SPECIAL ISSUE Psychedelic Toads and Many Other Amazing Animals

ScienceNews

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Rulers of the Sky

New clues shed light on the lives of pterosaurs

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ScienceNews

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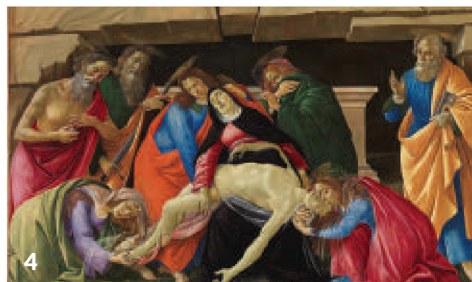

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COVER Pterosaurs, the first flying vertebrates, ate from a diverse menu that included fish. *Warpaintcobra/iStock/ Getty Images Plus*

The animal kingdom never ceases to amaze

It's a rare day at *Science News* when we're not discussing animal attributes, conversations that more often than not include the phrase "That's amazing." Whether it's a croakless frog that communicates by touch or the unique genetics of dogs living near the remains of the Chernobyl nuclear power plant, there's always something new to learn about the creatures that share our world.

In this issue of the magazine, we go all in for animals. We regale you with ants that break the rules of reproduction (Page 7), snail-eating leeches (Page 9) and the world's longest known butterfly migration (Page 14). We also explain why it's hard to tell if a whale shark is pregnant (Page 14), how hibernating bears avoid blood clots (Page 16) and how sea cucumbers shoot a sticky organ out of their rear ends to ward off predators (Page 18). And those are just the stories in the news section.

We also explore animals that can induce hallucinations. It's a talent we got hip to after the U.S. National Park Service sent out a plaintive message asking people to please not lick the Sonoran Desert toad, which secretes a psychedelic compound. That inspired freelance writer and former *Science News* intern Deborah Balthazar to learn about other animals — including a fish, a frog, an ant and a sponge — that may have mind-altering powers (Page 20).

Octopuses don't need to be hallucinogenic to be cool, but finding out that these intelligent, adaptive cephalopods extensively edit their own RNA molecules adds even more evidence of their awesomeness, molecular biology and senior writer Tina Hesman Saey tells us (Page 34). And who wouldn't want to spend some time with a pterosaur? Alas, the last opportunity for going aloft with *Quetzalcoatlus northropi*, a giraffe-sized reptile that was the largest creature ever to take flight, was about 66 million years ago. But humans continue to be enchanted by pterosaurs, and freelance writer Sid Perkins explains how scientists are discovering new clues to pterosaurs' origins, preferred cuisine and global dominance (Page 26).

Truth be told, even the humblest of creatures are amazing. At *Science News*, our online group chat for discussing all things animal hums with reports of our recent local sightings. They include swarming bees, muskrats, turtles, Caspian terns and green herons. There was even a little brown bird with odd white patches that our resident avian expert, editorial assistant Aaron Tremper, thinks might be a leucistic house sparrow.

These creatures are hardly as exotic as a pterosaur, but they command our attention all the same. As Ed Yong notes in his book *An Immense World*, every animal lives in its own sensory bubble defined by its way of perceiving the world around it (SN: 7/16/22 & 7/30/22, p. 36). Each is remarkable, from the fox that cuts through my backyard to the ant that wandered across my desk the other day. Humans have learned a lot about how such animals experience the world, but we have also drastically reshaped their environments. Let's make sure that we preserve their worlds, so that future generations can appreciate them, too. — *Nancy Shute, Editor in Chief*

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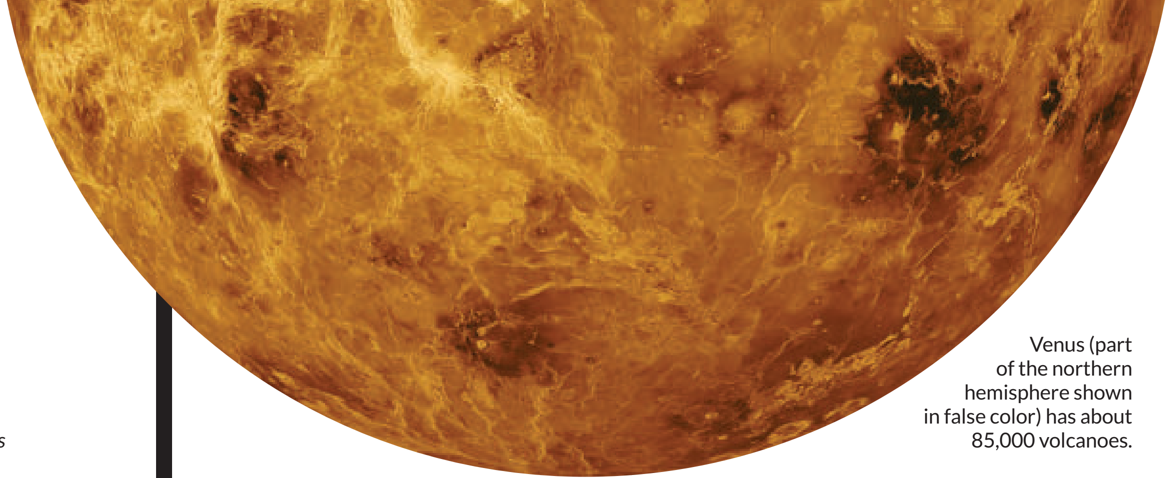
Excerpt from the May 12, 1973 issue of *Science News*

50 YEARS AGO

Light flashes no danger

The light flashes and streaks seen by [Apollo] astronauts have long been attributed to high-energy, heavy cosmic particles (HZE) passing through the eyes.... A new report ... concludes that the particles are not a serious hazard for short trips to the moon or Earth-orbital missions such as Skylab.

UPDATE: The mechanism behind the flashes described by Apollo astronauts remains a mystery. Perhaps the particles, which are components of cosmic rays, emit radiation as they pass through part of the eye. Or perhaps they trick nerve cells to create the illusion of light. However the flashes happen, they are still an issue for astronauts. In 2006, about 80 percent of NASA and European Space Agency astronauts reported experiencing the flashes. How the phenomenon impacts astronaut health after months or years in deep space is unclear. As NASA plans crewed missions to Mars and the moon, scientists are devising new ways to protect astronauts from radiation (*SN: 7/4/20 & 7/18/20, p. 18*), such as portable magnetic shields that can deflect cosmic rays.



Venus (part of the northern hemisphere shown in false color) has about 85,000 volcanoes.

PICTURE THIS

Venus is a volcanic bonanza, a new map shows

The hellscape of Venus is riddled with even more volcanoes than scientists thought.

Using radar images taken by NASA's Magellan spacecraft in the 1990s, researchers cataloged about 85,000 volcanoes strewn across the Venusian surface. That's nearly 50 times as many volcanoes as past surveys counted. Planetary scientists Rebecca Hahn and Paul Byrne of Washington University in St. Louis debuted the map in the April *JGR Planets*.

Such a thorough inventory of volcanism on Venus could offer clues about the planet's interior, such as hot spots of magma production, Byrne says. And with the recent discovery that Venus is volcanically active, the map could also help pinpoint places to look for new eruptions (*SN: 4/8/23, p. 10*).

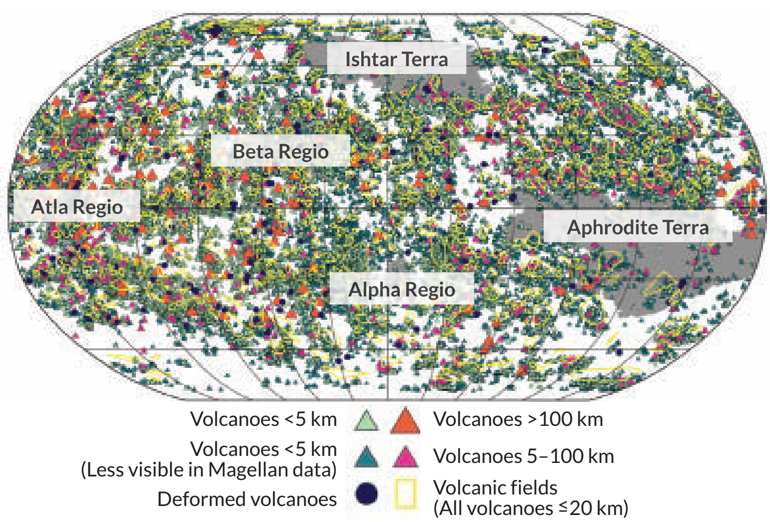
Almost all the volcanoes that Hahn and Byrne found are less than 5 kilometers wide. About 700 are 5 to 100 kilometers across, and about 100 are wider than 100 kilometers. The team also found many tight clusters of small volcanoes called volcanic fields.

"We have a better handle of how many volcanoes are on Venus than are on Earth," where most volcanoes are probably hidden beneath the oceans, Byrne says. But he doesn't think the Magellan data tell the whole story of Venus' volcanism. That spacecraft could see features as small as about 1 kilometer in diameter. Earth has "lots and lots of volcanoes that are far smaller than a kilometer across," Byrne says. "That's probably the case with Venus, too."

We may soon find out. The European Space Agency's EnVision mission is slated to turn its much sharper eyes on Venus' surface within the next decade or so (*SN Online: 6/2/21*).

— Maria Temming

Literal hot spots This map of Venus shows the locations and diameters of volcanoes visible in radar data from the Magellan spacecraft. Continents and other geographic regions are shown in gray.



JPL-CALTECH/NASA; R. HAHN AND P. BYRNE/*JGR PLANETS* 2023

MYSTERY SOLVED

Why scramble eggs with oil paints

Art historians often wish that Renaissance painters could shell out secrets of the craft. Now, scientists may have cracked one using chemistry and physics.

Around the turn of the 15th century in Italy, oil-based paints replaced egg-based tempera paints as the dominant medium. During this transition, artists including Leonardo da Vinci and Sandro Botticelli also experimented with paints made from oil and egg. But it has been unclear how adding egg to oil paints may have affected the artwork.

Italian artist Sandro Botticelli used oil mixed with egg yolk to paint portions of "Lamentation Over the Dead Christ" in 1480. The medium may have added texture and helped prevent wrinkling, scientists say.

So chemical engineer Ophélie Ranquet of the Karlsruhe Institute of Technology in Germany and colleagues whipped up two recipes to compare with plain oil paint. One mixture contained fresh egg yolk mixed into oil paint and had a similar consistency to mayonnaise. For the other blend, the scientists ground pigment into the yolk, dried it and mixed it with oil — a process the old masters might have used, according to the scant historical records that exist today. Each medium was subjected to a battery of tests that analyzed its mass, moisture, oxidation, heat capacity, drying time and more.

In both mixtures, yolk proteins, phospholipids and antioxidants slowed paint oxidation, which can cause paintings to turn yellow, the team reports March 28 in *Nature Communications*.

In the mayolike blend, the yolk created sturdy links between pigment particles, resulting in stiffer paint. Such consistency would have been ideal for techniques like impasto, a raised, thick style that adds texture to art. The firmer consistency also could have reduced wrinkling, which sometimes happens with oil paints when the top layer dries faster than the paint underneath, and the dried film buckles over looser, still-wet paint.

The hybrid mediums have some less than eggs-ellent qualities, though. The paints dry very slowly, and if they were too yolky, Renaissance artists would have had to wait a long time to add the next layer, Ranquet says. — *Jude Coleman*

HOW BIZARRE

Special cells let beetles recycle water in their poop

Some beetles "drink" using their rear ends, and scientists are starting to understand how.

Red flour beetles, a major agricultural pest, open their anus to get water vapor in the air flowing into the lower gut and condensing on any poop there. The insects then draw water out of the fecal material using special cells lining the lower digestive system, researchers report in the March 28 *Proceedings of the National Academy of Sciences*.

This "amazing mechanism" could one day be exploited to make beetle-specific pesticides that could protect crops while safeguarding bees and other insects, says Kenneth Halberg, a comparative endocrinologist and physiologist at the University of Copenhagen.

Insect pests get into as much as 20 percent of the global food supply every year, destroying food and costing farmers money, the United Nations' Food and Agriculture Organization estimates.

Beetles are particularly pernicious. These insects can thrive in arid environments, including in supplies of wheat and other bone-dry crops. One way dry-adapted beetles survive is by recycling water out of their poop using the rectal complex, an organ near the end of their digestive system. But researchers didn't know how the insects achieved the feat.

In red flour beetles (*Tribolium castaneum*), the gene *Nha1* is more active in cells pockmarking the lining of the rectal complex than elsewhere in the body, Halberg and colleagues found. Previous studies suggested that these blisterlike cells were involved in sucking water out of material in the organ.

Nha1 produces a protein that pumps potassium ions across the cells' membranes, Halberg's team found. That may result in a buildup of the ions on the outside of the rectal complex, which could allow water to move through the wall of the rectal complex and into the rest of the body through osmosis, the scientists suspect.

Red flour beetles use certain cells in an organ in the digestive system to suck water out of fecal matter and back into the body.

Experiments confirmed that the insects opened their anuses in high humidity, allowing water vapor to flow into the rectal complex. And beetles with *Nha1* deactivated didn't survive as well in dry conditions as normal beetles.

The finding, Halberg says, shows how "nature has its way of developing some quite interesting solutions to some very interesting problems." — *Freda Kreier*

In May 2020, thousands of tons of diesel fuel spilled from a destabilized tank facility in Siberia. The spill was blamed partly on the loss of soil stability in thawed permafrost.

ENVIRONMENT

Thawing threatens to pollute the Arctic

As permafrost warms, industrial substances could be released

BY NIKK OGASA

As the Arctic's icebound ground warms, it may unleash toxic substances.

The thawing threatens to destabilize facilities, such as mines and pipelines, at more than 2,000 industrial sites and further compromise more than 5,000 already contaminated areas by the end of the century, researchers report March 28 in *Nature Communications*.

Those numbers come from the first comprehensive study to pinpoint where thawing Arctic permafrost could release industrial pollutants. But there are probably additional contaminated areas that we don't know about, says permafrost researcher Moritz Langer of the Alfred Wegener Institute in Potsdam, Germany. "We only see the tip of the iceberg."

Toxic substances released in these locations could jeopardize fish and other animals in Arctic waterways, as well as the health of people who depend on them.

Permafrost is any soil, sediment or rock that remains frozen for at least two years. Step on the ground in the Arctic, and chances are that permafrost lies underfoot. For decades, people have treated the frozen earth as staunch and largely immobile. Industries constructed infrastructure atop its firmness, and within it they buried their refuse and sludge. In some places, scientists and others have used permafrost to store radioactive waste.

But the Arctic is warming nearly four times as fast as the rest of the planet as a result of climate change, and as much as 65 percent of the region's shallow permafrost may disappear by 2100.

That could release some worrisome things, says climate scientist Kimberley Miner of NASA's Jet Propulsion Laboratory in Pasadena, Calif., who wasn't involved in the study. In 2021, Miner and colleagues warned that thawing permafrost could release antibiotic-resistant bacteria, viruses and radioactive waste from nuclear-testing programs.

To identify where the warming could spread industrial pollutants, Langer and colleagues first analyzed the range of Arctic permafrost and whereabouts of industrial infrastructure. They identified about 4,500 sites — including oil fields, mines and abandoned military installations — in places where permafrost probably exists. Next, the team mapped contamination in permafrost areas of Alaska and Canada — regions with accessible records. The team found that as of January 2021, another 3,600 contaminated locations occupied the two regions. These include waste areas and places where pollutants were accidentally released.

Focusing on Alaska, the researchers found that diesel, gasoline and related petrochemicals make up about half of the pollutants reported. Lead, arsenic and mercury — substances toxic to fish, people and other organisms — were reported too. But in many cases, the type of pollutant was not documented. "That's a big problem," Langer says, in part because it makes understanding the risks of a particular leak or spill much harder.

By analyzing the association of industrial sites and contamination places in North America, Langer and colleagues extrapolated where industrial contamination and permafrost might coexist across all of the Arctic, finding that 13,000 to 20,000 such sites may exist today.

Then the team used computer simulations to investigate the impact of current and future levels of climate change. Today, there may already be a risk of permafrost degrading at about 1,000 of the known industrial sites and 2,200 to 4,800 of the known and estimated contaminated areas.

In a low-emissions scenario in which warming rises by up to 2 degrees Celsius above preindustrial levels by the end of the century, those numbers increase to more than 2,100 industrial sites and 5,600 to 10,000 contaminated areas. An increase of about 4.3 degrees C would probably affect almost all known and projected locations.

The findings are probably conservative, Langer says, partly because the analysis didn't consider that infrastructure itself can warm the ground. And even if it doesn't fully thaw, "warming of the permafrost causes quite a bit of a problem," says civil engineer Guy Doré of Université Laval in Quebec City. Permafrost that warms from –5° C to –2° C can lose half of its load-bearing capacity, he says, destabilizing infrastructure.

No international regulations mandate industries in the Arctic to document the substances they use and store, or what happens to them. So it'll be difficult to assess and manage the growing risk of contamination, Langer says.

He plans to visit decades-old oil drilling facilities in Canada to see how the changing permafrost has affected the containment of drilling fluids. The next step, he says, is "to understand better how [contaminants] spread into the landscape." ■

IRINA YARINSKAYA/AFP VIA GETTY IMAGES PLUS

ANIMALS

Invasive ants are genetic oddballs

Yellow crazy ants need male 'chimeras' to reproduce

BY MCKENZIE PRILLAMAN

Yellow crazy ants break the rules of reproduction.

Every male ant contains separate populations of cells from two distinct genetic lineages, making them "chimeras," researchers report in the April 7 *Science*. Yellow crazy ants (*Anoplolepis gracilipes*) are the first known species that requires chimerism to create fertile males.

It's "an elegant response to the kinds of unusual mating systems we've observed in other ants," says Waring "Buck" Trible, an evolutionary geneticist at Harvard University who was not involved in the work. "We might consider this as the next evolutionary step" in ants, Trible says.

Most animals develop from a sperm cell and an egg cell uniting into one, combining their DNA. As a creature grows, all of the subsequent cells, save for sex cells, carry two sets of DNA-bearing chromosomes, one from each parent. In other words, these somatic cells all carry the same genetic information. Sperm and egg cells contain just one set of chromosomes.

But in many ants, along with other insects such as wasps and bees, only females have somatic cells with chromosome pairs. Males typically develop from unfertilized eggs, so their somatic cells hold only one set of chromosomes.

A 2007 study, however, found that about half of the sampled male yellow crazy ants possessed two copies of the same genes, just like the species's female worker ants.

But "it didn't make any sense that all males in this species would be diploid," or have two sets of chromosomes in each somatic cell, says evolutionary biologist Hugo Darras of Johannes Gutenberg University Mainz in Germany. When this happens in other ants, the males are usually sterile. "Nobody had any explanation," Darras says.

Whether a yellow crazy ant is a sterile female (left) or a fertile male (two shown, right) depends on whether DNA from two lineages merges when sex cells combine.

So he and colleagues collected hundreds of yellow crazy ants from across East and Southeast Asia. Analyzing females — queens and workers — revealed that royalty in this species has a genetic source. Reproductive queens came from combining sperm and egg cells from the same lineage, which the team dubbed R. Queens had R/R genomes. Workers were hybrids of the R lineage and another lineage that the team called W. These ants had R/W genomes.

Consistent with the previous study, the researchers also identified R/W males. But rather than having two sets of chromosomes within somatic cells, these males had just one set, as is typical of other ant species. Each cell contained chromosomes from either the R lineage or the W lineage, the team found.

Further experiments revealed that the R and W cells were unevenly distributed throughout the males' bodies. Most of the body contained majority R cells, almost 75 percent based on the sampled tissue. The ratio nearly flipped in the ants' sperm — 65 percent were W cells.

Since both female workers and males come from combining W sperm with R eggs, the sex depends on whether the cells' packets of DNA, or nuclei, merge. Fusion creates a female. Failure to fuse causes egg and sperm nuclei to divide separately within the egg, producing a male.

It's unclear why this never-before-seen mode of reproduction evolved in yellow crazy ants. By not fusing its nucleus with that of the egg, the sperm "might be able to increase its reproductive output," Trible says. Female worker ants are sterile and therefore can't pass on the W genome.

"We think it's maybe an interaction between two genomes that are in conflict but sometimes cooperate," Darras says. The distinct lineages may have evolved independently in two separate ant populations that eventually intermingled. Or perhaps the lineages started with similar genes that diverged over time, he suggests. Regardless, "it looks like the whole genomes are separated and don't exchange any genetic material," Darras says.

That odd reproductive strategy may provide benefits for yellow crazy ants, helping them earn the title of one of the world's worst invasive species (*SN: 10/10/09, p. 13*). Because fusion of R and W nuclei results only in sterile workers, the genomes can never mix and be passed to the next generation. Thus, the ants avoid any possibility of inbreeding, which helps small populations invading new areas maintain genetic diversity.

Chimeras have been observed in other animals, including humans, but it's rare and usually a developmental accident. Yellow crazy ants are the first known species in which chimerism determines sex. But some scientists estimate there are around 20,000 ant species, and the reproductive systems of most have not been studied.

"This is a very special system," says Guojie Zhang, an evolutionary biologist at Zhejiang University in Hangzhou, China, who was not involved in the research. "The question would be how frequently this system can be observed in other ant lineages." ■

NEUROSCIENCE

Scientists make waves in awake brains

Controlling spinal fluid might help treat neurological diseases

BY SIMON MAKIN

Waves of cerebrospinal fluid that normally wash over brains during sleep can be made to pulse in the brains of people who are wide awake, a new study finds.

Previous research has suggested that the clear fluid may flush out harmful waste, such as the sticky proteins that accumulate in Alzheimer's disease (SN: 7/21/18, *p.* 22). So being able to control the fluid's flow in the brain might have implications for treating certain brain disorders.

"I think this [finding] will help with many neurological disorders," says Jonathan Kipnis, a neuroscientist at Washington University in St. Louis who was not involved in the work. "Think of Formula One. You can have the best car and driver, but without a great maintenance crew, that driver will not win the race." Spinal fluid flow in the brain is a major part of that maintenance crew, Kipnis says. But he and other researchers, including the study's authors, caution that any potential therapeutic applications are still far off.

In 2019, neuroscientist Laura Lewis of Boston University and colleagues reported that strong waves of cerebrospinal fluid wash through our brains while we slumber, suggesting that sleep may give the brain a deep clean (SN: 11/23/19, *p.* 11). The slow neural oscillations that characterize deep, non-REM sleep occur in lockstep with the waves of spinal fluid, the team showed. These flows are far larger than the rhythmic influences that breathing and heartbeat have on spinal fluid.

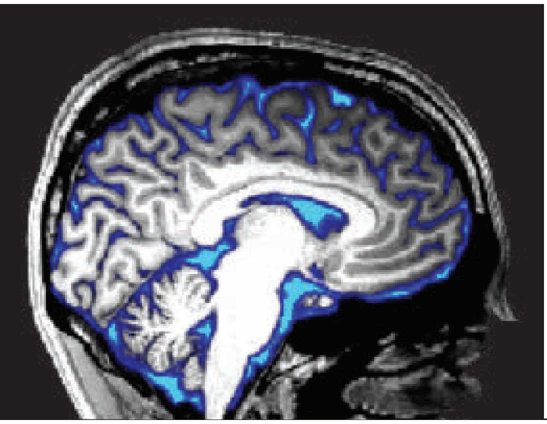
As brain activity during sleep causes blood to flow through the brain, spinal fluid flows in behind the blood. Such fluid infusions clear out toxic proteins and maintain constant pressure in the skull, experiments in mice have shown.

In the new study, "the first question we wanted to answer is, can you manipulate [blood flow] enough to also drive [fluid] flow when someone's awake?" says Stephanie Williams, a neuroscientist also at Boston University.

To stimulate blood flow in the brain, Williams, Lewis and colleagues showed six healthy adults a flickering checkerboard pattern. A mix of techniques, including functional MRI and electrodes, confirmed that the intense stimulation affected blood flow in the brain and allowed the team to see the order of events.

Neural activity increased when the flashing pattern was turned on, followed by increased blood flow. Cerebrospinal fluid flow was suppressed while blood flow increased, and then surged into the brain as blood flow ebbed when the stimulation stopped, the team reports March 30 in *PLOS Biology*. Longer stimulation produced larger spinal fluid flows,

Studies suggest that spinal fluid (blue in this MRI image) clears harmful waste from the brain.



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HEALTH & MEDICINE

Battery starves cancer of oxygen

The device gives tumor treatments a boost in mice

BY BETHANY BROOKSHIRE

It's not great when a person sucks all the oxygen out of a room. When a battery does it to a tumor, though, it could be a good thing.

A small self-charging battery wrapped around a tumor removes oxygen from the cancer cells' environment, boosting the power of some cancer therapies, a study in mice shows. Mice that had the batteries wrapped around their breast cancer tumors, combined with cancer therapy, showed a 90 percent decrease in tumor volume in two weeks, scientists report March 31 in *Science Advances*.

Solid tumors like those that can develop in breast cancer often grow so rapidly that the tumor's growth is faster than its blood supply can support (SN: 6/10/17, *p.* 15). This means that the centers of many tumors can become hypoxic, with much lower oxygen levels than surrounding tissue.

"Hypoxia is a double-edged sword," says materials scientist Yongyao Xia of Fudan University in Shanghai. Low oxygen levels in tumors mean the body's immune cells often cannot survive long enough to kill the cancerous cells (SN: 3/4/17, *p.* 24). Hypoxic cells are also resistant to treatments like radiotherapy and traditional chemotherapy, as there isn't enough blood flow to deliver an effective dose, says coauthor Fan Zhang, a materials scientist also at Fudan University. On the other hand, it provides a target for precision treatment, Xia, Zhang and colleagues say.

Hypoxia could act as a beacon for treatments that use hypoxia-activated prodrugs, which become active only in a low-oxygen environment, says Qing Zhang, a molecular biologist at the University of Texas Southwestern Medical Center in Dallas who was not involved in the work. But these prodrugs haven't shown much benefit in clinical trials, possibly because the solid tumors they target are not evenly hypoxic or not hypoxic enough.

To make tumors more hypoxic so that the prodrugs have a better chance of working, Xia, Fan Zhang and colleagues deployed a flexible battery that can partially wrap around a tumor. One of the battery's electrodes self-charges by sucking up oxygen from the environment. It also creates highly reactive oxygen molecules suggesting it was possible to maximize the response.

The effect of brain activity on spinal fluid flow is separate from the influences of heartbeat and breathing, the team found. "The brain has a way to control its own fluid flow," Lewis says.

The team did not measure whether the waking flows cleared waste from the brain. However, previous studies in mice have found that certain audiovisual stimuli reduce levels of toxic proteins linked to Alzheimer's and Parkinson's. Testing of the technique in humans is under way.

"It's a beautiful study, but I wouldn't draw therapeutic conclusions from this," says neurologist Steven Goldman of the University of Rochester Medical Center in New York. The brain's fluid flow system is optimally set up for cleaning during sleep. "It would be more effective to just ensure a good night's sleep," Goldman says. "Any manipulations over and above that would be best employed during sleep."

Lewis' team acknowledges that the induced flows were smaller than those seen during sleep. But the change in flow was still "pretty substantial," Lewis says. The technique could help scientists figure out how the process might be disrupted in diseases like Alzheimer's, she says. ■

that cells can't use and damage DNA.

By using up most of the available oxygen and producing lots of reactive oxygen molecules, the battery shrunk tumors in mice by up to 26 percent of their original size two weeks after implantation. Pairing the battery with a hypoxia-activated prodrug shrunk average tumor size by 90 percent.

The findings are encouraging but extremely preliminary, Qing Zhang says. The battery "has to be tested in several breast cancer models, and also has to be tested in other cancer models," he says. And, of course, in humans. What's more, if the tumor cells that remain survive, it could mean they are resistant to the hypoxia and the tumor could grow back.

As with many treatments, Qing Zhang says, it will probably have to be combined with other therapies to make sure the whole tumor is zapped for good. ■

NAIM SAGLAM

ANIMALS

This leech has a taste for snails

Its hearty appetite could keep infectious gastropods in check

BY BETHANY BROOKSHIRE

Helobdella austinensis leeches eat a snail in a lab test. The leeches, which aren't too picky when it comes to snail snacks, could be used to control snail-borne diseases.

Leeches might seem like relics of a bygone age of medicine, but they haven't outlived their usefulness. The freshwater leech *Helobdella austinensis* can eat up to its weight in snails every day, suggesting that leeches could be used to control freshwater snail populations — and the host of diseases they carry, researchers report in the April *Biology Letters*.

Snails spread diseases such as schistosomiasis and fascioliasis to humans and livestock. Both of those conditions are caused by flatworms called flukes that spend part of their life cycle in snails. In 2021, more than 250 million people needed preventive treatment against the fluke that causes schistosomiasis. A more effective prevention would be controlling snail populations that host the parasite.

Leeches may be staple frights for horror movie characters, but the animals that should really live in terror of *H. austinensis* are snails. "Everybody who works in the very small leech world globally, we all know that these particular types of leeches love snails," says evolutionary biologist Daniel Shain of Rutgers University in Camden, N.J. The leeches aren't picky in terms of the types of snails they eat. "And snails are a big problem globally, in terms of health, and so we just connected a few dots."

In lab tests, Shain and colleagues paired *H. austinensis* and *H. serendipitous* leeches raised in the lab, plus *H. modesta* leeches found in local New Jersey lakes, with seven different freshwater snail species. Only *H. austinensis* proved an indiscriminate devotee of escargot. If enough snails were present, one of these leeches could eat 0.97 milligrams of snail per day — roughly the leech's own weight.

Using a ratio of one leech per every 10 snails, Shain and colleagues put together predator-prey computer simulations that suggested leeches introduced to snail-ridden areas could tank mollusk populations within about six months.

It's an interesting idea, says ecologist David Civitello of Emory University in Atlanta. But he thinks much more research is needed.

In the lab, leeches had a hard time finding snails once the mollusk populations decreased. That indicates "a poor ability to drive [prey] extinct," Civitello says. Indiscriminately killing but not eradicating snails may weaken competition among the mollusks for food. Big, well-fed snails are much more infectious than smaller, hungrier ones, he says. So if the leeches leave small populations of large snails, the mollusks' infectiousness could mean snail-borne disease ends up getting worse.

More importantly, *H. austinensis* will eat other things besides snails, Civitello says. This is a problem that has plagued snail biocontrol efforts. "These predators are often not specialists on the snails we want them to eat," he says. In the lab, the leeches also eat dead insect larvae. Civitello worries that if introduced to new wild areas, the leeches will prove to have dangerously diverse diets.

Shain and colleagues want to test whether the leeches stick to snail snacks in field trials. In the meantime, he hopes that people won't be put off by the concept of leeches. *H. austinensis* is tiny — and uninterested in humans. Only the snails need to shiver. ■

ANTHROPOLOGY

Native Americans drove horses north

Research reveals how equines may have come to the Great Plains

BY BRUCE BOWER

Indigenous knowledge and Western science have written a new tale about when domesticated horses most recently arrived in what is now the United States.

Spaniards brought horses to Mexico in 1519. Indigenous peoples then took the reins, rapidly transporting offspring of those equine newcomers north along trade routes. As a result, a new study finds, many Native American populations across the Great Plains and the Rocky Mountains had incorporated horses into their ways of life by the early 1600s, decades before encountering any Europeans.

This unconventional scenario of how domesticated horses originally spread throughout central and western North America bucks a previous narrative: European written accounts dating mainly to the 1700s and 1800s had contended that horses first spread into western North America in large numbers after Pueblo people temporarily drove Spanish settlers out of New Mexico in 1680. But little evidence existed to confirm or deny that claim.

Europeans' historical texts didn't ring true for molecular archaeologist Yvette Running Horse Collin of the Center for Anthropobiology and Genomics of Toulouse in France. Running Horse Collin is a member of the Oglala Lakota Nation. Great Plains populations such as the Lakota and Comanche speak of having cared for, herded and otherwise interacted with horses long before Europeans showed up.

Rock art of an undetermined age at a Wyoming site depicts a horse and rider that researchers suspect was carved by ancestral Comanche or Shoshone people.

Running Horse Collin contacted Toulouse colleague Ludovic Orlando, a molecular archaeologist who has traced the origins of domesticated horses to southwestern Asia more than 4,200 years ago (SN: *11/20/21, p. 15*). The duo organized a large collaboration of Western scientists and Indigenous scholars and officials, including members of the Lakota, Comanche, Pawnee and Pueblo nations.

"Our findings indicate that horses spread [north] from Mexico … by the turn of the 17th century and were raised locally, which strikingly lines up with Native American perspectives," William Taylor, an archaeozoologist at the University of Colorado Boulder, said at a March 28 news conference. Results of the team's investigation appear in the March 31 *Science*.

Taylor directed an effort that located and radiocarbon-dated previously excavated remains of 23 horses from North America and six horses from Argentina. Three of the North American horses dated to the second half of the 1500s, well before the 1680 Pueblo Revolt. Those specimens came from sites in Kansas, New Mexico and Wyoming. Reanalysis of a previously radiocarbon-dated horse's remains from an Idaho site, using a technique that measures the amount of near-infrared radiation absorbed by bone, produced a comparably early age estimate.

What's particularly important is that those finds yielded evidence of Native American groups caring for, riding and culturally embracing horses by the early 1600s, says archaeologist Mark Mitchell of the Paleocultural Research Group in Broomfield, Colo., who did not participate in the study.

The earliest of the 23 North American horse remains include bony growths at the back of the skull consistent with the use of a halter or bridle, Taylor said at the news conference. One horse from the 1500s displayed the kind of dental damage seen from use of a bridle's metal bit. Another early horse had been found among various ritual artifacts, indicating that it had held ceremonial meaning of some kind.

Analyses of diet-related chemical elements in teeth typical of particular geographic regions indicated that one early North American horse had grown up locally. Another was raised even farther north, probably part of a managed herd that was fed maize during part of the year, the researchers say.

DNA comparisons with a range of modern horses showed that early North American horses were primarily of Spanish ancestry.

Some Indigenous oral histories suggest that Indigenous peoples' interactions with horses go back thousands of years to equines that might have survived the Ice Age. But analysis of DNA retrieved from remains of two Ice Age horses previously found in Alaska — one dating to about 26,100 years ago and another to around 28,400 years ago — showed no direct ties to later North American horses. Scientists generally suspect that wild horses first evolved in North America over tens of millions of years before dying out around 10,000 years ago.

For now, the scientific evidence supports just the pre-European integration of horses into Great Plains societies, says Peter Mitchell, an archaeologist at the University of Oxford who was not part of the investigation. Further research needs to establish precisely how long ancient wild horses survived in Alaska, he says.

Taylor and colleagues have nonetheless married Western science to Indigenous knowledge in a way that "sets a new standard for archaeological research into the early spread of the horse and the take-up of horse usage by Indigenous groups" throughout the world, Mitchell says. ■

PAT DOAK

PARTICLE PHYSICS

W boson might not be a heavyweight

A recalculation of the particle's mass closely aligns with theory

BY JAMES R. RIORDON

The battle over the heft of a hard-to-detect particle is heating up. What's at stake? Only the leading theory describing all known matter in the universe.

A recalculation of the mass of an elementary particle, the W boson, has increased the conflict between measurements from competing particle collider experiments. The ultimate outcome could bolster the standard model of particle physics, which describes the fundamental forces that make up everything we see in the cosmos. Or it could reveal signs of a breakdown in the standard model, depending on which lab's answer prevails.

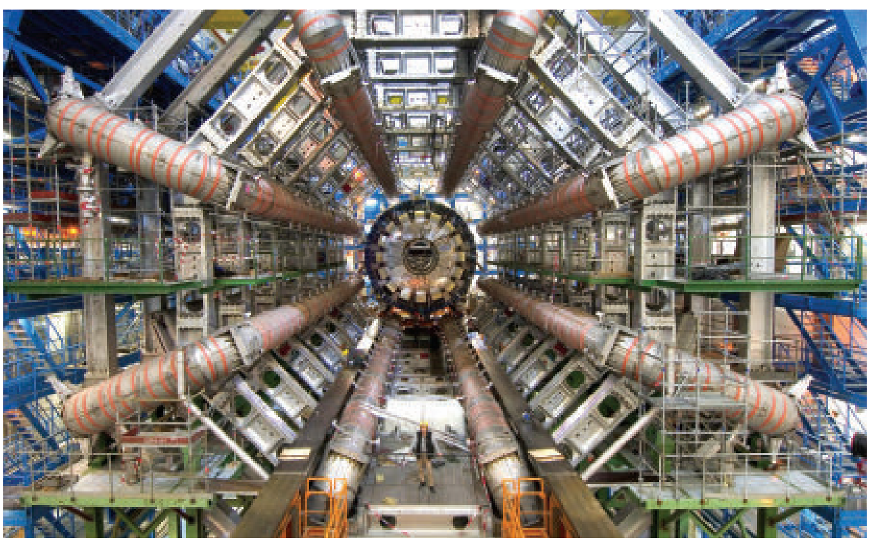
A reanalysis of old data from the Large Hadron Collider's ATLAS experiment yields a W boson mass of about 80,360 million electron volts. Researchers with the experiment, at CERN near Geneva, reported the measurement March 23 at the Rencontres de Moriond conference in La Thuile, Italy. The revised value closely aligns with predictions from the standard model.

It also boasts reduced uncertainty compared with the researchers' previous analysis of the same data, which they reported in 2018. That increases confidence that the team got the mass right.

The updated mass is now even more at odds with a different group's mass measurement. In April 2022, scientists from the CDF experiment at Fermilab in Batavia, Ill., shocked the physics community with a measurement of 80,434 MeV — about 80 MeV heavier than expected (*SN: 5/7/22 & 5/21/22, p. 12*). If the CDF finding is correct, it implies that something is off with the standard model, which has persevered in the face of every experimental challenge thrown at it over the last 50 years.

The W boson is responsible for the weak force, one of three fundamental forces in the standard model (*SN: 2/5/83, p. 84*). And "it's the only mass of a particle in the standard model that can be calculated," says theoretical physicist Sven Heinemeyer of the Karlsruhe Institute of Technology in Germany.

The standard model theory specifies a value for the mass of the W boson, but not for any of the other types of standard model particles, such as electrons and quarks. Finding a W boson mass that's different from standard model predictions would show something is wrong with the current theory.



A new analysis of W boson data from the ATLAS experiment (shown) at CERN's Large Hadron Collider is in close agreement with theory. However, it does not negate a larger W boson mass measurement announced last year by scientists with Fermilab's CDF experiment.

MAXIMILIEN BRICE/CERN

The ATLAS reanalysis offers a stronger counterpoint to the CDF claim than the earlier ATLAS analysis of the same data. "The new analysis is an important confirmation of our previous result," says Andreas Hoecker, a physicist at CERN.

The latest ATLAS value widens the chasm that separates CDF's mass measurement from what other experiments have found. But it shouldn't be seen as erasing CDF's standard model challenge, says physicist Ashutosh Kotwal of Duke University, who is a member of the CDF collaboration.

The ATLAS reanalysis doesn't change the perspective on CDF's announcement in 2022 of a heftier W boson, Kotwal says. Because the reanalysis is based on data that ATLAS released in 2017, he says, "the fact that ATLAS obtains a similar value as before is to be expected."

Heinemeyer, who is not affiliated with ATLAS or CDF, sees a shift in the W boson mass landscape, but no sign of a resolution of the discrepancy.

"Having one new measurement is not enough," Heinemeyer says. "If more and more measurements were to come out now from ATLAS and [other experiments], and they would all be in the same ballpark, at some point the community would decide CDF did something wrong."

The next word on the W boson mass will probably come with pending studies from ATLAS and other experiments at CERN. The CDF experiment shut down in 2011, so it will not contribute further to the debate.

In the meantime, researchers hope to scrutinize each other's analyses to search for clues that might help explain discrepancies in W boson mass measurements. "The CDF April 2022 paper provides a number of cross-checks of the CDF methodology and is transparent," Kotwal says. "I look forward to detailed discussions of the ATLAS methodology."

In the end, the conflict might reveal a new crack in the standard model. Or it could turn out to be another example of one of the most successful theories in history standing strong. ■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ANIMALS

Longest butterfly migration mapped

Europe's painted ladies cross the Sahara to breed in savannas

BY ERIN GARCIA DE JESÚS

Every year, painted lady butterflies born in Europe embark south on an epic journey to Africa. Now, researchers know exactly where on the continent these long-haul travelers spend their winter vacation.

From December through February, after flying across the Sahara in the fall, the orange-and-brown-winged insects set up camp and breed in savannas and highlands across central Africa, scientists report in the April 18 *Proceedings of the National Academy of Sciences*. As the rainy season brings greenery to the region, the butterflies and their caterpillar offspring feast on a variety of plants until the wintering spots dry up. Then the butterflies fly north to Europe.

Exactly where painted lady butterflies (*Vanessa cardui*) overwinter and breed was the last unknown piece of their roughly 15,000-kilometer migration, says Gerard Talavera, an entomologist and evolutionary biologist at the Botanical Institute of Barcelona. The species — one of the most common butterflies in the world — boasts the longest round-trip journey of any butterfly (SN: 7/21/18, p. 4).

Painted ladies aren't the only insects to make long migratory trips, says Constantí Stefanescu, a butterfly ecologist at Museu de Ciències Naturals de Granollers in Spain who was not involved in the work. Understanding how these butterflies do it provides a framework to explore how other migratory insects, including destructive pests, make such treks.

This brand new painted lady butterfly in central Africa may migrate to Europe if it survives.

G. TALAVERA

Scientists knew that painted ladies went to Africa to wait out European winters. The butterflies cross the Sahara and arrive in countries such as Chad in the fall. Around November the insects fly elsewhere, but it was unknown where they landed.

Talavera and colleagues had predicted that subtropical regions close to the equator might provide suitable habitat. From late 2017 through early 2020, the team searched a wide variety of sites across nine countries in sub-Saharan Africa either during the months of December and January or year-round. Another 15 sites were monitored year-round for about two years.

Their search paid off. The scientists found more than 2,700 caterpillars and nearly 2,000 butterflies, from as far west as Cote d'Ivoire and all the way east to Kenya and Ethiopia. From September to November, the butterflies occupy semi-arid savannas. As those areas dry up, the painted ladies move south to savannas and highlands in slightly humid regions from December to February. Central Africa's tropical rainforests stop the insects from going any farther south, Talavera says. "These butterflies don't like wet areas."

Warm weather across the region could help the butterflies reproduce more quickly than they do in some parts of Europe, Talavera says. Three to five generations might be born in Africa before any surviving adults head north in February.

The findings could help scientists figure out why there are population booms with 100 times as many butterflies in some years as others, Stefanescu says. In 2021, his team linked the phenomenon to rains in sub-Saharan Africa. But the part of West Africa identified in that study is different than where the newfound breeding grounds are. Now, scientists can verify the link by looking at rainfall and other conditions where baby butterflies are found.

But the next mystery Talavera's group hopes to solve is why painted ladies make such a long journey at all. ■

ANIMALS

Wild whale sharks get ultrasounds

New underwater techniques could help detect pregnancies

BY BRIANNA RANDALL

How do you know if the world's largest fish is expecting babies? Not by her bulging belly, it turns out.

Scientists thought that an enlarged area on the underside of a female whale shark was a sign of pregnancy. But ultrasound, used for the first time on free-swimming animals, showed only skin and muscle. The humps might instead be a secondary sex characteristic on mature females, like breasts on humans, researchers report March 23 in *Endangered Species Research*.

The ultrasound is part of a suite of new methods including underwater "jet packs" and blood tests that scientists hope could unlock secrets about whale shark (*Rhincodon typus*) reproduction. Whale shark numbers have declined by more than 50 percent in the last 75 years. Now, there are only 100,000 to 238,000 individuals left worldwide, scientists estimate.

In part because whale sharks are relatively rare, their reproductive biology is mostly a mystery (SN: 9/24/22, p. 4). Nearly everything biologists think they know is based on the examination of one pregnant female caught by a commercial fishing boat in 1995.

"Protecting organisms without knowing about their biology is like trying to catch a fly with our eyes closed," says Rui Matsumoto, a fisheries biologist with the Okinawa Churashima Foundation in Japan. The organization researches subtropical animals and plants to maintain or improve natural resources in national parks.

To learn more about these gentle giants, Matsumoto and shark biologist Kiyomi Murakumo of Japan's Okinawa Churaumi Aquarium had to figure out how to keep up with them. Like superheroes in a comic book, the biologists used underwater jet packs — propellers attached to their scuba tanks — to swim alongside the fish, which average 12 meters in length and move

Fisheries biologist Rui Matsumoto uses a propeller mounted on his scuba tank to keep pace with a female whale shark to take an ultrasound of her belly.

about 5 kilometers per hour.

Then the team held a 17-kilogram briefcase containing an ultrasound machine and maneuvered the wand on the bellies of 22 females near the Galápagos Islands. Until this study, ultrasound wands had never been used outside of an aquarium on free-swimming wildlife. The team also drew blood from the fins with syringes. To prevent seawater from contaminating the samples, the researchers used one syringe to create a vacuum, which allowed another syringe to draw only blood.

Performing these tests on whale sharks is especially challenging, says coauthor Simon Pierce, a whale shark ecologist with the Marine Megafauna Foundation, a marine conservation nonprofit in West Palm Beach, Fla. The fish "have some of the thickest skin of any animal — up to about 30 centimeters thick," Pierce says.

Back in the lab, blood plasma from six of the females had hormone levels similar to those of a captive immature female, indicating the wild females were not pregnant. Ultrasound imagery showed egg follicles in two wild females, indicating the whale sharks were mature enough to reproduce but were also not pregnant. The biologists did not locate a pregnant whale shark.

Pioneering these noninvasive techniques on whale sharks has opened the door to learning about other endangered marine animals. Waterproof ultrasound wands mounted on poles are already being used to study tiger sharks, Pierce says.

Developing these sampling techniques is an "astounding feat," says Rachel Graham, a marine conservation scientist and founder of MarAlliance, a marine wildlife conservation nonprofit headquartered in Houston. But she doubts whether sharks or marine mammals that swim faster than whale sharks would tolerate similar tests.

Coupled with satellite tracking, the new methods could help pinpoint where whale sharks give birth, Pierce says. That would go "quite a long way towards conserving the population," he says. ■

CLIMATE

Climate change spikes baseball homers

High temps caused over 500 major league home runs since 2010

BY DARREN INCORVAIA

Baseball is the best sport in the world for numberphiles. There are so many stats collected that the analysis of them even has its own name: sabermetrics. Like in *Moneyball*, team managers, coaches and players use these statistics in game strategy, but the mountain of available data can also be put to other uses.

An analysis of baseball's number hoard shows that climate change caused more than 500 home runs on average since 2010, with higher air temperatures contributing to the sport's ongoing home run heyday, researchers report April 7 in the *Bulletin of the American Meteorological Society*.

Many factors have led to players hitting it out of the park more often in recent decades, from steroid use to the height of the stitches on the ball. Blog posts and news stories have also speculated about whether climate change could be contributing to the increase, says Christopher Callahan, a climate change researcher at Dartmouth College. "But nobody had quantitatively investigated it."

The theorized relationship between global warming and home runs stems from fundamental physics — the ideal gas law says as temperature goes up, air density and thus air resistance goes down. To see if home runs were happening due to warming, Callahan and colleagues analyzed data from more than 100,000 Major League Baseball games from 1962 to 2019.

A 1-degree-Celsius increase in the daily high temperature boosted the number of home runs in a game by nearly 2 percent, the team found. For example, a game like the one on June 10, 2019, where the Arizona Diamondbacks and Philadelphia Phillies set the record for most home runs in a game, would be expected to have 14 home runs instead of 13 if the temperature was 4 degrees C warmer.

Running game-day temperatures through a climate model that controls for greenhouse gas emissions found that human-caused warming led to an extra 58 home runs on average per season from 2010 to 2019. The relationship between warmer days and more home runs goes back to the 1960s.

The team followed that analysis by comparing the speeds and trajectories of more than 220,000 batted balls tracked by high-speed cameras, controlling for factors like wind speed and humidity. That analysis showed a similar increase in home runs per degree Celsius as the game-level analysis, with only lower air density due to higher temperatures left to explain higher numbers of home runs.

Shifting day games to night games and adding domes to stadiums could help teams adjust to rising temperatures. But climate change may soon cause even more dramatic changes to America's pastime, even with those adaptations, says Madeleine Orr, who studies the impacts of climate change on sports at Loughborough University London.

Baseball seasons are also susceptible to snow, storms, wildfires and flooding. "I don't think, without substantial change, baseball exists in the current model" within 30 years, Orr says. ■

S. PIERCE

ANIMALS

Hibernating bears avoid blood clots

Scientists identify a target for developing anticlotting drugs

BY ERIN GARCIA DE JESÚS

People stuck sitting in tight airplane seats for a long-haul flight are at risk of deadly blood clots. But immobile, hibernating bears are not. Now scientists know why.

Bears settled in for winterlong slumbers are deficient in a protein that helps blood clots form, researchers report in the April 14 *Science*. Platelets lacking this protein don't easily stick together.

The study is a "huge step forward," says Tinen Iles, a computational biologist at the University of Minnesota in Minneapolis. It brought together researchers from many backgrounds — from wildlife biologists to health care experts — to show how animals have adapted to stop immobility-related blood clots. Now, there's a road map to mimic nature's solutions with drugs.

In platelets, heat shock protein 47, or HSP47, attaches to collagen, a protein that helps platelets stick together. This is helpful when the body responds to a cut or other injury; it's dangerous when a clump of platelets blocks blood flow to the lungs.

Staying still for long periods of time can put people at risk of developing rare but dangerous blood clots that usually take shape in the legs, a condition called deep vein thrombosis. Inflammation and slow blood flow can cause the clots to form.

To see why hibernating bears don't develop blood clots, cardiologist Tobias Petzold of University Hospital at Ludwig-Maximilians-Universität München and colleagues analyzed blood samples from 13 wild brown bears taken in winter and summer. Platelets taken during hibernation were less likely to clump than those in summer samples and clotted more slowly. In hibernating bears, HSP47 levels were about one-fiftieth of those in active bears.

Tests with mice confirmed HSP47's role. Mice lacking the protein had fewer clots and lower levels of inflammation than mice with HSP47. The team also found that people with long-term immobility because of spinal cord injury had low levels of HSP47 and no signs of inflammation-related clotting. The same was true for 10 healthy participants in a monthlong bed rest study. By day 27, their HSP47 levels decreased.

Potential anticlotting drugs could aim to stop HSP47 from interacting with proteins or immune cells that spark clots, Petzold says. The trick will be finding the right balance between preventing clots and causing too much bleeding.

But the next question to address, Petzold says, is how being motionless prompts the body to make less HSP47. ■

ASTRONOMY

Machine learning touches up the first black hole portrait

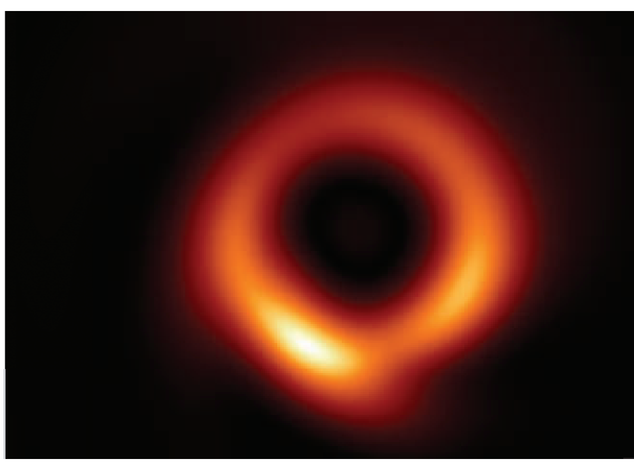
If the first image of a black hole looked like a fuzzy doughnut, this one is a thin onion ring. Using machine learning, scientists sharpened the portrait of the supermassive black hole at the center of galaxy M87.

In 2019, scientists with the Event Horizon Telescope unveiled an image of M87's black hole. The picture showed a blurry orange ring of glowing gas surrounding the dark behemoth (below left). The new ring's thickness (right) is half that of the original, despite being based on the same data, researchers report April 13 in the *Astrophysical Journal Letters*.

The Event Horizon Telescope takes data using a network of radio telescopes across the globe. But that still leaves holes in the data. "Since we can't just cover the entire Earth in telescopes, what that means is that there is some missing information," says astrophysicist Lia Medeiros of the Institute for Advanced Study in Princeton, N.J. "We need to have an algorithm that can fill in those gaps."

Previous analyses had used certain assumptions to fill in the details, such as preferring an image that is smooth. But the new technique uses machine learning to address the gaps based on over 30,000 simulated images of matter swirling around a black hole, creating a sharper image.

In the future, this technique could help scientists get a better handle on the black hole's mass. — *Emily Conover*



L. MEDEIROS *ET AL* 2023

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موهبة

Contribute Positively to Their Prosperity

Lessons from the Mawhiba Foundation

• Parents understand their children the most, thus, they should always be in contact with the school and provide them with important feedback about their child to contribute positively to their prosperity.

• To better understand your gifted child's needs, read and learn more about gifted students.

• Make sure to provide a variety of learning opportunities and resources to support your gifted child's development.

• It is important to participate in your child's school activities that are specially designed for gifted students and celebrate their achievements.

• Gifted students are known for being curious and inquisitive. For that reason, try not to give them straight answers, but encourage them to find out answers and pose questions, and always spend enough time listening to them.

• Always have high expectations for your gifted child's performance.

• Your child might be gifted in some aspects and average in others.

• Be in contact with parents of other gifted children to support your child's educational journey.

• Ensure that your gifted child interacts within a normal social life.

"Mawhiba" is a non-profit organization in the Kingdom of Saudi Arabia. It was founded 1999 to identify and nurture gifted students through a well-established education system that includes a variety ofnational and international opportunities in STEM fields.

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ISEF awards

813
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Number of schools involved in Mawhiba classes program

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186,915
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ANIMALS

Genes help unravel sea cucumber 'silk'

The animal ejects a sticky organ from its butt to deter predators

BY DARREN INCORVAIA

Some lizards shed their still-wriggling tails to distract predators, but sea cucumbers take this sort of strategy to the next level. When startled, the marine invertebrates shoot a silky, sticky substance out of their rear ends that is actually an entire organ.

The tangle of tubules looks like intestines, but it evolved from the sea cucumber respiratory system and, like lizard tails, regenerates after use. Now, a closer look at the genetic instruction book, or genome, of one sea cucumber species is helping unravel how the tubules work on the molecular level, scientists report in the April 18 *Proceedings of the National Academy of Sciences*.

The black sea cucumber (*Holothuria leucospilota*) is "the most dominant sea cucumber species in the South China Sea," says biologist Ting Chen of the South China Sea Institute of Oceanology in Guangzhou. "We would like to know what evolutionary advantage this sea cucumber has gained … so that its population can expand so widely and predominantly."

Chen and colleagues identified genes from the tubules, known collectively as the Cuvierian organ, then predicted what their proteins would look like using a program called AlphaFold (SN: 9/24/22, *p. 16*). The program predicted new types of receptors on cell surfaces that might play a role in expelling the organ.

An analysis of the tubules' "silk" proteins found that even though their amino acid sequences differ from those in spider silk, both silks are made up of long repeating chains of amino acids. Those chains might be a shared structure across silklike proteins, even when the proteins evolved independently, the team says.

Proteins responsible for the organ's stickiness — which stops sea cucumber predators like fish, crabs and starfish in their tracks — have features similar to amyloids, Chen says. In humans, amyloid proteins are associated with neurodegenerative conditions like Alzheimer's.

The team's data can be used to answer other questions about how the enigmatic organ evolved, says biologist Patrick Flammang of the University of Mons in Belgium. A good genome is "a cornerstone to be able to do this work," he says. ■

A startled black sea cucumber will expel a sticky, stringlike organ (thin white lines in this artist's illustration) as a defense against predators such as crabs.

LIANG LI

PLANETARY SCIENCE

Saturn's icy rings may bring the heat

Ultraviolet glow could help scientists ID ringed exoplanets

BY KEN CROSWELL

The rings that make Saturn a spectacle are probably heating its atmosphere, making it glow at ultraviolet wavelengths.

In the planet's northern hemisphere, researchers detected an excess of ultraviolet emission that comes from hydrogen atoms. Known as Lyman-alpha radiation, the emission is probably the result of water ice falling into the atmosphere from the planet's rings, the team proposes in the March *Planetary Science Journal*.

The detection of a similar emission from a distant world could someday lead to the discovery of a Saturn-like planet orbiting another star.

The key to the discovery came when the Hubble Space Telescope and the Cassini spacecraft observed Saturn simultaneously in 2017, right before Cassini plunged into the planet's atmosphere, says astrophysicist Lotfi Ben-Jaffel of the Institut d'Astrophysique de Paris.

This allowed Ben-Jaffel and colleagues to calibrate the ultraviolet detectors on those spacecraft and on the International Ultraviolet Explorer, an Earth-orbiting satellite that also observed Saturn. The team also calibrated data from Voyager 1 and 2, which flew past the planet in 1980 and 1981. Comparing these observations revealed a band of excess Lyman-alpha radiation spanning 5° to 35° N latitude.

The team's explanation for the extra glow is plausible, says planetary scientist Paul Estrada of NASA's Ames Research Center in Mountain View, Calif. "We know material is falling in from the rings," Estrada says, because Cassini detected it (SN: 1/20/18, *p. 7*). "The rings are predominantly water ice. It may be the source of the atomic hydrogen" emitting the Lyman-alpha radiation, he says.

Icy ring particles falling into Saturn's atmosphere carry the energy of their motion with them. "They have to release that energy to the surrounding gas," Ben-Jaffel says, and that energy heats up the atmosphere. When the particles vaporize, they release additional energy, further heating the atmosphere and making it glow at ultraviolet wavelengths. The emission may also appear in the planet's southern hemisphere, the team suspects.

Astronomers don't yet know whether any of the thousands of worlds found orbiting other stars have rings that are as magnificent as Saturn's. But the new discovery may help scientists identify such worlds, if they exist. Future planet hunters could look for the telltale glow of Lyman-alpha radiation, Ben-Jaffel says, and then further observations could confirm the rings' existence. ■


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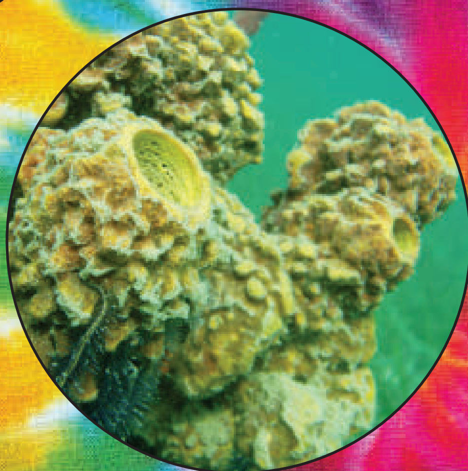


These animals can BEND THE MIND

At least one of their compounds is psychedelic, while others remain mysterious

By Deborah Balthazar

The adage "all attention is good attention" may be true for marketers — not so for the Sonoran Desert toad. Last fall, the U.S. National Park Service sent out a message on Facebook asking visitors to "refrain from licking" the toad (technically *Incilius alvarius* but commonly called *Bufo alvarius*). That message came months after a *New York Times* article covered the booming interest in the psychedelic compound that the toad excretes from its skin — along with the "poaching, over-harvesting and illegal trafficking" that have accompanied that interest.

People don't typically lick the toads to get high, says Robert Villa, a community outreach specialist at the University of Arizona's Desert Laboratory on Tumamoc Hill. The secretions the toads produce are toxic when ingested. They "work orally, through the mucous membranes, and cause really dangerous side effects, like cardiac arrest," Villa says.

Instead, for decades, people have been collecting the secretions, then drying and smoking them. When inhaled, a compound within, 5-MeO-DMT, can cause auditory and visual hallucinations. "It's a very powerful psychedelic sometimes called the 'God molecule,'" says pharmacologist and chemist David Nichols of Purdue University in West Lafayette, Ind.

The drug's growing popularity could be bad news for toad populations. "If you relocate it outside of its home territory," Villa says, which often happens when people collect a toad for its secretions, "it gets lost and its chances for survival go way down." What's more, collecting large numbers of toads increases the risk of disease transmission, like chytrid fungus, between toads.

We at *Science News* heard the PSA loud and clear: Just leave this toad alone. But we couldn't help but wonder: What other amazing animals may have psychedelic potential? On the following pages, freelance writer Deborah Balthazar takes us on a tour, by land and sea, of some of the world's mind-altering fauna.

Sonoran desert toad (*Incilius alvarius*)

All toads secrete toxins from their skin. These secretions, whose specific compounds vary from species to species, probably evolved as a way to keep a toad's body moist. Over time, the compounds, which can also act on the brain and affect heart muscle when ingested, came to aid in self-defense.

But the Sonoran Desert toad, also known as the Colorado River toad, appears to have taken evolution one step further.

The toad, one of the largest in North America, secretes an enzyme that converts bufotenine, a compound also made by other toads, into 5-MeO-DMT, a powerful hallucinogen related to the psychedelic drug DMT.

A frightened Sonoran Desert toad gushes its toxic mix, which includes 5-MeO-DMT, from its parotoid glands — located behind each eye — and from glands on its legs. It's a way to say, "Please don't eat me! I don't taste good!" When swallowed in large quantities by a potential predator, the toxins can cause coma, cardiac arrest and even death.

Scientists aren't yet sure why the Sonoran Desert toad produces 5-MeO-DMT, and why it is the only toad known to make it. "There's a lot of mystery," Villa says.

SONORAN DESERT TOAD

Habitat: The Sonoran Desert, in the southwestern United States and northern Mexico

GIANT MONKEY FROG

Habitat: The Amazon Basin in South America

Giant monkey frog (*Phyllomedusa bicolor*)

There's no scientific consensus on whether kambô, the name for the toxic secretion produced by the giant monkey frog, should be considered a psychedelic. The term psychedelic comes from Greek meaning "mind manifesting," Nichols says. "You can imagine, it's enhancing the properties of your mind, rather than just intoxicating you." Other compounds such as stimulants and depressants modify the activity of the brain, but they don't leave users with the kind of new insights and memorable experiences that come with psychedelics.

Wuelton Monteiro, a tropical medicine researcher at the Universidade do Estado do Amazonas in Manaus, Brazil, points to a 2020 study in *Scientific Reports* as an example of why the classification has been unclear. In the small study, nearly half of participants who reported using kambô said they had a spiritual experience, and some experiences came with what resembled the afterglow often associated with hallucinogens. But kambô doesn't activate the 5-HT2A receptor, a protein that senses the chemical messenger serotonin, while classic psychedelics do.

Among Indigenous populations in the southwestern Amazon, the frog's skin secretions have been used for centuries as a stimulant in shamanistic rituals. According to Villa, the secretions are usually applied on small, superficial burns on the body to increase the stamina of hunters.

In predators attempting to gobble the frog, kambô might cause regurgitation, seizures and a change in heart function. Researchers are still trying to decipher the specific compounds that explain these effects, but they do know that species of *Phyllomedusa* collectively produce over 200 short protein fragments that can influence body function. Some might be promising for future medicines.

California harvester ant (*Pogonomyrmex californicus*)

The venom of the California harvester ant is made up of enzymes that aren't known to cause hallucinations on their own, but the Indigenous peoples of central California once ate them during rituals including vision quests. Ethnographic reports suggest people would swallow hundreds of live ants in balls of eagle down feathers. No doubt the people were stung, likely on the insides.

Justin Schmidt, an entomologist at the Southwestern Biological Institute and University of Arizona in Tucson who died in February, said the pain of being stung by so many ants, along with extreme cold, fasting and in some cases sleep deprivation, triggered hallucinations that connected the people with spiritual guides.

A harvester ant's sting is "nothing like a bee sting," Schmidt wrote in *The Sting of the Wild* (*SN: 8/6/16, p. 26*). "The pain is intense, comes in waves, and is deeply visceral." Lasting from four to eight hours, the pain is accompanied by a numb sensation at the site of the sting. The ants deliver stings to defend their colonies from large predators, including lizards, birds and people. (Smaller enemies such as other insects and spiders are bitten.)

A person who eats 1,000 ants would probably die; according to Schmidt's book, one ant is enough to kill a mouse. But some predators have defenses: The regal horned lizard (*Phrynosoma solare*) has a mucus lining its mouth and digestive system that allows it to eat hundreds of ants and a substance in its blood that neutralizes the venom. Some birds somehow avoid getting stung too.

It's hard to get more information on how the ants were used in rituals and the nature of the experience. Disease and violence that came with Westerners during California's gold rush destroyed the Indigenous communities in the Central Valley and their way of life.

CALIFORNIA HARVESTER ANT

Habitat: Southwestern United States and northern Mexico

Salema (*Sarpa salpa*)

SALEMA

Habitat: Temperate and tropical ocean waters, from the Atlantic coast of Africa to the Mediterranean Sea

Fishes including this species of sea bream, as well as some sea chubs and clownfish, can cause auditory and visual hallucinations when eaten, though reports are rare. *Sarpa salpa* was known as the "dream fish" in ancient Rome, according to a 2018 review of psychedelic fauna published in *Frontiers in Psychiatry*. Two cases of hallucinatory fish poisoning were documented in 2006 in the journal *Clinical Toxicology*. In one case, a 40-year-old man ate baked *S. sarpa* and later experienced hallucinations of screaming animals and giant arthropods surrounding his car. The symptoms went away, with medical attention, 36 hours after he ate the fish.

Researchers don't know what compounds cause this ichthyoallyeinotoxism, or fish poisoning, which can include nightmares. Evolutionary biologist Leo Smith of the University of Kansas in Lawrence, who studies fish history and diversification, says he and other scientists suspect that the compounds are a by-product of the fishes' diets.

But ichthyoallyeinotoxism is distinct from two other forms of fish poisoning. Symbiotic bacteria within puffer fish produce a neurotoxin called tetrodotoxin, or TTX, that can cause paralysis and death. And ciguatera fish poisoning comes from eating fish contaminated with a neurotoxin produced by some dinoflagellates. It can cause diarrhea, vomiting and weakness, as well as a reverse sensory disruption, where hot things seem cold and vice versa. But it does not cause hallucinations, says Sandric Leong, a biological oceanographer at the National University of Singapore.

How and why many of these neurotoxins are produced is still being worked out. "There are so many relationships with the marine environment which we are not very sure of," Leong says.

PITTED SPONGE

Habitat: The Caribbean

Pitted sponge (*Verongula rigida*)

The pitted sponge and some other sponges including *Smenospongia aura* and *S. echina* contain 5-bromo-DMT and 5,6-dibromo-DMT. Because of their relationship with the psychedelic drug DMT, these compounds are plausible psychedelics. American chemist Alexander Shulgin, famous for his research into psychedelic compounds and for introducing the world to the synthetic hallucinogen MDMA, or ecstasy, and his wife Ann Shulgin wrote in *TIHKAL: The Continuation* that they don't know whether the sponge compounds are activated by smoking or not. They are, however, "quantitatively reduced to DMT by stirring under hydrogen in methanol, in the presence of palladium on charcoal."

The pitted sponge is known to concentrate in its tissue chemicals called monoamines that can modify the behavior of nerve cells. Not only can these compounds make the sponge taste bitter, but they can also alter the behavior of predatory fish that dine on the sponge.

"They wouldn't prevent the fish from ever trying to take a bite, but it would prevent it from persisting or consuming the sponge any beyond an initial several bites," says Mark Hamann, a pharmacologist from the Medical University of South Carolina in Charleston.

V. rigida's ability to alter animal behavior intrigued Hamann, who reported in a 2008 study in the *Journal of Natural Products* that 5,6-dibromo-DMT acted like an antidepressant in rats, while 5-bromo-DMT acted like a sedative. Hamann says that related compounds may one day be isolated and might make for promising antidepressants, anxiety-reducing drugs or pain relievers in people. ■

Explore more

■ Laura Orsolini *et al.* "Psychedelic fauna for psychonaut hunters: A mini-review." *Frontiers in Psychiatry*. May 22, 2018.

FEATURE

The Original Highfliers

New discoveries are updating scientists' picture of pterosaurs, the first flying vertebrates

By Sid Perkins

With a wingspan of at least 2.5 meters, *Dearc sgiathanach* was the largest pterosaur of its era, the middle of the Jurassic Period.

N. JAGIELSKA

In an eat-or-be-eaten world, flight conveys a bevy of benefits. A creature that takes to the third dimension can more easily escape earthbound predators, dine off a much broader menu or drop down on unsuspecting victims from above. Flying also allows an animal to cover distance more quickly, forage more efficiently and find mates more easily.

So it's perhaps surprising that only three groups of vertebrates have ever evolved sustained, muscle-powered flight. Pterosaurs, Greek for "wing lizards," arrived on the scene in the Triassic Period, perhaps as early as around 237 million years ago. These original vertebrate fliers preceded birds by at least 70 million years and bats by more than twice that.

What caused pterosaurs' demise is clear: The same asteroid that wiped out the non-avian dinosaurs about 66 million years ago also took them out — along with more than 75 percent of all life on

Earth. But how pterosaurs took to the air in the first place remains a big mystery. "We don't have any properly transitional fossils for pterosaurs, or at least ones that we recognize," says Matthew Baron, a freelance vertebrate paleontologist.

Despite the gap in the early fossil record, recent research offers clues to who pterosaurs' earliest cousins were and what they looked like, and how pterosaurs evolved from small, flitting creatures into an incredibly varied group. They eventually occupied ecosystems worldwide and consumed a wide variety of prey — getting bigger and spreading farther earlier than previously thought, recent studies reveal. Some grew bizarre crests atop their heads, while others sported mouths full of teeth that projected threateningly at various angles. "Some pterosaurs looked like creatures from your nightmares," says Brian Andres, a vertebrate paleontologist at the University of Sheffield in England.

During their lengthy reign of the skies, pterosaurs ranged in size from creatures that could sit in the palm of your hand to soaring behemoths with wingspans that rivaled those of an F-16 fighter jet. In fact, the largest animal that ever took flight — an iconic species discovered more than half a century ago but only recently described in great detail — was a pterosaur.

In the beginning

Pterosaur fossils were first unearthed in the late 1700s — coincidentally, from the same limestone formation in Germany that later yielded the earliest known bird, *Archaeopteryx*. Scientists didn't quite know what to make of the fossils. One scientist proposed they belonged to a weird sea creature, and another thought they represented a transitional form between birds and bats. But soon, experts settled on the fact that pterosaurs were flying reptiles, distinct from dinosaurs.

The first discovered species was named *Pterodactylus antiquus*, the genus name stemming from the Greek words for "wing finger." (Although this species and many discovered soon after were commonly referred to as pterodactyls, that term officially applies only to this species and a small group of related species within the broader pterosaur lineage.) Unlike in bats, whose wing membranes are stretched between four elongated fingers of the hand, a pterosaur's wing is supported by only one hyperelongated finger, a hallmark that helps distinguish pterosaurs from other creatures.

But something pterosaurs and bats do share is that when they first appear in the fossil record, they're already able to fly. Direct evidence of how the reptiles took to the skies is lacking. "As yet, we do not know of any 'missing link' pterosaurs," Baron reported in 2021 in *Earth-Science Reviews*.

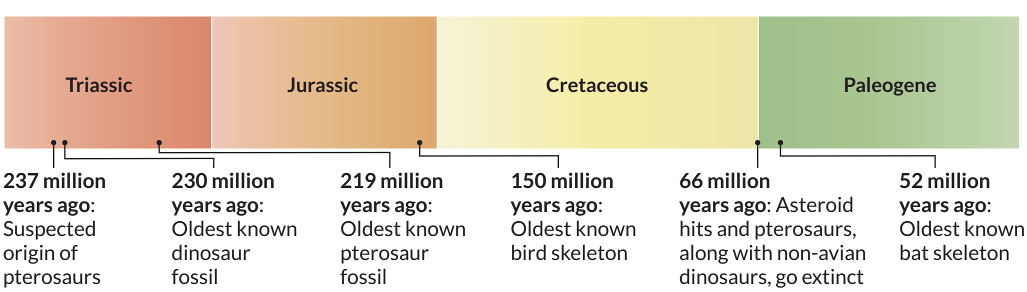
The oldest known pterosaur fossils date to about 219 million years ago, though paleontologists suspect pterosaurs originated as early as 237 million years ago, Baron notes. That's when the oldest and closest relatives of pterosaurs lived, and thus probably around the time that pterosaurs would have split off and formed their own lineage. The gap in the fossil record is in part due to the fact that rocks from this period are scarce worldwide. And many pterosaur bones were hollow, so they were vulnerable to being crushed soon after death or during fossilization. "Often, pterosaur remains are just a jumble of bones," Baron says.

But there are indirect clues to what a proto-pterosaur might have looked like and whether pterosaur flight evolved from the ground up — in terrestrial creatures that flapped and leaped into the air — or from the trees down — in tree-living animals that glided.

Those clues come from studies of pterosaurs and their relatives. In 2020, researchers published a

Pterosaur timeline Pterosaurs originated during the Triassic Period — well before the other two groups of flying vertebrates, birds and bats — and then died out in the same mass extinction that killed off non-avian dinosaurs.

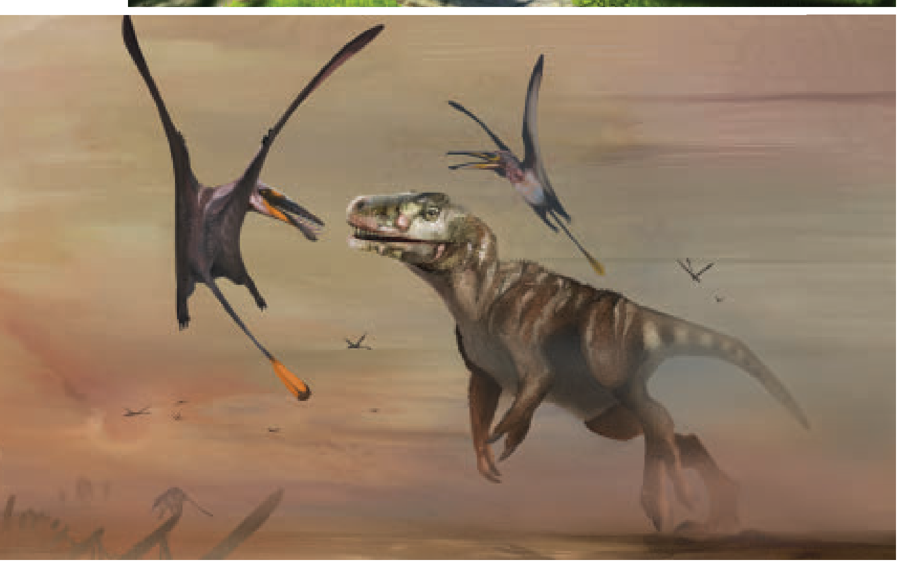
Milestones in the history of vertebrate flight



paper in *Nature* comparing the anatomy of 157 species of early pterosaurs, primitive dinosaurs and a variety of reptiles that lived at the same time or earlier. A group known as lagerpetids — from the Greek for "rabbit reptiles," so named because of the general proportions of the bones in the limbs — was most closely related to pterosaurs.

A separate analysis, reported last year in *Nature*, showed that a fast-running, roughly 20-centimeter-long reptile that lived about 230 million years ago was a close relative of both lagerpetids and pterosaurs. Given that close relationship, this creature, called *Scleromochlus taylori*, may serve as a good stand-in for the kind of animal that pterosaurs evolved from (SN: 11/5/22, p. 15).

S. *taylori* had slender limbs, small hands and straight claws, all of which point to a ground-dwelling creature, says Davide Foffa, a vertebrate paleontologist at National Museums Scotland in Edinburgh. Because a critter like S. *taylori* presumably didn't spend a lot of time in trees, that argues against the idea that pterosaur flight evolved out of gliding. But a small pelvic girdle suggests that S. *taylori* wasn't a leaper, Foffa says. That would seem to argue against the standard idea for how a ground dweller would take to the skies. However, he says, "it's not necessary to be a leaper to evolve flight."



Pterosaurs may have evolved from small ground-dwelling reptiles similar to *Scleromochlus taylori* (top), which was about as long as a dinner fork, during the late Triassic Period. The recent discovery of *Dearc sgiathanach* (bottom) suggests that pterosaurs evolved large body sizes by at least the middle of the Jurassic Period.

FROM TOP: GABRIEL UGUETO; N. JAGIELSKA

What's for lunch?

What pterosaurs ate is often a matter of conjecture. Although some fossils preserve stomach contents — direct evidence of what was consumed — most of the time researchers must look at where a pterosaur lived and how its anatomy compares with modern creatures to reconstruct diet. Based on such comparisons, researchers have speculated that various species of pterosaurs ate everything from insects and worms to fish, crustaceans and meatier prey such as small land vertebrates.

But sometimes, researchers are left to comb through other types of evidence.

Take *Kunpengopterus sinensis*, a pterosaur that lived in what is now China between 165 million and 153 million years ago. Last year, researchers reported unearthing fossils of this species alongside gastric pellets chock-full of fish scales, a strong hint that the creatures had eaten fish and then regurgitated the indigestible bits, as modern owls and gulls do (SN: 3/12/22, p. 5).

Other evidence comes à la fossilized poop — or, more delicately, coprolites. If a coprolite can be linked to the creature that made it, any contents can be reasonably identified as a part of the diet, says Martin Qvarnström, a vertebrate paleontologist at Uppsala University in Sweden. A few years ago, he and colleagues analyzed three coprolites from more than 150-million-year-old rocks unearthed in south-central Poland. The fossilized dung was deposited on an ancient tidal flat that also preserved a multitude of pterosaur footprints, Qvarnström says. The well-trampled surface appears to have been rapidly buried, perhaps as soon as the next tide came in, so it's very likely that both the footprints and the coprolites were made by pterosaurs, he and colleagues reported in 2019 in *PeerJ*.

Using high-energy radiation to perform CT-like scans of the fossilized poop, the team found that the largest coprolite, which was about 1.5 centimeters long and 6 millimeters in diameter, contained more than 100 calcium-rich shells of single-celled organisms called foraminifera. One of the smaller coprolites contained many bristles from what may have been bottom-dwelling marine worms. The large numbers alone suggest that ingestion of these forams and worms wasn't accidental, Qvarnström says. Instead, the researchers propose, the pterosaur had been targeting this prey.

For these pterosaurs to consume such minuscule prey, they must have been filter feeders, much like flamingos or baleen whales. To capture the forams — which were mostly about 300 micrometers across, about the size of a large dust mite — these pterosaurs must have had jaws full of closely spaced teeth, the team suggests. Although filter-feeding pterosaurs are known from later ages, this is the first strong evidence for them living as early as about 150 million years ago, says Qvarnström.

Because skeletal fossils of these pterosaurs aren't yet known, Qvarnström's group doesn't know what the mystery filter feeders looked like or how big they were. But maybe they resembled the newly discovered species *Balaenognathus maeuseri*. (*Balaenognathus*, roughly translated from Latin, means "whale jaw," a reference to baleen whales.) Its fossils were unearthed from limestone rocks laid down as sediment sometime between 157 million and 152 million years ago in what is now Germany, says David Martill, a vertebrate paleontologist at the University of Portsmouth in England.

B. maeuseri had a wingspan of about 1.5 meters, similar to a large flamingo. The pterosaur had a 10-centimeter-long, spatula-shaped bill that sported at least 480 teeth. Many of those long, thin teeth — not strong enough to provide a clamping bite on struggling prey — had tiny hooks on their ends, Martill says. That's unlike anything seen in any other pterosaur. The crochet hook–like features probably helped the pterosaur filter and trap itty-bitty prey more effectively than straight teeth would have, Martill and colleagues reported January 21 in *PalZ*. When foraging, this long-legged creature probably waded through shallow water, facing into the flow and opening its jaws just enough for plankton-rich water to enter, Martill says. Then, water drained away through the teeth, leaving behind a food-rich slurry.

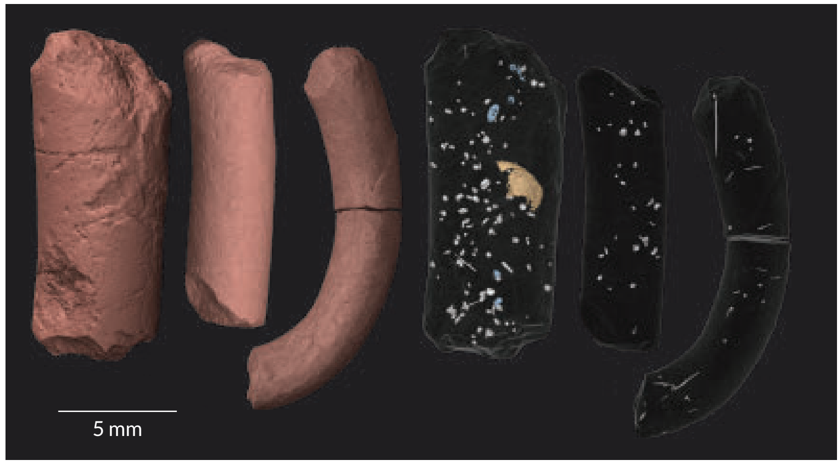
Bigger, wider, faster

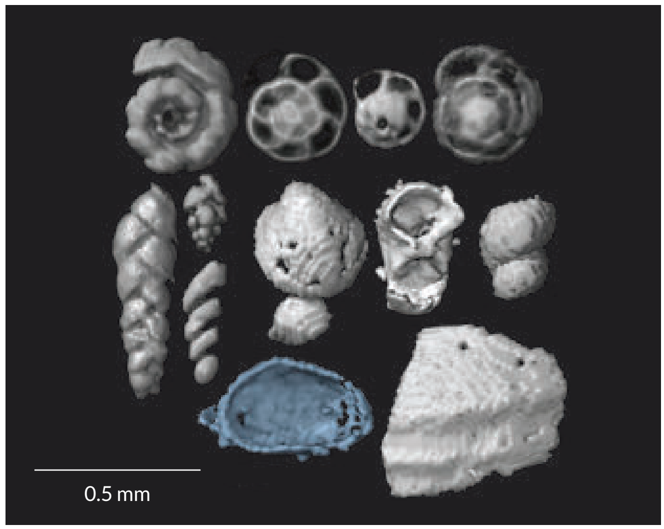
Thanks to a fossil discovered in 2017 on Scotland's Isle of Skye, researchers now realize that pterosaurs grew to larger sizes much earlier than once thought. That, in turn, has helped debunk some theories about why pterosaurs evolved large body sizes.

Embedded in limestone laid down as sediments in a lagoon about 167 million years ago, the well-preserved fossil lacks only parts of the skull, wings, hind limbs and tail, says Natalia Jagielska, a vertebrate paleontologist at the University of Edinburgh. She and colleagues dubbed the creature *Dearc sgiathanach*, which in Scottish Gaelic means "winged reptile from Skye."

Microscopic analyses of cross sections of some bones revealed features akin to the growth rings in trees, hinting that the pterosaur was at least 2 years old and still growing when it died, Jagielska and colleagues reported in February 2022 in *Current Biology*. Based on the size of the pterosaur's upper-arm bone, the team estimates the youngster had a wingspan of around 2 meters.

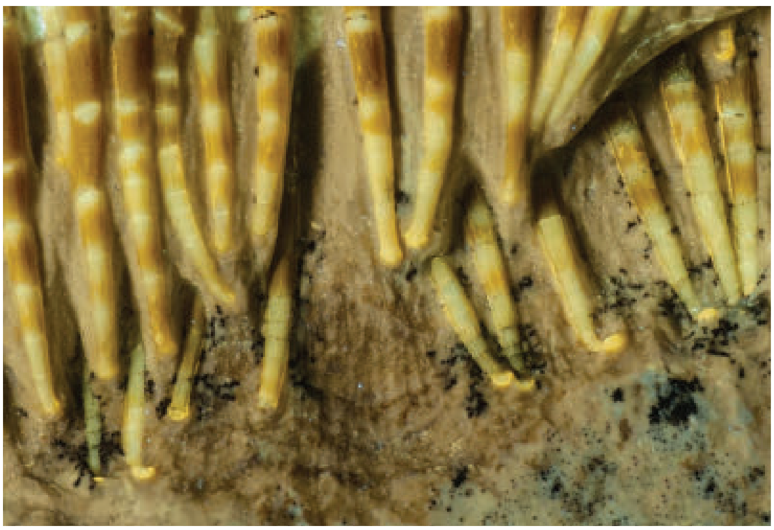
Comparisons with the growth patterns of closely related pterosaurs suggest that an adult would have had a wingspan of at least 2.5 meters and possibly





Fossilized dung, or coprolites, can help reveal what pterosaurs ate. CT-like scans of three coprolites (virtual reconstructions, top left) revealed the shells of microscopic organisms (shown within the coprolites, top right, and isolated, bottom). They include foraminifera, mollusks and crustaceans (one highlighted blue).

M. QVARNSTRÖM *ET AL*/*PEERJ* 2019



A pterosaur named *Balaenognathus maeuseri* was probably a filter feeder similar to modern flamingos. Little hooks (visible in the fossil close-up) at the ends of *B. maeuseri*'s skinny teeth probably helped trap tiny prey.

3 meters or more. That makes *D. sgiathanach* the largest pterosaur to have lived up until that time, with a wingspan that rivaled a trumpeter swan's.

Before the discovery of *D. sgiathanach*, studies had suggested that pterosaurs didn't start to become larger until the late Jurassic Period, between about 160 million and 145 million years ago. At that point, the story goes, competition with newly evolved birds forced pterosaurs to expand beyond being just insect eaters and into new ecological roles. But *D. sgiathanach* evolved tens of millions of years before the first birds took wing, so other, not-yet-identified factors must have been at play, the researchers say.

Another recent study speaks to how widely and how quickly pterosaurs spread around the world, Andres says. Some extremely fragmentary specimens unearthed from sandstone in northwestern Argentina, including scattered portions of a snout, a jawbone and a wing bone, are distinct enough to be classified as belonging to pterosaurs. The features are so distinct that Andres and colleagues named two brand-new species: *Yelaphomte praderioi* and *Pachagnathus benitoi*. The team described the fossils in March 2022 in *Papers in Palaeontology*.

The sandstone probably dates to sometime between 206 million and 200 million years ago, the researchers estimate. Unequivocal pterosaur remains known from that time come from North America, Europe and Greenland—all then part of the northwestern portions of the supercontinent Pangaea. The new fossils were found in an area that was once southwestern Pangaea, Andres notes. That reveals a wider distribution tens of millions of years earlier in pterosaur history than was previously presumed, Andres' team argues. And because the sandstone formed in upland areas far from the nearest coast, the find reveals that pterosaurs lived in a greater diversity of habitats in this era than previously recognized.

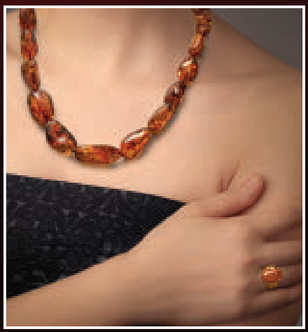
An icon revealed

Of all the pterosaurs ever found, none has captured imaginations as much as *Quetzalcoatlus northropi*, the largest creature to ever take flight. Besides cameos in *Jurassic Park: Dominion* and the comic strip *Calvin and Hobbes*, the species has appeared on the postage stamps of more than two dozen nations and on two coins struck by the Royal Canadian Mint.

Scientists are enamored of the species too. The 1975 paper that initially described it has been cited more than 500 times, despite its brevity, Andres says. In late 2021, Andres and colleagues built on that paper's description with a number of papers that, for the first time, delved deeply into the iconic species' size, appearance, movements and the habitat where it lived.

Only a handful of *Q. northropi* fossils have been found, most in the Big Bend area of southwestern Texas, Andres says. Most of the identifiable remains come from a handful of creatures and together comprise a partial wing and a few leg bones. They, and several hundred other poorly preserved pterosaur bone fragments, were unearthed from rocks formed from sediments that accumulated in stream channels between 69 million and about 66 million years ago, says

FROM TOP: MEGAN JACOBS/UNIV. OF PORTSMOUTH; D. MARTILL *ET AL*/*PALZ* 2023



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Giraffe-sized *Quetzalcoatlus northropi*, the largest flying creature that ever lived, may have foraged in meadows and shallow waters like modern herons and storks do.

Tom Lehman, a vertebrate paleontologist at Texas Tech University in Lubbock. That means some of these pterosaurs could have been alive when or just before an asteroid struck Earth and brought on a long-lasting and worldwide climate catastrophe.

Much of what scientists suspect about Q. *northropi* stems from the more common fossils of a related species, Q. *lawsoni*. Andres and his colleagues have unearthed fossils of more than 200 of these individuals, offering enough bones to reconstruct the majority of the pterosaur. The team estimates that this smaller relative had a wingspan of about 4.5 meters and lived in the same area around the same time as Q. *northropi*, Lehman says. He and colleagues estimate that Q. *northropi* had a wingspan of about 10 meters.

"The worst thing about pterosaurs is that they're no longer around."
BRIAN ANDRES

If these two species did live simultaneously, Lehman says, they evidently divvied up the ecosystem and foraged separately. When they died, their carcasses ended up in different types of sedimentary rocks, suggesting different parts of the environment. Q. *lawsoni* apparently spent a lot of time in oxbow lakes. Q. *northropi*, on the other hand, seems to have foraged along the edges of the river itself. Plenty of water snails and other creatures lived in these bodies of water and would have provided ample food for hungry pterosaurs and other predators, Lehman says.

Based on their measurements, the researchers made life-size models of Q. *northropi*'s bones to see how the creatures would have moved and to reconstruct the range of motion of their joints. "First of all, their back is so short and their legs are so long that they couldn't walk like other quadrupeds," says Kevin Padian, a vertebrate paleontologist at the University of California, Berkeley. "And their forelimbs are so long, they couldn't avoid touching the ground." Yet pterosaur footprints suggest that those forelimbs weren't helping propel the creature forward when it walked, he says. Instead, they appear to have been used for support only, like walking sticks.

It appears that *Quetzalcoatlus* could reach down to the ground with its long, toothless beak — and even lower, into bodies of water. Once it grabbed its prey, it could tilt its beak to the sky and swallow its victims whole. So Padian and colleagues suggest that this pterosaur patrolled through meadows or waded in shallow waters as modern-day storks or herons do, plucking up fish, mammals or even small dinosaurs using a beak that acted like chopsticks.

The sight of a giraffe-sized predator stalking through swamps would have undoubtedly been impressive. "The worst thing about pterosaurs," Andres says, "is that they're no longer around." ■

Explore more

- Matthew G. Baron. "The origin of pterosaurs." *Earth-Science Reviews*. October 2021.

Sid Perkins is a freelance science writer based in Crossville, Tenn.

JAMES KUETHER

Kraken the code

Octopuses and other shell-less cephalopods commonly edit their RNA without changing their DNA. Scientists don't yet know why.

WRANGEL/ISTOCK/GETTY IMAGES PLUS

Cephalopods may edit RNA to adapt to their surroundings

By Tina Hesman Saey

Many writers grouse when an editor makes a change in a story, but the consequences of changing a single word usually aren't that dire.

Not so with genetic instructions for making proteins. Even a small change can prevent a protein from doing its job properly, with possibly deadly consequences. Only occasionally is a change beneficial. It seems wisest to preserve genetic instructions as they are written. Unless you're an octopus.

Octopuses are like aliens living among us—they do a lot of things differently from land animals, or even other sea creatures. Their flexible tentacles taste what they touch and have minds of their own. Octopuses' eyes are color-blind, but their skin can detect light on its own (*SN: 6/27/15, p. 10*). They are masters of disguise, changing color and skin textures to blend into their surroundings or scare off rivals. And to a greater extent than most creatures, octopuses squirt the molecular equivalent of red ink over their genetic instructions with astounding abandon, like a copy editor run amok.

These edits modify RNA, the molecule used to translate information from the genetic blueprint stored in DNA, while leaving the DNA unaltered.

Scientists don't yet know for sure why octopuses, and other shell-less cephalopods including squid and cuttlefish, are such prolific editors. Researchers are debating whether this form of genetic editing gave cephalopods an evolutionary leg (or tentacle) up or whether the editing is just a sometimes useful accident. Scientists are also probing what consequences the RNA alterations may have under various conditions. Some evidence suggests editing may give cephalopods some of their smarts but could come at the cost of holding back evolution in their DNA (*SN: 4/29/17, p. 6*).

"These animals are just magical," says Caroline Albertin, a comparative developmental biologist at the Marine Biological Laboratory in Woods Hole, Mass. "They have all sorts of different solutions to living in the world they come from." RNA editing may help give the creatures vast numbers of solutions for problems they may face.

Wielding a red pen

Molecular biology's central dogma holds that instructions for building an organism are contained in DNA. Cells copy those instructions into messenger RNAs, or mRNAs. Then, cellular machinery called ribosomes read the mRNAs to build proteins by stringing amino acids together. Most of the time, the protein's composition conforms to the DNA template for the protein's sequence of amino acids.

But RNA editing can cause divergences from the DNA instructions, creating some proteins that have different amino acids than specified by the DNA.

Editing chemically modifies one of RNA's four building blocks, or bases. Those bases are often referred to by the first letters of their names: A, C, G and U, for adenine, cytosine, guanine and uracil (RNA's version of the DNA base thymine). In an RNA molecule, the bases are linked to sugars; the adenine-sugar unit, for instance, is referred to as adenosine.

There are many ways to edit RNA letters. Cephalopods excel at a type of editing known as adenosine to inosine, or A-to-I, editing. This happens when an enzyme called ADAR2 strips a nitrogen and two hydrogen atoms off adenosine (the A). That chemical peel turns adenosine into inosine (I).

Ribosomes read inosine as guanine instead of adenine. Sometimes that switch has no effect on the resulting protein's chain of amino acids. But in some cases, having a G where an A should be results in a different amino acid being inserted into the protein. Such protein-altering RNA editing is called RNA recoding.

Soft-bodied cephalopods have embraced RNA recoding with all of their arms while even closely related species are more tentative about accepting rewrites, Albertin says. "Other mollusks don't seem to do it" to the same extent.

RNA editing isn't limited to creatures of the deep. Almost every multicellular organism has one or more RNA editing enzymes called ADAR enzymes, short for "adenosine deaminase that acts on RNA," says Joshua Rosenthal, a molecular neurobiologist also at the Marine Biological Laboratory.

Cephalopods have two ADAR enzymes. Humans have versions of them, too. "In our brains, we edit a ton of RNA. We do it a lot," Rosenthal says. Over the last decade, scientists have discovered millions of places in human RNAs where editing occurs.

But those edits rarely change the amino acids in a protein. For instance, Eli Eisenberg of Tel Aviv University and colleagues identified more than 4.6 million editing sites in human RNAs. Of those, only 1,517 recode proteins, the researchers reported last year in *Nature Communications*. Of those recoding sites, up to 835 are shared with other mammals, suggesting that evolutionary forces preserved editing at those locations.

Cephalopods take RNA recoding to a whole new level, Albertin says. Longfin squid (*Doryteuthis pealeii*) have 57,108 recoding sites, Rosenthal, Eisenberg and colleagues reported in 2015 in *eLife*. Since then, the researchers have examined multiple species of octopus, squid and cuttlefish, each time finding tens of thousands of recoding sites.

Soft-bodied, or coleoid, cephalopods may have more opportunities for editing than other animals because of where at least one of the ADAR enzymes, ADAR2, is located in the cell. Most animals edit RNAs in the nucleus — the compartment where DNA is stored and copied into RNA — before sending the messages out to meet up with ribosomes. But cephalopods also have the enzymes in the cytoplasm, the cells' jellylike guts, Rosenthal and colleagues discovered (SN: 4/25/20, *p.* 10).

Having editing enzymes in two locales doesn't fully explain why cephalopods' RNA recoding so far outstrips that of humans and other animals. Nor does it explain the patterns of editing scientists have uncovered.

All about flexibility

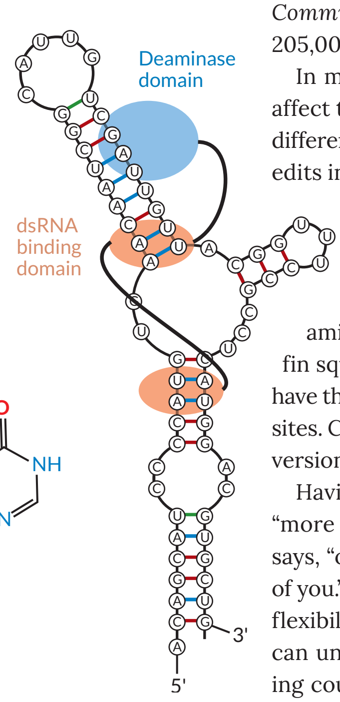
Editing isn't an all-or-nothing proposition. Rarely are all copies of an RNA in a cell edited. It's much more common for some percentage of RNAs to be edited while the rest retain their original information. The percentage, or frequency, of editing can vary widely from RNA to RNA or between cells or tissues, and may depend on water temperature or other conditions. In longfin squid, most RNA editing sites were edited 2 percent or less of the time, Albertin and colleagues reported last year in *Nature Communications*. But the researchers also found more than 205,000 sites that were edited 25 percent of the time or more.

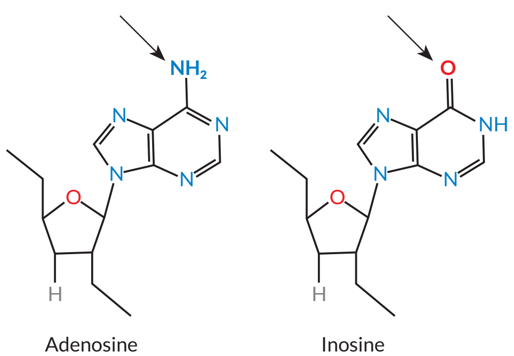
In most of a cephalopod's body, RNA editing doesn't often affect the makeup of proteins. But in the nervous system, it's a different story. In longfin squids' nervous systems, 70 percent of edits in protein-producing RNAs recode proteins. And RNAs in the nervous system of the California two-spot octopus (*Octopus bimaculoides*) are recoded three to six times as often as in other organs or tissues.

Some mRNAs have multiple edit sites that alter amino acids in the proteins the mRNAs encode. In the longfin squid's nervous system, for instance, 27 percent of mRNAs have three or more recoding sites. Some contain 10 or more such sites. Combinations of those editing sites could result in multiple versions of a protein being made in a cell.

Having a wide selection of proteins may give cephalopods "more flexibility in responding to the environment," Albertin says, "or give you a variety of solutions to the problem in front of you." In the nervous system, RNA editing might contribute to flexibility in thinking, which could help explain why octopuses can unlock cages or use tools, some researchers think. Editing could be an easy way to create one or more versions of a

Recode away In a common form of RNA editing, an adenosine becomes an inosine (below) through a reaction that removes an amino group and replaces it with an oxygen (arrows). The illustration at right shows an ADAR enzyme attaching to a double-stranded RNA at the "dsRNA binding domain." The region of the molecule that will interact to cause the reaction, the "deaminase domain," is positioned near the adenosine that will become an inosine.





J.J.C. ROSENTHAL AND E. EISENBERG/ANNUAL REVIEW OF ANIMAL BIOSCIENCES 2023 protein in the nervous system and different ones in the rest of the body, Albertin says.

When humans and other vertebrates have different versions of a protein, it often comes from having multiple copies of a gene. Doubling, tripling or quadrupling copies of a gene "results in a whole genetic playground to allow genes to go off and do different functions," Albertin says. But cephalopods tend not to duplicate genes. Instead, their innovations come from editing.

And there is a lot of room for innovation. In squid, mRNAs for building the alpha-spectrin protein have 242 recoding sites. All the combinations of edited and unedited sites theoretically could create up to 7×10^{72} forms of the protein, Rosenthal and Eisenberg report in this year's issue of *Annual Review of Animal Biosciences*. "To put this number in perspective," the researchers wrote, "suffice it to say that it dwarfs the number of all alpha-spectrin molecules (or, for that matter, all protein molecules) synthesized in all cells of all the squids that have ever lived on our planet since the dawn of time."

That incredible level of complexity would be possible only if every site were independent, says Kavita Rangan, a molecular biologist at the University of California, San Diego. Rangan has been studying RNA recoding in California market squid (*Doryteuthis opalescens*) and in longfin squid. Water temperature triggers the squid to recode motor proteins called kinesins that move cargo inside cells.

In longfin squid, the mRNA that produces kinesin-1 has 14 recoding sites, Rangan has found. She examined mRNAs from the optic lobe — the part of the brain that processes visual information — and from the stellate ganglion, a collection of nerves involved in generating the muscle contractions that produce jets of water to propel the squid.

Each tissue made several versions of the protein. But certain sites tended to be edited together, Rangan and Samara Reck-Peterson, also of UC San Diego, reported last September in a preprint posted online at bioRxiv.org. Their data suggest that editing of some sites is coordinated and "very strongly rejects the idea that editing is independent," Rangan says. "The frequency of the combos that we see don't match if every site was edited independently."

Yoking editing sites may prevent squid and other cephalopods from reaching the pinnacles of complexity that they're theoretically capable of. Still, RNA editing provides cephalopods a way to try out many versions of a protein without getting locked into a permanent change in DNA, Rangan says.

That lack of commitment puzzles Jianzhi Zhang, an evolutionary geneticist at the University of Michigan in Ann Arbor. "It doesn't make sense to me," he says. "If you want a particular amino acid in a protein, you should change the DNA. Why do you change the RNA?"

Is RNA recoding adaptive?

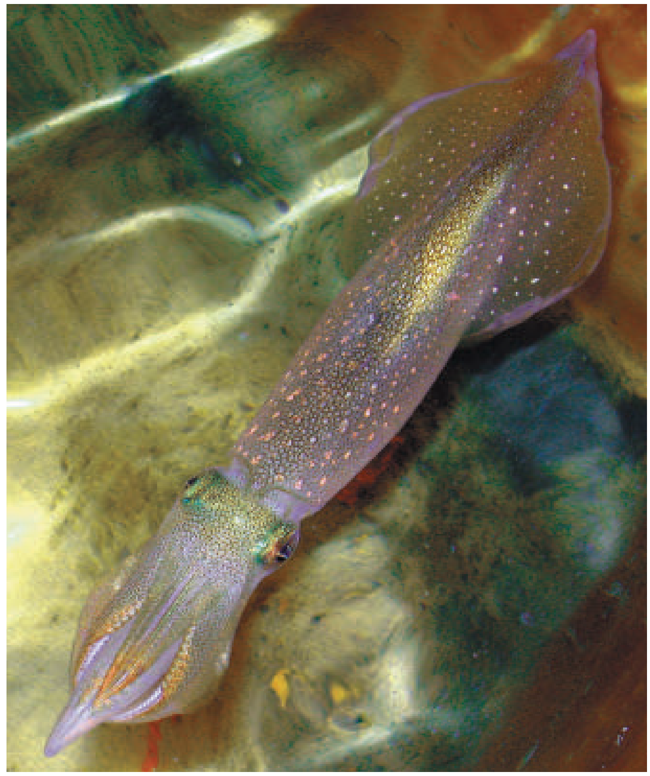
Perhaps RNA editing provides some evolutionary advantage. To test that idea, Zhang and then–graduate student Daohan Jiang compared "synonymous" sites, where edits do not change amino acids, with "nonsynonymous" sites where recoding happens. Since synonymous edits don't change amino acids, the researchers considered those edits to be neutral as far as evolution is concerned. In humans, recoding, or nonsynonymous editing, happens at fewer sites than synonymous editing, and the percentage of RNA molecules that are edited is lower than at synonymous sites.

"If we assume synonymous editing is just like noise that happens in the cell, and nonsynonymous editing is less frequent and [at a] lower level, that suggests nonsynonymous editing is actually harmful," Zhang says. Even though recoding in cephalopods happens much more frequently than for humans, in most cases, recoding is not advantageous, or adaptive, for cephalopods, the researchers argued in 2019 in *Nature Communications*.

There are a few shared sites where octopuses, squid and cuttlefish all recode their RNAs, the researchers found, suggesting the recoding is useful in those instances. But this is a small fraction of editing sites. A few other sites that are edited in one species of cephalopod but not others were also adaptive, Zhang and Jiang found.

If it's not all that helpful, why have cephalopods persisted with RNA recoding for hundreds of millions of years? RNA editing may stick around not because it is adaptive, but because it is addictive, Zhang says.

He and Jiang proposed a harm-permitting model (that is, a



ELAINE BEARER

The longfin squid recodes RNA at more than 50,000 locations. RNA recoding might help the squid respond more flexibly to its environment, but whether recoding has evolutionary value is not yet clear.

situation that permits harmful changes to DNA). Imagine, he says, a situation in which a G (guanine) in an organism's DNA gets mutated to an A (adenine). If that mutation leads to a harmful amino acid change in a protein, natural selection should weed out individuals that carry that mutation. But if, by chance, the organism has RNA editing, the mistake in the DNA might be corrected by editing RNA, essentially changing the A back to G. If the protein is essential for life, then the RNA would have to be edited at high levels so that nearly every copy is corrected.

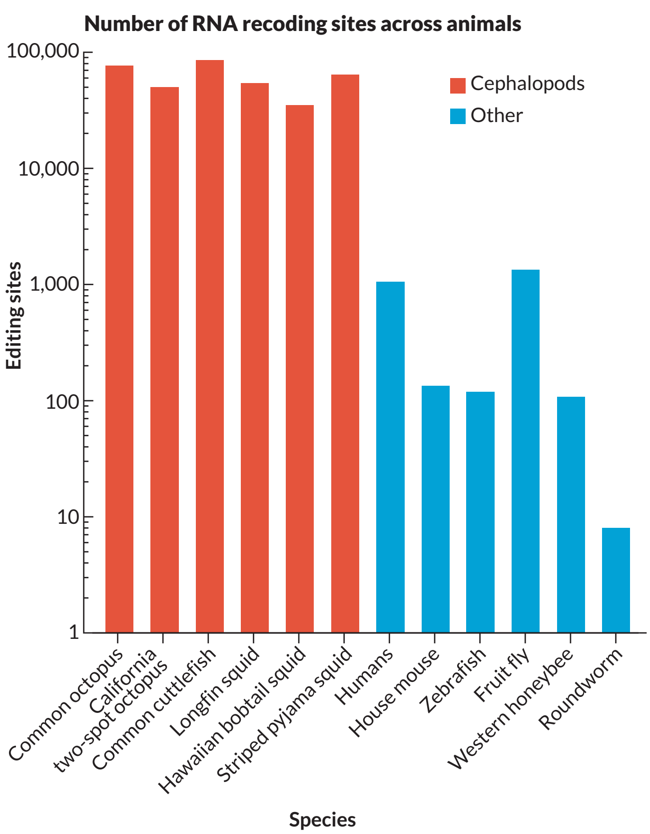
When that happens, "You're locked into the system," Zhang says. Now the organism is dependent on RNA editing machinery. "It cannot be lost, because you will require the A to be edited back to G for survival, so the editing will be kept at high levels.... In the beginning you really didn't need it, but after you got it, you became addicted."

Zhang argues that that sort of editing is neutral, not adaptive. But other research suggests RNA editing can be adaptive.

RNA editing may work as a transition phase, letting organisms try out a switch from adenine to guanine without making a permanent change in their DNA. Over the course of evolution, sites where adenines are recoded in RNA in one cephalopod species are more likely than unedited adenines to be replaced with guanine in the DNA of one or more related species, researchers reported in 2020 in *PeerJ*. And for heavily edited sites, evolution across cephalopods seems to favor a transition from A to G in DNA (rather than to cytosine or thymine, the other two DNA building blocks). That favors the idea that editing can be adaptive.

Other recent work by Rosenthal and colleagues, which examined A-to-G replacements in different species, suggests that having an editable A is an evolutionary boon over an uneditable A or a hardwired G.

Making changes Soft-bodied cephalopod species including octopuses, squid and cuttlefish recode RNA in their nervous systems at tens of thousands of sites, compared with about a thousand or fewer sites in humans, mice, fruit flies and other animal species. Though scientists have been documenting the number of editing sites, they will need new tools to directly test how recoding influences cephalopod biology.



J.J.C. ROSENTHAL AND E. EISENBERG/*ANNUAL REVIEW OF ANIMAL BIOSCIENCES* 2023

Open questions

Evidence for and against RNA recoding's evolutionary value has come mainly from examining the total genetic makeup, or genomes, of various cephalopod species. But scientists would like to directly test whether recoded RNAs have an effect on cephalopod biology. Doing that will require some new tools and creative thinking.

Rangan tested synthetic versions of squid motor proteins and found that two edited versions that squid make in the cold moved slower but traveled farther along protein tracks called microtubules than unedited proteins did. But that's in artificial laboratory conditions on microscope slides. To understand what is happening in cells, Rangan says, she would like to be able to grow squid cells in lab dishes. Right now, she has to take tissue directly from the squid and can only get snapshots of what is happening. Lab-grown cells might allow her to follow what happens over time.

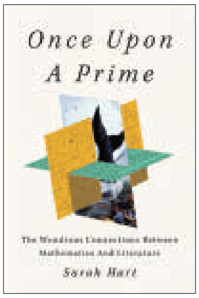
Zhang says he is testing his harm-permitting hypothesis by getting yeast hooked on RNA editing. Baker's yeast (*Saccharomyces cerevisiae*) doesn't have ADAR enzymes. But Zhang engineered a strain of the yeast to carry a human version of the enzyme. The ADAR enzymes make the yeast sick and grow slowly, he says. To speed up the experiment, the strain he is using has a higher-than-normal mutation rate, and may build up G-to-A mutations. But if RNA editing can correct those mutations, the ADAR-carrying yeast may grow better than ones that don't have the enzyme. And after many generations, the yeast may become addicted to editing, Zhang predicts.

Albertin, Rosenthal and colleagues have developed ways to change the genes of squid with the gene editor CRISPR/Cas9. The team created an albino squid by using CRISPR/Cas9 to knock out, or disable, a gene that produces pigment. The researchers may be able to change editing sites in DNA or in RNA and test their function, Albertin says.

This science is still in its early stages, and the story may lead somewhere unexpected. Still, with cephalopods' skillful editing, it's bound to be a good read. ■

Explore more

- Joshua J.C. Rosenthal and Eli Eisenberg. "Extensive recoding of the neural proteome in cephalopods by RNA editing." *Annual Review of Animal Biosciences*. February 2023.
- Joshua J.C. Rosenthal. "The emerging role of RNA editing in plasticity." *Journal of Experimental Biology*. June 2015.



Once Upon a Prime
Sarah Hart
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Math plus literature equals a good pair

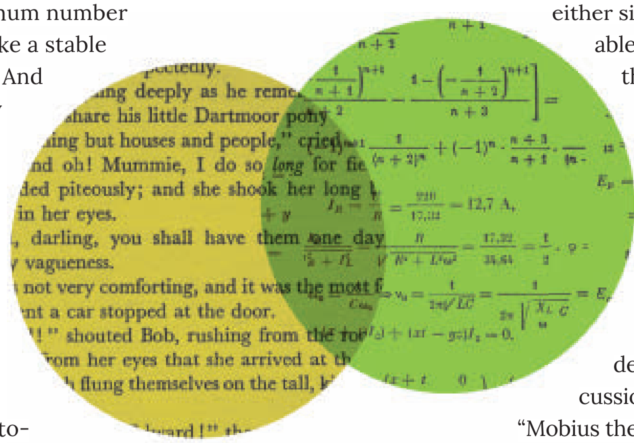
"Mathematical symbolism and metaphor are present in every kind of literature, from the humblest of fairy tales right through to *War and Peace*," claims mathematician Sarah Hart. In *Once Upon a Prime*, she lays bare some of this hidden math and meaning in a host of poetry, novels and folklore.

She starts with nursery rhymes, often rife with counting — such as "One, Two, Buckle My Shoe" — showing how numbers bleed into our very first encounters with the world of words. This is not just through counting but also more subtly through the rhythms and rhyme patterns. It's also through trebling — where a word or phrase is repeated three times, such as "Row, row, row your boat."

The number three has a special hold on Western literature and languages in general. It pervades common phrases — "Three cheers for…," "Ready, Set, Go," "Learning your ABCs." It's also central to story structure; for example, trilogies are more prevalent than tetralogies. Characters tend to come in threes too, like "The Three Little Pigs," and even in jokes like "A priest, a minister and a rabbi…"

Sarah Hart lays bare some of the hidden math and meaning in a host of poetry, novels and folklore.

Hart suggests this emphasis on three has some basis in geometry. Three is the minimum number of points that can define a two-dimensional shape, and the minimum number of sticks that can be bound to make a stable rigid structure, that is, a triangle. And the equilateral triangle is the only shape with both equal-length sides and equidistant corners. These geometric properties give the number three "a sense of strength and completeness, and also often of equitability," Hart writes.



C. CHANG

It's a poetic argument, if not completely convincing. To bolster her case, she also points to trichotomies. Take a number, any number, and every other number is either more, less or equal to that number — a trichotomy that has direct parallels with Aristotle's doctrine of the mean: "Every ethical virtue is a golden mean (just right) between two vices — one an excess, the other a deficiency," as Hart describes it. This doctrine is playfully illustrated in Goldilocks' experiences with porridge, chairs and beds.

For a book about math and literature, it's not surprising that Hart focuses quite a bit on poetry, which is often defined by patterns of some sort. Perhaps more revelatory is her look at how math also molds the structure or pace of novels. For example, I had noticed Amor Towles was not moving through time in a strictly linear fashion when I read his 2016 book *A Gentleman in Moscow*, but I completely missed how the number two orchestrates the story's structure. The novel takes us through 32 years in the protagonist's life, starting in 1922 when he begins living under house arrest. Each chapter advances in a roughly doubling interval of time since his sentence begins: the first day after, then the second, fifth, 10th, three weeks after, six weeks after and so on. Then from the middle of the book, the intervals climb down again, reversing the sequence. Some readers may wonder if Hart's love of math simply leads her to find patterns like this everywhere. But the odds must be astronomically high for the examples she presents to be mere chance.

Among the numerous math-loving authors Hart cites is Herman Melville, who steals the limelight for a good 10 pages that are sheer joy to read. Melville tended to lace his novels with so much philosophy and mathematics that his publisher worried about profitability. At one point, Melville promised his next novels would have "no metaphysics, no conic-sections, nothing but cakes & ale." He did not keep that promise. One of his next books was *Moby-Dick*. The novel is thick with math, from the concept of a quoin — a kind of lopsided wedge, which the main character Ishmael defines through geometric descriptions of a sperm whale's head — to the analogy for how such a creature must see two distinct views of the world from eyes on either side of its head, "as if a man were able simultaneously to go through the demonstrations of two distinct problems in Euclid."

Cover to cover, Hart's love of math fizzes off the page, such as when she implores readers to put down the book and twist a line of paper into a Möbius strip. She admits it's a bit of a detour, but in her defense, it is leading up to a discussion of a 1974 short story called "Mobius the Stripper," which has a particular kind of circular narrative.

Hart's simple breakdowns of both math and literature make the book easy for anyone to follow, no matter their proficiency in either subject, though a familiarity with some of the math and literature references might make for a slightly more satisfying read. Not everyone will finish the book primed (ha!) to discover the mathematical gems hidden in a book or poem. But that takes little away from the charm of reading *Once Upon a Prime*, a joyous tour de force of mathematical and literary delights. — *Anna Demming*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CONVERSATIONS WITH MAYA

RAJ CHETTY
Founder of Opportunity Insights, a nonpartisan research and policy institute that uses big data to improve economic opportunity and mobility in the United States

Maya Ajmera, President & CEO of the Society for Science and Executive Publisher of Science News, chatted with Raj Chetty, an alumnus of the 1997 Science Talent Search (STS) and the 1997 International Science and Engineering Fair (ISEF). In 2018, Chetty founded Opportunity Insights, an institute based at Harvard University dedicated to harnessing big data to improve upward mobility out of poverty. Chetty is the William A. Ackman Professor of Economics at Harvard, a MacArthur Fellow and a recipient of the John Bates Clark Medal. Chetty, who recently joined the Society's Honorary Board, sat down with Ajmera this fall for a fireside chat hosted by the Society. We are thrilled to share an edited version of that conversation.

Tell us about yourself and a little bit about your upbringing.
I grew up in New Delhi, India, until I was 9 years old. Then I came to the United States with my parents. I had what I think is a common experience for many immigrant kids: I saw the U.S. as a land of opportunity. Seeing the big contrast between India and the United States has shaped some of my perspective and interest in issues of inequality, social mobility and opportunity.

That experience, in part, inspired my research into what factors lead people to pursue careers in science and innovation. We found that America has many "lost Einsteins"—women and people from minoritized or low-income groups who could have made significant discoveries if they had been exposed to innovation as children.

You participated in ISEF and STS. What are your memories of those competitions?
I have vivid memories of participating in ISEF and STS. I had an opportunity to work during the summers and after school at the Medical College of Wisconsin in a microbiology lab, which is where I did my research project. At ISEF, I remember being struck by the experience of seeing all these students from different parts of the U.S. doing lots of different exciting things. Conducting research in high school and participating in ISEF shaped my own interest in research and the types of questions I'm focused on today.

What inspired you to apply big data to the study of economic mobility?
In high school, I started to realize that I was very interested in research, science and discovering things. But at the same time, I realized I was more interested in statistical analysis of the data I was generating. My interest in math and statistics and my experience seeing vast differences in outcomes between kids in India and kids in the U.S. led me towards economics and social science. Big data came later. When I was in college and in graduate school, big data wasn't a thing. But I later discovered that it could be a great vehicle to study some of the questions I and many others had been thinking about for decades.

You have studied a range of variables that both coincide with and challenge our perceptions of economic mobility and the American dream. What findings have surprised you the most?
What surprised me the most is how the U.S. is not actually all that much of a land of opportunity, despite that perception.

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If you grow up in the U.S. in a low-income family, your odds of reaching up into the middle class or beyond don't look that great. In some sense, if you want to achieve the American dream, you are better off growing up in Canada or in many parts of Scandinavia.

But when I started digging further into the data on millions of children's experiences from anonymized tax return data, it became clear how disparate opportunities are, depending upon where you live and the color of your skin.

For whom is the American dream possible?

In simple terms, white Americans growing up in middle class families in certain communities—often higher-income areas with better schools and better social networks—have great outcomes. We also see very good outcomes for many kids who come here as immigrants. But there are vast swaths of America, including much of the Southeast and many cities in the industrial Midwest, where even white kids don't have great chances of rising up. For Black kids, unfortunately, and Black boys in particular, the American dream is not a reality almost everywhere in the U.S.

Your most recent research highlights the importance of forging relationships that transcend socioeconomic status. Can you tell us about those findings?

The vast differences in children's chances of rising up across different communities became a motivating puzzle for our research: What factors explain why we're seeing kids from low-income families do really well in certain parts of Iowa, for example? Is it about the schools? Is it about the types of jobs? Something else?

Over the years, many sociologists have discussed the idea that it might be about who you're connected to, who shapes your aspirations, and what your social network looks like. But the problem was we didn't have a good way to measure social capital empirically. With the advent of online social networks, I started talking with the team at Meta about the possibility

As a high school student at the University School of Milwaukee, Raj Chetty interned in the lab of Vladimir M. Kushnaryov at Medical College of Wisconsin.

A young Raj Chetty plays in front of a chalkboard at Stony Brook University, where his father, V. K. Chetty, was a visiting professor.

of launching a large-scale collaboration between Meta and our research team to study these questions. We were able to use anonymized Facebook social network data on 80 million people and looked at their friendships in the U.S.—21 billion friendships between them—and constructed very fine-grained measures, zip code by zip code, about the extent to which low- and high-income people were interacting with each other. Connections like these have turned out to be the single strongest predictor of differences in economic mobility that we or anybody else has identified to date.

We found that low-income kids growing up in communities where there is a lot of interaction across class lines have a much better chance of going to college and achieving a higher level of income. It remains to be understood exactly why that is the case, but we think it's things like being aware of career paths they may not have otherwise considered.

What's your favorite book?

I will go back to my childhood and say *Charlie and the Chocolate Factory*, which in retrospect, I realize is a book about upward mobility. I don't think I had quite figured that out as a kid.

What's keeping you up at night?

Knowing that the pandemic has made all the issues that we're studying only worse. Finding solutions to these problems is all the more imperative with that in mind. Not just because the American dream in and of itself is important, but also because it has very important political implications. Democracy itself is at risk at the moment because many people feel disenfranchised. I would like to have more answers to the question of what we can do to make a difference. If somebody were to ask me how we can narrow racial disparities or improve outcomes for many low-income kids, I have a couple guesses but don't really have the answer. I think that lack of scientific understanding prevents us from finding a solution. That's the kind of thing that I often lie in bed thinking about and what I think makes social science so important and exciting.

MARCH 25, 2023

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A song for the (stone) ages

People have long eaten putrid foods, forcing scientists to rethink the diets of Neandertals and other hominids, ***Bruce Bower*** *reported in "Stone Age cuisine" (SN: 3/25/23, p. 16).*

Reader **Maria Reidelbach** asked Google's AI chatbot to write a song inspired by the story, in the style of musician Tom Waits:

Deep in the cave, the Neandertals eat
Putrid meat, their only treat
They gnaw on the bones, they chew on the skin
And they don't give a damn if it's been in

Chorus:
Putrid meat, putrid meat
It's all they've got, it's all they eat
Putrid meat, putrid meat
It's the only thing that keeps them going

The Neandertals are a tough bunch
They've been through a lot, they've seen a lot
But they're still here, they're still alive
And they're still eating putrid meat

(Repeat chorus)

Some people say the Neandertals are extinct
But I know they're not, I've seen them
They're out there, somewhere, eating putrid meat

(Repeat chorus)

So if you're ever feeling down
And you think your life is tough
Just remember the Neandertals
And their putrid meat diet
They're still here, they're still alive
And they're still eating putrid meat

Making an impression

Air pollution from the Industrial Revolution may have helped give rise to 19th century impressionist art, ***Bas den Hond*** *reported in "Smog influenced impressionism's dreamy style" (SN: 3/25/23, p. 4).*

Reader **Bill Clendenen** asked if pollutants trapped in impressionist paintings could reveal increasing levels of air pollution during this time.

Paints can trap environmental elements. Vincent van Gogh's 1882 painting "Beach at Scheveningen in Stormy Weather" contains sand from the beach where it was made. But analyzing paints for pollutants would be challenging. The chemicals that make up pigments and varnishes would need to be carefully controlled for, say climate physicist **Anna Lea Albright** of the Laboratory of Dynamic Meteorology, Sorbonne University and École Normale Supérieure in Paris and climatologist **Peter Huybers** of Harvard University. "Looking at other materials from that time [like outdoor sculptures] might be easier," they say.

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A.

B.

I guess I was a little bored. For the past hour, I'd been on the phone with Daniele, the head of my office in Italy, reviewing our latest purchases of Italian gold, Murano glass and Italian-made shoes and handbags.

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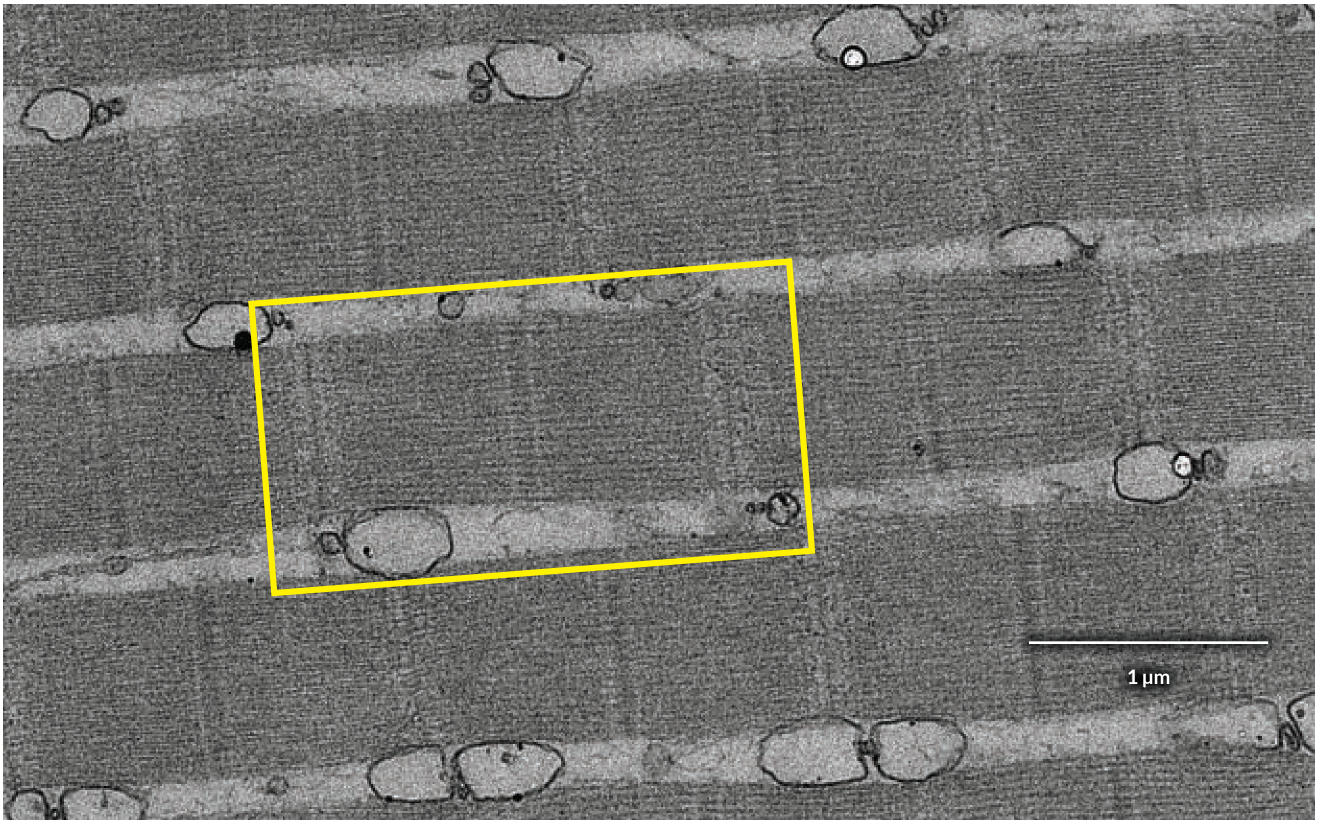
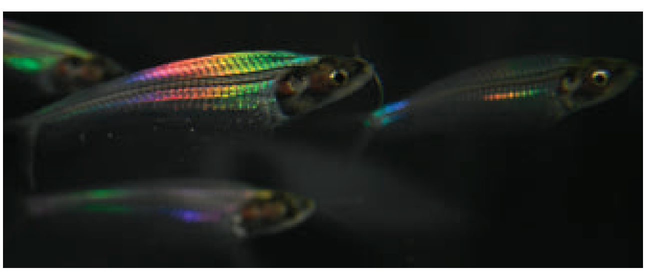


How a transparent fish turns rainbow

The ghost catfish transforms from glassy to glam when white light passes through its mostly transparent body. Now scientists know why: The fish's iridescence comes from light bending as it travels through microscopic banded structures in the animal's muscles, researchers report in the March 21 *Proceedings of the National Academy of Sciences*.

Many fishes with iridescent flair have tiny crystals in either their skin or scales that reflect light (*SN Online*: 4/6/21). But the ghost catfish (*Kryptopterus vitreolus*) and most other transparent fishes, like eel larvae and icefishes, lack such structures to explain their luster.

The iridescence of the roughly 5-centimeter-long ghost catfish caught the eye of Qibin Zhao, a physicist at Shanghai Jiao Tong University, when he was in an aquarium store. To investigate the freshwater fish's colorful properties, Zhao and colleagues examined several ghost catfish under different lighting conditions. The researchers determined that the iridescence arose from light passing through a fish rather than reflecting off it. By using a white light laser to illuminate the animal's muscles and skin separately, the team found that the muscles generated the multicolored sheen.



The researchers then analyzed how X-rays scatter when traveling through the muscle and looked at the tissue with an electron microscope. The team identified sarcomeres — regularly spaced, banded structures, each roughly 2 micrometers long, that run along the length of muscle fibers — as the source of the iridescence.

Each sarcomere (one highlighted in yellow in the electron microscope image above) consists of two adjacent "tiles" of interlocking myosin filaments and actin filaments, threadlike protein structures responsible for muscle contraction. The repeating bands bend white light in a way that separates and enhances its different wavelengths. The collective diffraction of light produces an array of colors (left). When a fish contracts and relaxes its muscles to swim, the sarcomeres slightly change in length, causing a shifting rainbow effect.

The purpose of the iridescence is a little unclear, says Heok Hee Ng, an independent ichthyologist in Singapore. Ghost catfish live in murky water and seldom rely on sight. But the iridescence might help them visually coordinate movements when traveling in schools, he says, or it could help them blend in with shimmering water to hide from land predators such as birds. — *McKenzie Prillaman*

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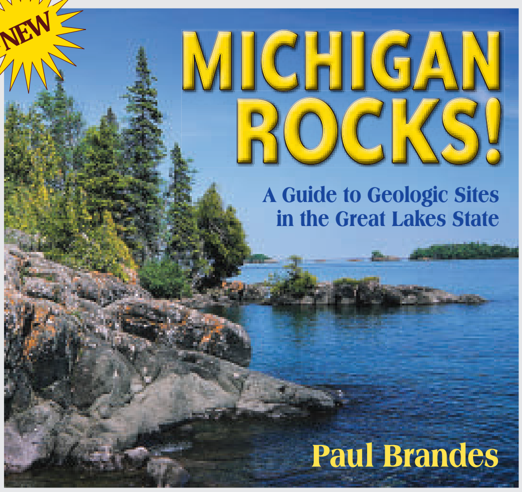

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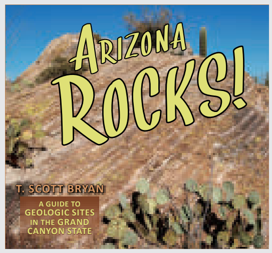

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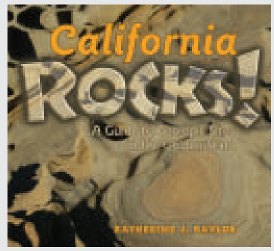

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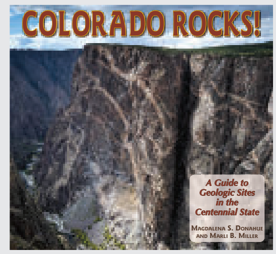

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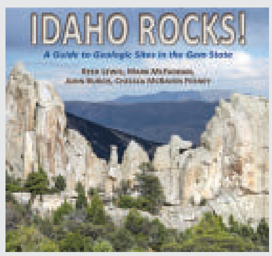

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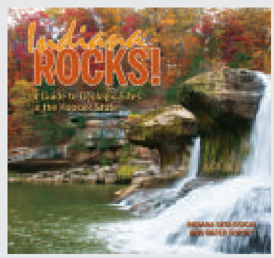

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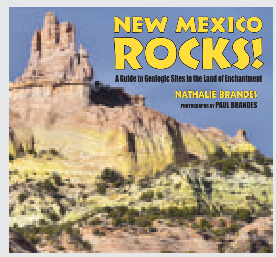

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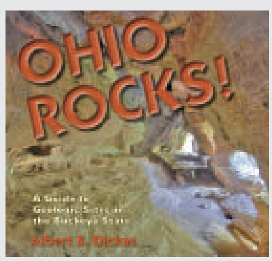

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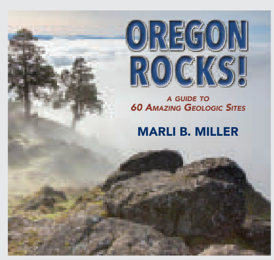

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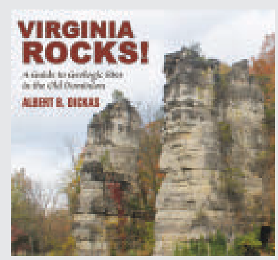

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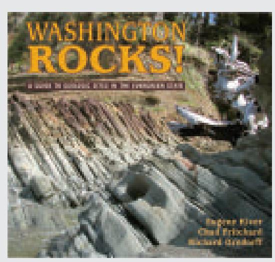

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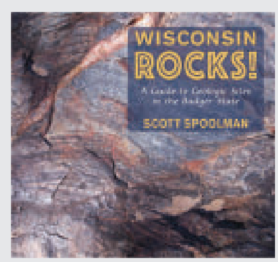

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