *Science News for Students*.

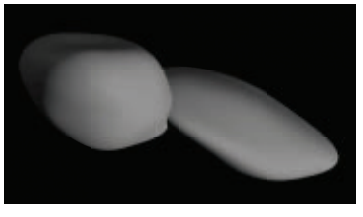
JESSICA YURINKO PHOTOGRAPHY/SSP

MARCH 16, 2019

SOCIAL MEDIA

Space pancakes

New images of Ultima Thule (simulation shown below) indicate that the Kuiper Belt object, officially named 2014 MU69, is a lot flatter than scientists initially thought, **Emily Conover** reported in "Ultima Thule is shaped like two lumpy, conjoined pancakes" (*SN: 3/16/19, p. 15*). On Facebook, reader **Jonathan Roberts** suggested a new nickname to better reflect MU69's shape: "The Interplanetary House of Pancakes."



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Lost Opportunity

*NASA's Opportunity rover explored Mars for more than a decade until a dust storm last year led to its demise, **Lisa Grossman** reported in "Farewell, Opportunity"* (SN: 3/16/19, p. 7).

Reddit users had a lot of questions about the rover, nicknamed Oppy. **scazon** wanted to know why the estimated life spans for Opportunity and another Mars rover, Spirit, were initially so short, and what these missions' longevity means for future Mars missions.

Scientists originally estimated that dust collecting on the rovers' solar panels would stop the rovers from recharging after about 90 Martian days, **Grossman** says. Luckily, winter wind storms cleaned off the solar panels often enough to allow the rovers to keep going. "No other rover or lander had spent so much time on Mars before, so the team didn't know to plan for that," she says. The next two NASA Mars rovers — Curiosity, which landed in 2012 and is still going, and Mars 2020, which is slated to launch next year — use nuclear batteries. So dust isn't much of a concern. But the next European and Russian Mars rover is a different story. That rover, named Rosalind Franklin, is solar powered, **Grossman** says. Scientists plan to "use what they learned from Spirit and Oppy to keep the batteries running."

Other readers on Reddit wondered if Opportunity might someday turn back on.

The chances are slim, **Grossman** says. "The team thinks the rover powered down to the point where its internal clock got out of sync with the Martian day/night cycle," she says. Plus, one of Opportunity's arm heaters has been stuck on since the mission's beginning. If the rover isn't going into a power-saving sleep mode at night, "that arm heater would drain the batteries before it has a chance to call Earth," she says. "So things look tough." But if Opportunity somehow started broadcasting again, the Deep Space Network, which listens to other spacecraft on Mars, would probably notice.

Conscious clues

*Brain scans of people at various awareness levels revealed a complex pattern of activity associated with consciousness, **Laura Sanders** reported in "Scans find key sign of consciousness"* (SN: 3/16/19, p. 8).

Reader **Tom Shoemaker** wondered if scientists plan to look for similar signs in animals.

Scientists don't fully understand human consciousness, but that hasn't stopped them from studying consciousness in other species, **Sanders** says. Clever studies of chimpanzees, crows, dolphins and octopuses have all turned up compelling signs of awareness (*SN: 12/19/09, p. 22*). Yet, animals' brains vary a lot, so "the same brain-scanning method used for people probably wouldn't be useful to characterize consciousness for most other animals," she says.

Shape-shifters

*Phase separation may be responsible for the diversity of pollen shapes, **Emily Conover** reported in "Pollen fashion, explained by physics"* (SN: 3/16/19, p. 32).

Online reader **Jan Steinman** asked if pollen shapes contribute to sneezing and other allergic reactions.

"To our knowledge, there is no connection between pollen shape and its allergenicity, but I also don't know if that problem has been well-studied," says **Alison Sweeney**, a biophysicist at the University of Pennsylvania. But, she says, pollen from plants that commonly triggers allergies — ragweed, grass and a few types of trees — doesn't have any obvious structural similarities.

Corrections

"Muons size up a storm's power" (*SN: 3/16/19, p. 10*) incorrectly described electric potential as the amount of work needed to move an electron from one place to another. It is the work needed to move a unit of electric charge.

In "The allure of CBD" (*SN: 3/30/19, p. 14*), a study that examined cannabidiol's effect on schizophrenia was published in March 2018 in the *American Journal of Psychiatry*, not 2019.

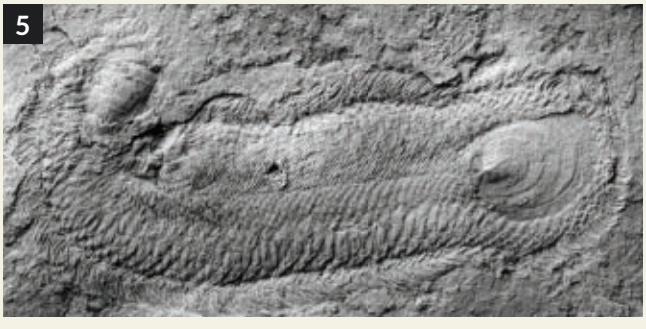
Iconic fossils from some of the world's top Cambrian sites

For most of the nearly 3.5 billion years of documented life on Earth, creatures were simple, dominated by organisms such as bacteria, algae and fungi (*SN: 10/13/18, p. 10*).

Then, beginning about 541 million years ago, life quickly diversified into an array of new, complex forms. This flourishing, called the Cambrian explosion, took place within about 25 million years. Fossils from the period have been preserved in rocks at more than 50 known sites worldwide, the most famous of which is Canada's Burgess Shale, discovered in 1909.

At five standout Cambrian sites, hundreds to thousands of different species were buried in the soft mud of long-ago seafloors. Rapid burial led to the exceptional preservation of soft-bodied animals as well as of soft tissues, such as brains, guts, eyes and skin, that typically don't fossilize well. A newly reported site, Qingjiang in China, holds a wealth of exquisitely preserved soft-bodied animals such as jellyfish and comb jellies (No. 3 below and see Page 14).

— Carolyn Gramling



1. *Marrella*

Canada's Burgess Shale (1909)

508 MILLION YEARS OLD

Marrella fossils were some of the first found at the Burgess Shale and are the most common. At first labeled trilobites, the small, spiny sea creatures were later revealed to be a distinct type of arthropod.

2. *Fuxianhuia*

China's Chengjiang (1984)

518 MILLION YEARS OLD

Fuxianhuia fossils offer what may be the best-known view of a Cambrian brain, tucked beneath a head shield. The organ could have evolved to help the marine arthropods process detailed visual information.

3. Ctenophore

China's Qingjiang (2007; reported 2019)

518 MILLION YEARS OLD

The detailed preservation of this ctenophore, or comb jelly, shows rows of combs, which are plates of fused hairlike structures called cilia. Modern comb jellies use the combs to propel themselves through the water.

4. *Anomalocaris*

Australia's Emu Bay Shale (1979)

514 MILLION YEARS OLD

Anomalocaris' compound eyes (one shown) sported a stunning 16,000 lenses, at least. Few other arthropods, living or extinct, have had as many lenses (details shown in inset) as this marine predator.

5. *Halkieria*

Greenland's Sirius Passet (1984)

515 MILLION YEARS OLD

Meet *Halkieria*, a scaly, sluglike creature with bivalve shells on the front and rear of its body. The animal continues to defy classification; it has been linked to early mollusks and brachiopods, also known as lamp shells.

CLOCKWISE FROM TOP LEFT: ROYAL ONTARIO MUSEUM; X. MA *ET AL/NATURE* 2012; D. FU *ET AL/SCIENCE* 2019; COURTESY OF JOHN S. PEEL, A. BUTLER/PALAEONTOLOGY ONLINE 2015; J.R. PATERSON *ET AL/JOURNAL OF THE GEOLOGICAL SOCIETY* 2016

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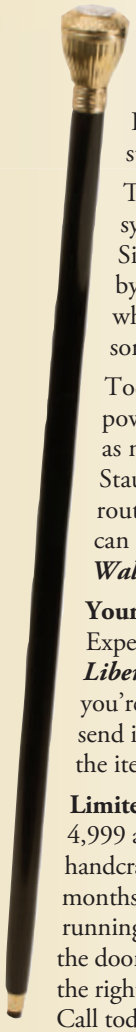

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