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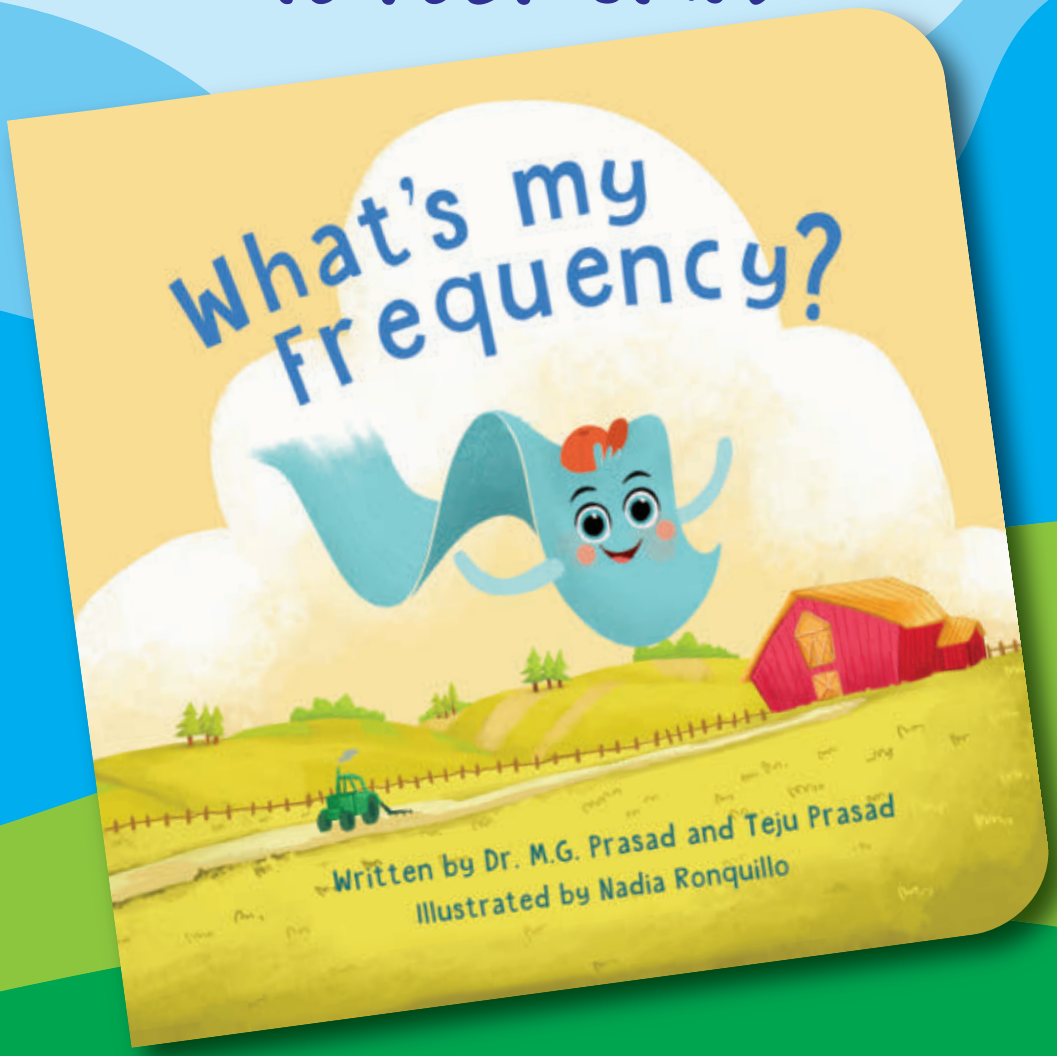


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# ScienceNews

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## Features



## News



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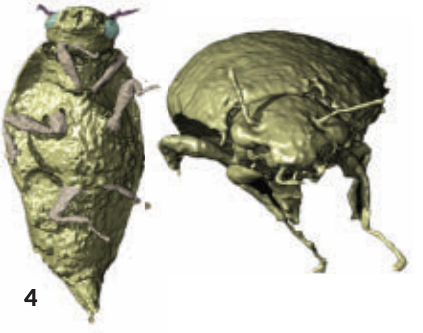

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## Departments



**COVER** How risky is playing a trombone, trumpet or clarinet when it comes to spreading the virus that causes COVID-19? *Neil Webb*

FROM TOP: GLENN HARVEY; M. QVARNSTRÖM *ET AL*./*CURRENT BIOLOGY* 2021; X-RAY: CXC/NASA AND SAO; OPTICAL: ROLF OLSEN; INFRARED: JPL-CALTECH/NASA

# Creating a 'science of us' has been a contentious effort

Figuring out how people think and feel is one of science's great challenges. In the last 100 years, we've seen the rise of psychology as an established field of study — a rise that has been marked by warring schools of thought and, at times, horrifying experiments. Big questions remain unanswered, but we've come a long way from Sigmund Freud and the Oedipus complex.

If you're going to step into that swamp, you need a trusted guide, and you couldn't ask for a better one than Bruce Bower, *Science News*' behavioral sciences writer. He's been on the beat for us since 1984, and we've benefited greatly from his ability to explain the complexities of research on human behavior, and his willingness to bluntly state when a seemingly great discovery is nonsense.

Bower deploys those skills to review the last century of behavioral science, making sense of a dizzyingly complex chronology, from Freud and Gestalt psychology through B.F. Skinner, the rise of behavioral economics, heuristics and ecological rationality (Page 18). "I entered journalism because I started out skeptical of psychology," Bower told me. That skepticism was earned; he holds a master's degree in psychology and worked in research and in clinical care before deciding that he'd rather write about it than practice it. "One of the first stories I covered at *Science News* was the John Hinckley insanity defense," Bower recalled, including the still-contentious verdict in which the man who shot President Ronald Reagan was found not guilty by reason of insanity.

There have been many memorable assignments since then, including an early experience covering the discovery of a lost pre-Inca city in the Andes. That was before computers and fax machines; press releases arrived by mail. After *Science News* and many other news outlets covered the story, Bower got a call from a reader saying he wanted to stop by the office and show Bower something. It was a tourist map showing the "lost" city. "I saw it and thought, 'Oh no, this is bad.'"

Bower re-reported the story, including a tense interview with the archaeologist who had claimed the find, and *Science News* ran Bower's article setting the record straight. "The only saving grace for me was that a lot of other people were scammed," Bower told me. "But it taught me to be very careful."

Bower has often applied scrutiny to other controversial topics, including highly publicized claims in the 1990s that many children had repressed memories of sexual abuse. Memory, he says, isn't that simple. "There's a good argument that consciousness is like something on a dimmer switch; the trauma can kind of fade in and out of memory at a very low level. But then, people are capable of remembering things that never happened. Brains are not computers."

Any reader of Bower's work knows that he is a graceful writer who can turn even the shortest news brief into a pleasurable excursion. But I was surprised when he told me he used to write satires for *Science News*. Satires? We have our own nerdy sense of humor here, but I don't think of *Science News* as the *Onion*. Yet the archive has Bower's satirical gifts on display, including a 2011 "interview" with Bozo the Clown, who is upset because he has lost his happiness. Bower uses science to explain how the pursuit of happiness is not always a good thing. The title: "Sometimes, happiness is for bozos." — *Nancy Shute, Editor in Chief*





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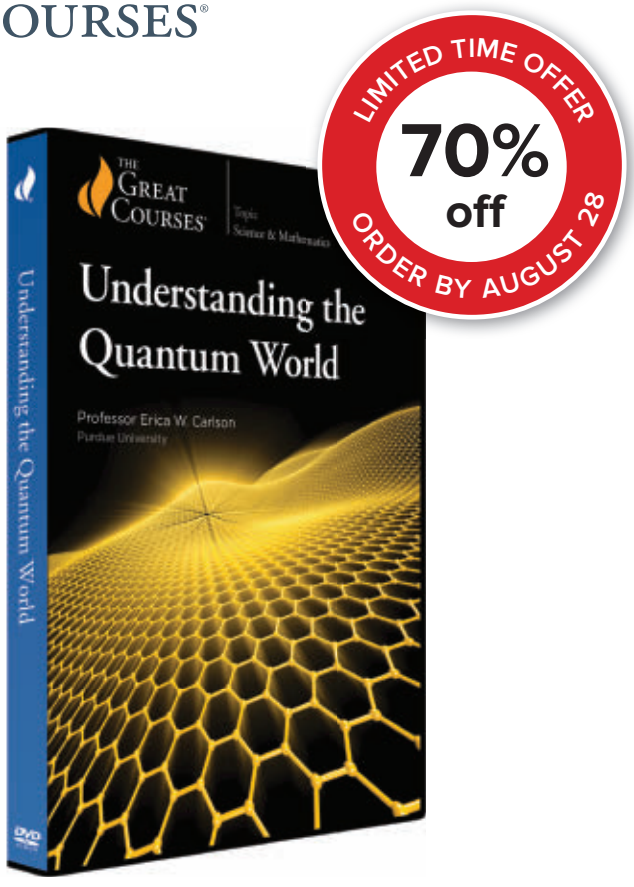


# Meet Schrödinger's Cat and Other Quantum Ideas

The word "quantum" evokes mystery and unreality such as the baffling paradox of Schrödinger's cat—a hypothetical pet that is simultaneously both dead and alive in a quantum experiment. Yet quantum mechanics is one of the most successful theories of reality ever developed, describing exactly how matter and radiation work, and leading to such inventions as lasers, atomic clocks, flash drives, and much more.

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Excerpt from the August 21, 1971 issue of *Science News*

50 YEARS AGO

## Finding the W particle

Physicists distinguish four different kinds of force by which objects in the universe act upon each other: the strong nuclear force, the weak force, electromagnetism and gravity. The developed theory of particle physics outfits each force with a so-called intermediate particle.... Now, from an abandoned silver mine at Park City, Utah, comes strong evidence of the existence of the weak-force quantum, known as the ... W particle.

**UPDATE:** The "strong evidence" for this W particle, or W boson, fell apart under additional scrutiny. Physicists with CERN near Geneva finally caught the boson about a decade later (*SN: 2/5/83, p. 84*). Besides helping mediate the weak force, which governs certain types of radioactive decay, the W boson has also helped scientists catch the Higgs boson (*SN: 7/28/12, p. 5*). Weighing the W boson narrowed down the Higgs' mass range, making the Higgs easier to look for. Physicists continue unraveling W boson mysteries, such as how the particle forms and whether more massive versions exist.

Experiments with torches (shown) and other Stone Age fire sources are helping scientists understand how ancient humans made cave art.

THE SCIENCE LIFE

## Fire-wielding scientists shed new light on cave art

Geologist Iñaki Intxaurbe is used to making subterranean treks in a head lamp and boots. But the first time he navigated a cave the way humans thousands of years ago would have — barefoot while holding a torch — he learned two things. "The first sensation is that the ground is very wet and cold," says Intxaurbe, of the University of the Basque Country in Leioa, Spain. The second: If something chases you, it will be hard to run. "You are not going to see what is in front of you," he says.

Torches are among several light sources Stone Age artists used to navigate caves. Intxaurbe and colleagues are wielding these fiery tools in caves in an effort to learn how humans journeyed into these dark, damp spaces and why they created art there (*SN: 12/8/18, p. 8*).

In Isuntza I Cave in the Basque region of Spain, the researchers tested torches, bowl-like stone lamps and fireplaces fueled by materials that Stone Age humans would have had at hand. The team measured flame intensity and duration, as well as how far each source cast light.

Each light source has its own quirks that make it well suited to specific cave spaces and tasks, the team reports June 16 in *PLOS ONE*. Stone Age humans would have controlled fire in varying ways to travel through caves and make and view art. Torches work best on the move, as their flames need motion to stay lit and produce a lot of smoke, but they burn for an average of just 41 minutes. Several torches would have been needed to travel through caves. Stone lamps, on the other hand, are nearly smokeless and can offer more than an hour of focused, candlelike light. That would have made it easy to stay in one spot. And while fireplaces produce a lot of light, they can also produce a lot of smoke. Fireplaces are best suited for large spaces that get lots of airflow, the team says.

The findings shed light on 12,500-year-old art that Intxaurbe helped discover in Atxurra Cave in northern Spain in 2015. Stone Age artists painted about 50 images of horses, goats and bison on a wall reached only by climbing up a roughly 2.5-meter-tall ledge. A lack of the right lighting may explain why previous explorers had failed to notice the art, the team says. Simulations of how torches, lamps and fireplaces lit up Atxurra revealed that the paintings stay hidden when using just a torch or a lamp from below. But fireplaces on the ledge illuminate the whole gallery so that anyone on the cave floor can see it, suggesting the artists may have wanted to keep their work hidden, the team says.

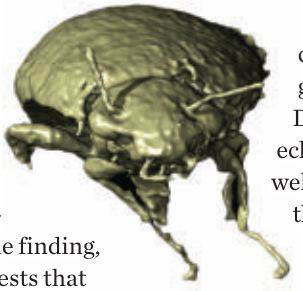
To unravel the mysteries of subterranean studios, it's key to understand how prehistoric artists lit their surroundings, Intxaurbe says. — *Jaime Chambers*

Geologist Iñaki Intxaurbe records observations of Atxurra Cave in northern Spain.

FROM TOP: I. INTXAURBE; BEFORE ART PROJECT

INTRODUCING

## Fossilized scat scans find a new beetle species



In a fossilized chunk of ancient reptilian poo, scientists have uncovered nearly complete specimens of a new beetle species. The finding, described June 30 in *Current Biology*, suggests that fossilized dung could contain more details about past life than previously thought.

Ancient feces have been "largely overlooked," says evolutionary biologist Martin Qvarnström of Uppsala University in Sweden. "But they often contain very well-preserved fossils. They're like hidden treasure chests."

> "They're like hidden treasure chests."
>
> MARTIN QVARNSTRÖM

Fossilized dung, or a coprolite, can reveal insights about extinct creatures' diets that body fossils can't. Lab experiments have shown that poop can harden and soft tissues can fossilize in just weeks, saving delicate structures within. "If you didn't get rapid mineralization, the feces would get flattened, but most coprolites are three-dimensional," says paleontologist Karen Chin of the University of Colorado Boulder.

Scientists found a new species of beetle in fossilized dung, or a coprolite, from an extinct dinosaur relative. Computer renderings of the beetle (right), named *Triamyxa coprolithica*, show it from the front (top) and underside (bottom).

Despite this preservation power, coprolites can be eclipsed by amber, a tree resin in which some of the most well-preserved insect fossils have been found. But since the resin became common only around 130 million years ago, amber fossils older than that are rare.

Curious whether much older fossilized poop could match the quality of amber specimens, Qvarnström and colleagues used X-rays to peek inside a coprolite from Poland. The dung likely comes from an extinct dinosaur relative called *Silesaurus opolensis*, which lived around 237 million to 227 million years ago. The scans revealed nearly whole beetle fossils that rival the quality of similar specimens found in amber, along with fragments of the same kind of beetle. Since the mostly intact beetles lacked the joints needed for classification, the scientists pieced together beetle fragments to ID the insects as a new species named *Triamyxa coprolithica*.

Qvarnström hopes more paleontologists will recognize how useful coprolites can be. "This dinosaur ancestor was doing a bit of the fieldwork for us," he says. "We wouldn't have been able to find these insects otherwise." — *Nikk Ogasa*

A lake in Antarctica seen by a satellite in March 2019 (top) vanished by September (bottom).

FROM TOP: M. QVARNSTRÖM ET AL/CURRENT BIOLOGY 2021; LANDSAT 8/USGS AND NASA

MYSTERY SOLVED

## How a massive Antarctic lake vanished

Over just three days in June 2019, an ice-covered lake atop Antarctica's Amery ice shelf vanished, leaving a sinkhole. The lake had held roughly 600 million to 750 million cubic meters of water, twice that of San Diego Bay, says glaciologist Helen Fricker of the Scripps Institution of Oceanography in La Jolla, Calif. Now, she and colleagues have solved the mystery of the disappearing lake: The water's weight fractured the ice shelf below and the water drained away in a Niagara Falls–like rush through rifts in the ice, the team reports in the July 28 *Geophysical Research Letters*.

Researchers spotted the sinkhole in satellite images while tracking wildfire smoke. Going through the archives, the scientists pinned down when the ice shelf began to give way and found that a lake had previously been at that spot since at least 1973. Satellite data let the team estimate how much water the lake once held. This is the first time that scientists have had evidence to piece together how such events happen. — *Carolyn Gramling*

SCIENCE STATS

## Pandemic causes millions more kids to miss routine vaccinations

The COVID-19 pandemic has forced millions of children around the world to miss out on important childhood vaccinations, increasing the risk of dangerous outbreaks of other infectious diseases, new research suggests.

A World Health Organization analysis, published online July 15, reports that in 2020, at least 3.5 million more children missed their first dose against diphtheria, tetanus and pertussis than in 2019. Another 3 million more children missed their first measles vaccine in 2020 than in 2019. Southeast Asian countries saw the largest increases in missed vaccinations, especially India. There, more than 3 million children didn't get a first dose of the DTP vaccine in 2020 compared with around 1.4 million in 2019.

**3.5 million**

Estimated number of additional children who missed a shot for diphtheria, tetanus and pertussis in 2020

The decline is troubling given the pandemic, says pediatrician Suzette Oyeku of the Children's Hospital at Montefiore and Albert Einstein College of Medicine, both in New York City. "The concern is that we're going to start to see clusters of outbreaks" of these diseases as well as COVID-19 in children, Oyeku says. — *Erin Garcia de Jesús*

ATOM & COSMOS

# New black hole portrait spotlights jets

## The Event Horizon Telescope probes a nearby galaxy's heart

The Event Horizon Telescope spied on galaxy Centaurus A (composite false-color image shown).

**BY MARIA TEMMING**

The Event Horizon Telescope is expanding its portfolio of black hole images.

In 2019, the telescope unveiled the first image of a black hole, revealing the supermassive beast 55 million light-years from Earth at the center of galaxy M87 (*SN: 4/27/19, p. 6*). That lopsided orange ring showed the shadow of the black hole on its glowing accretion disk of infalling material. Since then, observations from the Event Horizon Telescope, or EHT, have yielded more detailed views of M87's black hole (*SN: 11/7/20, p. 8*). Now, EHT data have provided new details of the supermassive black hole at the heart of a galaxy near our own, called Centaurus A.

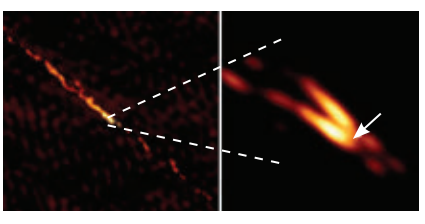
Rather than zooming in close enough to see the black hole's shadow, the new picture offers the clearest view yet of the powerful plasma jets erupting from the black hole. This perspective gives insight into how supermassive black holes blast such plasma jets into space, researchers report July 19 in *Nature Astronomy*.

"It's a fairly impressive feat," says radio astronomer Craig Walker of capturing the new high-resolution image. "These [jets] are some of the most powerful things in the universe," says Walker, of the National Radio Astronomy Observatory in Socorro, N.M. Because such superfast plasma streams are thought to influence how galaxies grow and evolve, astronomers are keen to understand how the jets form.

Researchers pointed the global network of radio dishes that make up the EHT at Centaurus A for six hours in April 2017, during the same observing run that delivered the first picture of a black hole (*SN: 4/27/19, p. 7*). About 12 million light-years from Earth, Centaurus A is one of the brightest galaxies in the sky and is known for the huge jets expelled by its central black hole.

"They extend to pretty much the entire scale of the galaxy," says radio astronomer Michael Janssen of the Max Planck Institute for Radio Astronomy in Bonn, Germany. "If we were to see radio light [with our eyes], and we were to look at the night sky, then we would see these jets of Centaurus A as a structure that is 16 times bigger than the full moon."

Plasma jets (zoomed-out view, left; closeup view from the Event Horizon Telescope, right) from galaxy Centaurus A's supermassive black hole (arrow, right) are bright only at the edges.



Using the EHT, Janssen and colleagues homed in on the base of those jets, which gush out from either side of the black hole's accretion disk. The new image is 16 times as sharp as previous observations of the jets, probing details less than one light-day across — about four times the distance from the sun to Pluto. One of the most striking features that the image reveals is that only the outer edges of the jets seem to glow.

"That's still a puzzle," Janssen says. One possibility is that the jets are rotating, which might cause material in some regions of the jets to emit light toward Earth, while other regions don't. Or the jets could be hollow, Janssen says.

Recent observations of a few other galaxies have hinted that the jets of supermassive black holes are brighter around the edges, says astrophysicist Denise Gabuzda of University College Cork in Ireland, who wasn't involved in the new work. "But it's been hard to know whether it was a common feature, or whether it was something quirky about the few that had been observed."

The new view of the supermassive black hole at the heart of Centaurus A provides evidence that such bright edges are common, Gabuzda says. "It's fairly rare to be able to detect the jets coming out in both directions, but in the images of Centaurus A ... you can clearly see that both of them are brighter at the edges."

The next step will be to compare the EHT image of Centaurus A's supermassive black hole with simulations based on Einstein's general theory of relativity, which describes the physics of black holes. That will test how well relativity holds up in this extreme environment, Janssen says. Examining the polarization, or orientation, of the light waves emanating from Centaurus A's jets could also reveal the structure of their magnetic fields — just as polarization revealed the magnetism around M87's black hole (*SN: 4/24/21, p. 6*). ■

FROM TOP: X-RAY: CXC/NASA AND SAO; OPTICAL: ROLF OLSEN; INFRARED: JPL-CALTECH/NASA; M. JANSSEN *ET AL*/*NATURE ASTRONOMY* 2021

GENES & CELLS

# Most human DNA is not unique to us

## Ancient hominid ancestors were key contributors

**BY TINA HESMAN SAEY**

The genetic tweaks that make humans uniquely human may come in small parcels interspersed with DNA inherited from extinct ancestors and cousins.

Only 1.5 percent to 7 percent of the collective human genetic instruction book, or genome, contains uniquely human DNA, researchers report July 16 in *Science Advances*.

That humans-only DNA, scattered throughout the genome, tends to contain genes involved in brain development and function, hinting that brain evolution was important in making humans human. But the researchers don't yet know exactly what the genes do and how the exclusively human tweaks to DNA near those genes may have affected brain evolution.

"I don't know if we'll ever be able to say what makes us uniquely human," says population geneticist Emilia Huerta-Sanchez of Brown University in Providence, R.I., who was not involved in the work. "We don't know whether that makes us think in a specific way or have specific behaviors." And Neandertals and Denisovans, both extinct human cousins, may have thought much like humans do (*SN: 3/17/18, p. 6*).

The findings don't mean that individual people are mostly Neandertal or Denisovan, or some other mix of ancient hominid. On average, people in sub-Saharan Africa inherited 0.096 percent to 0.46 percent of their DNA from ancient interbreeding between humans and Neandertals, the researchers found. Non-African people inherited more DNA from Neandertals: about 0.73 percent to 1.3 percent. And some people inherited a fraction of their DNA from Denisovans as well.

Using a new computational method, researchers at the University of California, Santa Cruz examined every spot of DNA in the genomes of 279 people. The team compiled results from those individual genomes into a collective picture of the human genome. For each spot, the team determined whether the DNA came from Denisovans, Neandertals or a common ancestor of humans and those two relatives.

Although each person may carry about 1 percent Neandertal DNA, "if you look at a couple hundred people, they mostly won't have their bit of Neandertal DNA in the same place," says population geneticist Kelley Harris of the University of Washington in Seattle. "So if you add up all the regions where someone has a bit of Neandertal DNA, that pretty soon covers most of the genome."

In this case, about 50 percent of the collective genome contains regions where one or more people inherited DNA from Neandertals or Denisovans, the researchers discovered. Most of the rest of the genome has been passed down from the most recent common ancestor of humans, Neandertals and Denisovans. After whittling away the ancient heirloom DNA, the team looked for regions where all people have tweaks to DNA that no other known hominid had. That got the estimate of uniquely human DNA down to anywhere between 1.5 percent and 7 percent of the genome.

1.5–7
Percent
Portion of human genome that is uniquely human

The finding underscores just how much interbreeding with other hominid species affected the human genome, says study coauthor Nathan Schaefer, a computational biologist now at the University of California, San Francisco. Schaefer and colleagues confirmed previous findings from other groups that humans bred with Neandertals and Denisovans, but also with other extinct, unknown hominids (*SN: 3/14/20, p. 12*). The mixing and mingling probably happened multiple times between different groups of humans and hominids, the team found.

The tweaks that make the uniquely human DNA distinctive arose in a couple of evolutionary bursts, probably around 600,000 years ago and again about 200,000 years ago, the team found. Around 600,000 years ago is about the time that humans and Neandertals were forming their own branches of the hominid family tree.

The estimate of the amount of uniquely human DNA doesn't take into account places where humans have gained DNA through duplication or other means, or lost it (*SN: 9/5/15, p. 7*), says genome scientist James Sikela of the University of Colorado Anschutz Medical Campus in Aurora. Such extra or missing DNA may have allowed humans to evolve new traits, including some involved in brain evolution (*SN: 3/21/15, p. 16*).

Ancient DNA is usually degraded into tiny fragments, and researchers have pieced together only portions of the genomes from extinct hominids. The fragmented genomes make it difficult to tell where big chunks of DNA may have been lost or gained. For that reason, the researchers studied only small tweaks to DNA involving one or more DNA bases — the information-carrying parts of the molecule.

Given that humans and Neandertals went their separate evolutionary ways relatively recently, it's not surprising that only 7 percent or less of the genome has evolved the uniquely human tweaks, Sikela says. "I'm not shocked by that number." Considering DNA that humans alone have added to their genomes might produce a higher estimate of exclusively human DNA, he says.

Or it could go the other way. As more genomes are deciphered from Neandertals, Denisovans and other extinct hominids, researchers may discover that some of what now seems like uniquely human DNA was also carried by those extinct relatives, Harris says. "This estimate of the amount of uniquely human regions is only going to go down." ■

ATOM & COSMOS

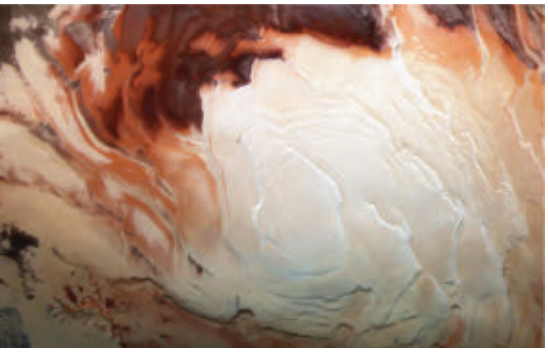
# Mars lakes appear to be mirages

## Clay minerals or frozen brine could explain radar data

**BY ADAM MANN**

Maybe hold off on that Martian ice fishing trip. Two studies splash cold water on the idea that potentially habitable lakes of liquid water exist deep under the Red Planet's southern polar ice cap.

The possibility of a lake about 20 kilometers across was first raised in 2018, after the European Space Agency's Mars Express spacecraft probed the planet's southern polar cap with its Mars Advanced Radar for Subsurface and Ionosphere Sounding, or MARSIS, instrument. The orbiter detected bright spots on radar measurements, hinting at a body of liquid water beneath 1.5 kilometers of ice that could be an abode to organisms (*SN: 8/18/18, p. 6*). Subsequent work found hints of more pools surrounding the main lake (*SN: 11/7/20, p. 8*).



An icy cap (bright white region in this Mars Express orbiter image) that covers the south pole of Mars probably does not hide liquid water lakes beneath it, two studies suggest.

But the planetary science community has had some skepticism over the lakes' existence. Below the ice, temperatures average –68° Celsius, far past the freezing point of water, even if the lakes are a brine containing enough salt to lower water's freezing point. An underground magma pool would be needed to keep the area liquid (*SN: 3/16/19, p. 7*) — an unlikely scenario given Mars' lack of present-day volcanism.

In a study in the July 16 *Geophysical Research Letters*, planetary scientist Carver Bierson of Arizona State University in Tempe and colleagues describe substances other than water that could explain the radar reflections. This reflectivity depends on the electrical conductivity of the material the radar signal moves through. Liquid water has a fairly distinct radar signature, but examining the electrical properties of both clay minerals and frozen brine reveal those materials could mimic this signal.

Adding weight to the nonlake explanation is a study from an independent team, published in the same issue of *Geophysical Research Letters*. The 2018 watery findings were based on MARSIS data that focused on a small section of the southern ice cap, but the instrument has now built up 3-D maps of the entire south pole, where hundreds to thousands of additional bright spots appear.

"We find them literally all over the region," says planetary scientist Aditya Khuller, also of Arizona State University. "We see them in places where we expect it to be really cold."

Creating plausible scenarios to maintain liquid water in all of these locations would be a tough exercise. Both Khuller and Bierson think it is far more likely that MARSIS is pointing to some kind of widespread geophysical process that created minerals or frozen brine.

"Putting these two papers together with the other existing literature, I would say this puts us at 85 percent confidence that this is not a lake," says Edgard Rivera-Valentín, a planetary scientist at the Lunar and Planetary Institute in Houston who was not involved in either study.

Khuller already has his eye on other areas of potential habitability on Mars, such as warmer midlatitude regions where satellites have seen evidence of ice melting in the sun. "I think there are places where liquid water could be on Mars today," he says. "But I don't think it's at the south pole." ■

ATOM & COSMOS

# Hyper supernovas may spread riches

## Ancient star points to another source of heavy elements

**BY MARA JOHNSON-GROH**

Violent explosions of massive, magnetized stars may forge most of the universe's heavy elements, scientists report.

These r-process elements, which include half of all elements heavier than iron, are known to be produced when neutron stars merge. But collisions of those dead stars alone can't form all of the r-process elements seen in the universe. Now, scientists have pinpointed a type of energetic supernova called a magnetorotational hypernova as another potential source.

The results, described in the July 8 *Nature*, stem from the discovery of an elderly red giant star — possibly 13 billion years old — in the Milky Way's halo. By analyzing the star's elemental makeup, which is like a star's genetic instruction book, astronomers peered back into the star's family history. Forty-four different elements seen in the star suggest that it formed from material left over "by a special explosion of one massive star soon after the Big Bang," says astronomer David Yong of the Australian National University in Canberra.

The ancient star's elements probably aren't from the remnants of a neutron star merger, Yong and colleagues say. Its abundances of certain heavy elements such as thorium and uranium are higher than would be expected from a neutron star merger. Additionally, the star also contains lighter elements such as zinc and nitrogen, which can't be produced by those mergers. And since the star is extremely deficient in iron — an element that builds up over many stellar births

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# Quakes offer a peek inside Mars

## Seismic waves reveal the Red Planet has a giant core

**BY SID PERKINS**

Mars has had its first CT scan, thanks to analyses of seismic waves picked up by NASA's InSight lander. Diagnosis: The Red Planet's core is at least partially liquid and somewhat larger than expected.

InSight reached Mars in 2018 and soon detected a marsquake. Since then, the lander has detected over 1,000 temblors, most of them minor. Many of the quakes originated at a seismically active region more than 1,000 kilometers away from the lander. A small fraction of the quakes had magnitudes ranging from 3 to 4, and the resulting vibrations have revealed new clues about Mars' interior.

Simon Stähler, a seismologist at ETH Zurich, and colleagues analyzed seismic waves from 11 marsquakes, looking for two types of waves: pressure and shear. Shear waves can't pass through a liquid like pressure waves do, and they move more slowly, traveling side to side through solid materials, rather than in a push-and-pull motion in the same direction that a wave is traveling.

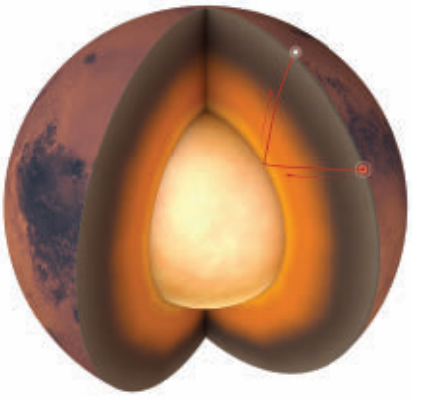
Of the 11 events, six sets of vibrations included shear waves strong enough to stand out from background noise. The strength of those waves suggests that they reflected off the outer surface of a liquid core, rather than entering a solid core and being partially absorbed, Stähler says. The difference in arrival times at InSight for the pressure waves and shear waves for each quake suggest that the core is about 3,660 kilometers wide, Stähler and colleagues report in the July 23 *Science*.

That's a little more than half of Mars' entire diameter and larger than most previous estimates. The Red Planet's core is so big, in fact, that it blocks InSight from receiving certain types of seismic waves from a large part of the planet. That, in turn, suggests that Mars may be more seismically active than the lander's sensors can detect. Indeed, one of the regions in the lander's seismic blind spot is Tharsis, home to large volcanoes. Volcanic activity there, as well as the motion of molten rock within the crust in that region, could trigger quakes or seismic waves.

Whether Mars has a solid inner core like Earth is still unclear, says study coauthor and geophysicist Amir Khan, also at ETH Zurich. "The signal should be there in the seismic data," he says. "We just need to locate it."

The seismic waves also hint at the thickness of Mars' crust. As they travel back and forth within the planet, the waves bounce off interfaces between different layers and types of rocks, says seismologist Brigitte Knapmeyer-Endrun of the University of Cologne in Germany. Also reporting in *Science*, her team estimates that the crust averages from 24 to 72 kilometers thick. For comparison, Earth's oceanic crust is about 6 to 7 kilometers thick, while its continental crust tends to be 35 to 40 kilometers thick.

All of these findings could provide insights that might help scientists better understand how Mars formed and ended up so unlike Earth, says geophysicist Sanne Cottaar of the University of Cambridge. Cottaar cowrote a commentary, also published in *Science*, on the new research. "Mars was put together with similar building blocks" as Earth, she says, "but had a different result." ■



Seismic waves (red lines in this illustration) traveling through Mars from a quake's source (red dot) to the InSight lander (white dot) reveal the Red Planet's internal structure, including a massive core (yellow-white).

CHRIS BICKEL/*SCIENCE*

and deaths — the scientists think that the red giant is a second-generation star whose heavy elements all came from one predecessor supernova-type event.

Simulations suggest that the event was a magnetorotational hypernova, created in the death of a rapidly spinning, highly magnetized star at least 25 times the mass of the sun. When these stars explode at the end of their lives, they may have the energetic, neutron-rich environments needed to forge heavy elements.

Magnetorotational hypernovas might be similar to collapsars — massive, spinning stars that collapse into black holes. Collapsars have also been proposed as birthplaces of r-process elements.

The researchers think that magnetorotational hypernovas are rare, only 1 in 1,000 supernovas. Even so, such explosions would be 10 times as common as neutron star mergers today and would produce similar amounts of heavy elements per event. Along with their less energetic counterparts, called magnetorotational supernovas, these hypernovas could be responsible for making 90 percent of all r-process elements, coauthor Chiaki Kobayashi, an astrophysicist at the University of Hertfordshire in Hatfield, England, had previously calculated. In the early universe, when massive, rapidly rotating stars were more common, such explosions could have been even more influential.

The observations are impressive, says Stan Woosley, an astrophysicist at the University of California, Santa Cruz. But "there is no proof that the [elemental] abundances in this metal-deficient star were made in a single event," he says. "It could have been one. It could have been 10." One of those events might even have been a neutron star merger, he adds.

Yong's group hopes to find more stars like the elderly red giant, which could reveal how frequent magnetorotational hypernovas are. For now, the newly analyzed star remains "incredibly rare and demonstrates the need for ... large surveys to find such objects," Yong says. ■

EARTH & ENVIRONMENT

# Hurricanes are not actually on the rise

## But climate change is making Atlantic storms more dangerous

**BY CAROLYN GRAMLING**

Climate change is helping Atlantic hurricanes pack more of a punch, making them rainier, intensifying them faster and helping the storms linger longer after making landfall. But a new statistical analysis of historical records and satellite data suggests that there aren't actually more Atlantic hurricanes now than there were roughly 170 years ago, researchers report July 13 in *Nature Communications*.

The busy 2020 Atlantic hurricane season, including a record-breaking 30 named storms, led to intense speculation over whether and how climate change was involved (*SN: 12/19/20 & 1/2/21, p. 32*). It's a question that scientists continue to grapple with, says climate scientist Gabriel Vecchi of Princeton University. "What is the impact of global warming — past impact and also our future impact — on the number and intensity of hurricanes and tropical storms?"

To get a longer-term perspective on trends in Atlantic storms, Vecchi and colleagues examined a dataset of hurricane observations stretching from 1851 to 2019, from the U.S. National Oceanic and Atmospheric Administration. The dataset includes old-school observations by people who weathered the tempests as well as remote sensing data from the modern satellite era.

Comparing those different types of data to get an accurate trend was a challenge. The team took a probabilistic approach to fill in likely gaps in the older record. For example, the researchers assumed that modern storm tracks are representative of presatellite storm tracks to account for storms that would have stayed out at sea and unseen.

The team found no clear increase in the number of storms in the Atlantic over the 168-year time frame. One possible reason, the researchers say, is a decrease in air pollution (*SN: 11/23/19, p. 4*). The amount of soot, sulfate and dust particles over the Atlantic Ocean was much higher in the mid-20th century than now. Those particles blocked and scattered sunlight, temporarily cooling the planet enough to counteract greenhouse gas warming and suppress Atlantic hurricane activity. Rebound from the pollution-induced lull may be obscuring some of the greenhouse gas signal in the data.

More surprisingly, Vecchi says, is that the data seem to show no significant increase in hurricane intensity over that time. But this conclusion is heavily caveated — and the study also doesn't provide evidence against the hypothesis that global warming "has acted and will act to intensify hurricane activity," he adds.

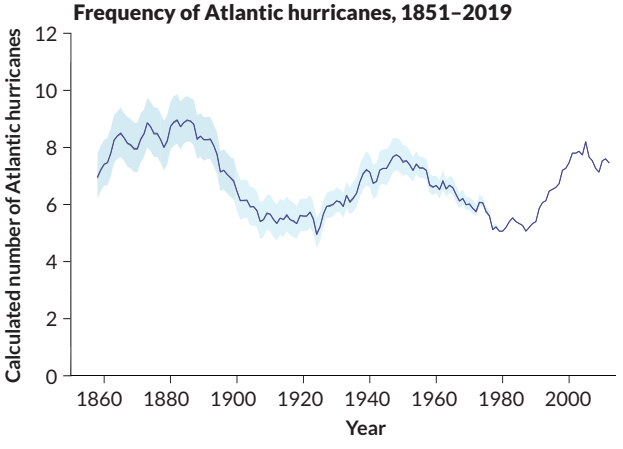
Scientists were already familiar with the possibility that storm frequency might not have increased much in the last few hundred years. The link between number of storms and warming has long been uncertain, as the changing climate also produces complex shifts in atmospheric patterns that could take the hurricane trend in either direction. The Intergovernmental Panel on Climate Change noted in a 2012 report that there is "low confidence" that tropical cyclone activity has increased in the long term.

Geologic evidence of Atlantic storm frequency, which can go back over 1,000 years, also suggests that hurricane frequency tends to wax and wane every few decades, says Elizabeth Wallace of Rice University in Houston. She searches deep underwater caverns for hurricane records in the form of telltale sediment deposits. Wallace's data also suggest that storm frequency over the last 170 years "hasn't been exceptional, compared to the past," she says.

But the deposits don't reveal whether climate change is producing more intense hurricanes over time, Wallace says. And modern observational data on changes in hurricane intensity is muddled by uncertainties, particularly the fact that the satellite record is relatively short.

The idea that storm numbers haven't increased isn't surprising, says atmospheric scientist Kerry Emanuel of MIT. But one reservation he has about the new study "is the implication that no significant trends in Atlantic hurricane metrics [going back to 1851] implies no effect of global warming on these storms," he says. Looking for such a long-term trend isn't that meaningful, he says. Scientists wouldn't expect to see any global warming–related hurricane trends become apparent until about the 1970s, as warming has ramped up.

Still, modern hurricanes have become more deadly in many ways, Vecchi says. There's evidence that global warming has increased the amount of rain from some storms, such as Hurricane Harvey in 2017, which led to devastating flooding (*SN: 1/20/18, p. 6*). And, Vecchi says, "sea level will rise over the coming century ... so [increasing] storm surge is one big hazard from hurricanes." ■




**Storm count**
The frequency of Atlantic hurricanes (blue line) was not higher in 2019 than in 1851, a statistical analysis of satellite data and historical observations from the National Oceanic and Atmospheric Administration suggests. The blue shaded area represents the margin of error for the number of observed hurricanes before the satellite era.

G.A. VECCHI *ET AL/NATURE COMMUNICATIONS* 2021

GENES & CELLS

# Human cells can wash away bacteria

## Detergent strategy could inspire new ways to treat infections

**BY JONATHAN LAMBERT**

When faced with bacterial invaders, some human cells dispense a surprising defense: soap.

These cells, which aren't part of the immune system, unleash a detergent-like protein that dissolves chunks of the inner membranes of bacteria, killing the infiltrators, researchers report in the July 16 *Science*.

Immune cells get lots of attention, but "all cells are endowed with some ability to combat infection," says immunologist John MacMicking of Yale University. In humans, these cellular defenses have often been overlooked, he says, even though they could inform the development of new treatments for infections.

Nonimmune cells often rely on a warning from the immune system to combat infections. Upon detecting outsiders, some immune cells release the molecule interferon gamma. That alarm signal rouses to action other cells, including epithelial cells that line the throat and intestines and are often targeted by pathogens.

MacMicking and colleagues looked for the molecular basis of that action by infecting lab versions of human epithelial cells with *Salmonella* bacteria. Then the team screened over 19,000 human genes, looking for those that conferred some protection from infection.

One gene, which contains instructions for a protein called APOL3, stood out. When this gene was disabled, epithelial cells succumbed to *Salmonella*, even when warned by interferon gamma. Zooming in on APOL3 molecules in action inside host cells showed that the protein swarms bacteria and kills them.

Further work revealed that APOL3 teams up with another molecule, GBP1, to overcome the protective outer and inner membrane of *Salmonella* microbes. GBP1 somehow loosens the outer membrane, opening doors for APOL3 to deliver its death-by-dissolution to the inner lipid membrane. APOL3 has both water-loving and lipid-loving parts, allowing it to bind to the inner membrane and dissolve it, like soap washing away grease.

Finding detergent-like activity in human cells was surprising, MacMicking says. Such a molecule could dissolve host membranes too. But APOL3 specifically targets lipids of bacteria, and its activity is blocked by cholesterol, a common component of mammalian cell membranes, leaving human tissues unaffected.

"The really interesting finding is how the APOL3 is able to distinguish between bacterial membranes and host membranes," says evolutionary immunologist Jessica Brinkworth of the University of Illinois at Urbana-Champaign. That evolution found such an elegant way to control this tool "is a beautiful thing." ■

LIFE & EVOLUTION

# Wild bonobo numbers may be inflated

## Drying habitats might skew scientists' counts of these great apes

**BY PRATIK PAWAR**

Climate change may be interfering with how researchers count bonobos, possibly leading to gross overestimates of the endangered apes, a new study suggests.

Like other great apes, bonobos build elevated sleeping nests out of tree branches and foliage every day. Counts of these nests can be used to estimate numbers of bonobos — as long as researchers have a good idea of how long a nest sticks around before it's broken down by the environment, or the nest's decay time.

New data on rainfall and bonobo nests show that the nests are persisting longer in the forests in Congo, from an average of roughly 87 days in 2003–2007 to about 107 days in 2016–2018, largely as a result of declining precipitation. This increase in decay time could be dramatically skewing population counts of the endangered apes and imperiling conservation efforts, researchers report June 30 in *PLOS ONE*.

Elevated nests built by bonobos are lasting longer, on average, in the environment than they used to, potentially affecting scientists' counts of the imperiled apes.

"Imagine going in that forest ... you count nests, but each single nest is around longer than it used to be 15 years ago, which means that you think that there are more bonobos than there really are," says behavioral ecologist Barbara Fruth of the Max Planck Institute of Animal Behavior in Konstanz, Germany.

Lowland tropical forests south of the Congo River in Africa are the only places in the world where bonobos still live in the wild (*SN: 4/10/21, p. 12*). There are at least 15,000 to 20,000 bonobos there, estimates suggest. But there could be as many as 50,000 individuals. "There have been very few surveys," Fruth says.

From 2003 to 2007, and then again from 2016 to 2018, Fruth and colleagues followed bonobos in Congo's LuiKotale rainforest, monitoring 1,511 nests. "The idea is that you follow [the bonobos] always," says wildlife researcher Mattia Bessone of Liverpool John Moores University in England. "You need to be up early in the morning so that you can be at the spot where the bonobos have nested, in time for them to wake up, and then you follow them till they nest again."

In doing so, Fruth, Bessone and colleagues were able to understand how many nests a bonobo builds in a day, what's known as the nest production rate. "It's not necessarily one because sometimes bonobos build day nests," Bessone says. On average, each bonobo builds 1.3 nests per day, the team found.

Tracking how long these nests stuck around revealed that the structures were lasting an average of 19 days longer in 2016–2018 than in 2003–2007. The team also compiled 15 years of climate data for

LIFE & EVOLUTION

# Dogs beat wolves in human relations

## People skills may be innate to tamed canines, a study hints

**BY JAIME CHAMBERS**

Wiggles and wobbles and a powerful pull toward people — that's what 8-week-old puppies are made of.

From an early age, dogs outpace wolves at engaging with and interpreting cues from humans, even if the dogs have had less exposure to people, researchers report July 12 in *Current Biology*. Compared with human-raised wolf pups, dog puppies that had limited exposure to people were still 30 times as likely to touch an unfamiliar human, and five times as likely to touch a familiar person. The findings suggest that domestication has reworked dogs' brains to make the pooches innately drawn to people and perhaps able to intuit human gestures.

Wolf pups are less entranced by people than dogs are. "When I walked into the [wolf] pen for the first time, they would all just run into the corner and hide," says evolutionary anthropologist Hannah Salomons of Duke University. Over time, most came to ignore her, "acting like I was a piece of furniture," Salomons says.

Dogs can't seem to resist humans' allure (*SN: 8/19/17, p. 8*). They respond more readily to people, following where a person points, for example. When wolves have been put to the task, the results have been mixed, suggesting that wolves need explicit training to learn the skill. Scientists haven't been sure if dogs' ability is learned or, after at least 14,000 years of domestication, has become innate.

To find out, Salomons and colleagues showered attention on wolf pups while restricting dog puppies' access to people. Days after birth, 37 wolves got nearly constant human attention. Meanwhile, 44 retriever puppies stayed with their littermates until they were 8 weeks old, with only brief visits from people.

The team then exposed both types of puppies to familiar and unfamiliar people and objects. Puppies' memories were tested by hiding treats within view. A cylinder with food inside challenged puppies' self-control. To observe puppies' response to human gestures, researchers pointed at hidden treats or placed a small wooden block next to a hiding spot to draw the eye.

Wolves and dogs were evenly matched in memory and self-control. But in tasks involving human communication, dogs surpassed wolves. Dogs were twice as

LuiKotale, which showed a decrease in average rainfall from 2003 to 2018. That change in rain may be linked to climate change, the team says, and could help explain why nests have become more resilient.

Scientists can estimate the number of bonobos in a region by counting the number of nests and then dividing that number by the product of the average nest decay time and nest production rate. But if researchers are using outdated, shorter nest decay times, they could be overestimating bonobo counts by up to 50 percent, Bessone says.

The results "highlight how indirect, and therefore prone to errors, our methods of density estimates of many species are," says behavioral ecologist Martin Surbeck of Harvard University. Technologies such as camera traps can be used to directly count animals, but until those methods become more common, nest counts remain vital for scientists' understanding of bonobo numbers.

Scientists use nest counts to estimate the numbers of other great apes too. So, the researchers say, the new findings could have implications for the conservation of those primates as well. ■

likely to follow a pointed finger or a wooden block. Dogs also made twice as much eye contact, meeting humans' gaze in four-second bursts compared with wolf pups' average of 1.47 seconds.

Dogs intuit human gestures from a young age, the team concludes, lending support to the idea that domestication has wired dogs' brains for communicating with humans.

Domestication's effects on dogs' brains may be more emotional than cognitive, says canine behavioral scientist Clive Wynne of Arizona State University in Tempe. "It doesn't strike me as surprising" that dogs explore objects near humans more often than wolves, he says. "Dogs are just generally happier getting close to a person."

One thing is clear: Domestication has molded dogs into people-seeking missiles, drawn to humans from the start. ■

Leaky energy-generating parts of muscle cells rev up sea otters' metabolism, helping the animals stay warm in frigid ocean waters, a study finds.

RANDALL DAVIS (IMAGE OBTAINED UNDER USFWS MARINE MAMMAL PERMIT NO. MA-043219 TO R. DAVIS)

LIFE & EVOLUTION

# How muscle cells keep otters warm

## Leaky mitochondria generate heat for the small ocean mammals

**BY JAIME CHAMBERS**

Sea otters' secret to staying warm is in their muscles. Leaks in the energy-generating parts of muscle cells help otters maintain a resting metabolism three times as fast as predicted for a mammal their size, researchers report in the July 9 *Science*.

The finding "could be a game changer in terms of how we think about the evolution of all marine mammals," says ecophysiologist Terrie Williams of the University of California, Santa Cruz. To dwell in cold oceans, mammals needed to develop ways to regulate their body temperature. "This is probably one of the clearest pieces of evidence saying here's [one way] they did it," Williams says.

Other marine mammals have high metabolisms to cope with cold water, but they also often rely on large bodies and blubber to stay toasty. Sea otters, the smallest mammals in the ocean, are lean and compact. And their fur's insulating properties can't fully protect them from losing too much heat. Small bodies with less surface area lose heat faster, even when covered in fluff.

Sea otters rely on an extreme metabolism, eating 25 percent of their body mass in food every day, to maintain an average body temperature of 37° Celsius. But scientists didn't understand the origins of "that revved-up metabolism," says comparative physiologist Traver Wright of Texas A&M University in College Station.

Wright and colleagues searched for the heat source in otters' skeletal muscles, which affect metabolism. The team collected tissue from 21 captive and wild sea otters and measured muscle cells' respiratory capacity in different states of oxygen flow — an indirect measurement of cells' heat production. That measurement was then compared with those for other animals including humans, sled dogs and elephant seals.

Leaks in energy-generating mitochondria account for about 40 percent of the total respiratory capacity of otters' muscle cells, the team found, higher than any known mammal except for small mice. Mitochondria pump protons across their inner membrane to store energy. But if those protons leak back over the membrane before being used for work, that energy is lost as heat. Because proton leaks increase the amount of energy lost as heat, otters need to eat more food to make up for that lost energy, revving up their metabolism.

Producing heat this way helps sea otters stay comfortable in 0° C Pacific waters, but "is not necessarily what they're running all the time," Wright says. Otters' cells probably use this method when the animals need to generate more warmth, but the team doesn't yet know how cells turn it on and off. Eventually, the findings could lead to new insights into how these creatures' ancestors evolved to live and thrive in the seas. ■

The Xerces blue butterfly (shown) was the first U.S. insect species that scientists had recognized went extinct because of people.

LIFE & EVOLUTION

# Lost blue butterfly was its own species

## Urban development drove California insect to extinction

**BY JAKE BUEHLER**

It's been roughly 80 years since the Xerces blue butterfly was last spotted flitting about on pastel wings across coastal California sand dunes. But scientists are still learning about the insect.

New research on DNA from a nearly century-old museum specimen shows that the butterfly was a distinct species. That finding means the Xerces blue butterfly (*Glaucopsyche xerces*) is the first U.S. insect species that researchers recognized went extinct because of people, scientists report in the July *Biology Letters*.

The butterfly used to live only on the San Francisco Peninsula. By the early 1940s, less than a century after its formal scientific description, the gossamer-winged butterfly had vanished. Its rapid disappearance is attributed to the loss of habitat and native plant food as a result of urban development and, possibly, an influx of invasive ants probably spread though the shipment of goods.

But it's long been unclear if the Xerces blue butterfly was its own species, or simply an isolated population of another, more widespread species of blue butterfly, says entomologist Corrie Moreau of Cornell University.

To find out, Moreau and colleagues turned to a 93-year-old Xerces specimen housed at the Field Museum in Chicago, extracting DNA from the insect's tissue. Despite the fact that the DNA had degraded over time, the team could compare select Xerces genes with those of several other closely related butterflies. The scientists also compared the genomes, or genetic instruction books, of the insects' mitochondria — cellular structures that are involved in energy production and that have their own set of DNA.

Using the genes and mitochondrial genomes, the researchers determined how all of the butterfly species are related to each other. The Xerces blue butterfly was genetically distinct, thus warranting classification as a species, the team found.

Akito Kawahara, a butterfly researcher at the Florida Museum of Natural History in Gainesville, says the finding that the Xerces blue butterfly was its own species is "fairly convincing."

For coauthor Felix Grewe, an evolutionary biologist at the Field Museum, the finding illustrates why museum collections are important: Specimens' true utility may not be clear for many years. After all, the techniques used to uncover the Xerces blue butterfly's true identity didn't exist when the insect went extinct. "You don't know what technology there [will be] 100 years from now," he says. ■

LIFE & EVOLUTION

# Froghoppers suck super hard

## Their suction power may be unrivaled among animals

**BY JONATHAN LAMBERT**

To tap an unlikely source of nutrition, insects small enough to sit on a pencil eraser have to suck harder than any known creature.

*Philaenus spumarius* froghoppers pierce plants with their mouthparts to feed on xylem sap, a fluid made mostly of water that moves through plants' internal plumbing. Not only is the substance largely bereft of nutrients, but it's also under negative pressures that can exceed one megapascal. Sucking the sap requires suction power equivalent to a person drinking water through a 100-meter-long straw.

Such a feat seemed so unlikely for the tiny insects that some scientists questioned whether xylem sap truly could be under such negative pressures, says comparative physiologist Philip Matthews of the University of British Columbia in Vancouver. Elephants, for example, only generate 0.02 megapascals of negative pressure when they suck large volumes of water through their trunks (*SN: 7/3/21 & 7/18/21, p. 11*), paltry compared with froghoppers. But both biomechanical and metabolic evidence suggests that froghoppers can produce negative pressures akin to those of xylem sap's, Matthews and colleagues report in the July 14 *Proceedings of the Royal Society B*.

"It's incredibly impressive," says biomechanist Jake Socha of Virginia Tech in Blacksburg. "These insects are really well adapted for generating" extreme negative pressures, he says.

Matthews and colleagues measured froghoppers' sucking abilities through two approaches, one biomechanical and one metabolic. Froghoppers produce suction power with a pumplike structure in their heads similar to a piston. Using micro-CT scans of four insects,

FIELD MUSEUM

the team measured the length and strength capacity of these structures, and then calculated the insects' sucking potential using the simple physical formula of pressure equals force divided by area. In principle, froghoppers can produce negative pressures from 1.06 to 1.57 megapascals, the researchers found.

"Clearly they can generate these tensions, so they must be feeding at xylem tensions around this level," Matthews says. "You wouldn't evolve such a massive capacity unless you were using it."

The team validated this more abstract estimate by calculating how much energy froghoppers expend while sucking on bean, pea or alfalfa plants. That energy should be proportional to the pressures that the insects have to overcome in plants. Feeding froghoppers in chambers that measure expelled carbon dioxide let the researchers calculate the insects' metabolic rate. Cameras tracked how much liquid the bugs excreted.

Froghoppers (one shown) generate extreme negative pressures to suck xylem sap — their sole food source — from plants.

Once froghoppers started sucking, their metabolic rate spiked by 50 to 85 percent from resting rates, and the insects were excreting more than when at rest. The effort is "like running a marathon," Matthews says. "They move a tremendous amount of fluid.... If a bug was human-sized, they'd be peeing 4 liters of liquid a minute."

Even though xylem sap is mostly water, there's enough nutrients to power froghoppers' outsize ability, the researchers estimate.

The suction power of froghoppers and other xylem sap specialists may be unmatched among animals, says coauthor Elisabeth Bergman, a comparative physiologist also of the University of British Columbia. There simply aren't other contexts where food is locked away under such high negative pressures, she says. "These little bugs are just awesome sucking machines." ■

LIFE & EVOLUTION

# Fossils may be oldest-known archaea

## Structures in 3.42-billion-year-old rock resemble microbial cells

**BY CAROLYN WILKE**

Threadlike filaments in rock may be the remnants of archaea that burped methane near hydrothermal vents 3.42 billion years ago. If so, these strands in rock excavated in South Africa would provide the earliest direct evidence of a methane-based metabolism, researchers report July 14 in *Science Advances*.

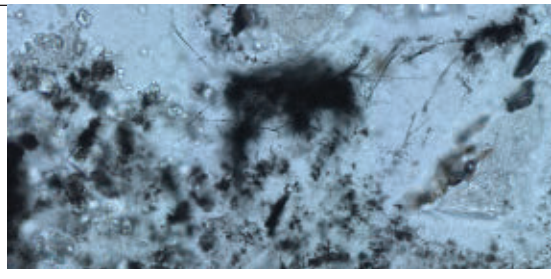
Such ancient fossil filaments may contain clues about Earth's early inhabitants and hint at where to look for extraterrestrial life. Scientists suspect that life on our planet could have arisen in such a hydrothermal environment.

Methane-based metabolisms evolved early in Earth's history, but biologists don't know exactly when, says geobiologist Barbara Cavalazzi of the University of Bologna in Italy. Previous research has found chemical evidence for methane-cycling microbes in fluid-filled pockets of rock from around 3.5 billion years ago, but not the actual microbes. The new analysis finds "evidence of about the same age," Cavalazzi says. "But this is a cellular remain. It's the organism."

The fossil threads have a carbon-based shell that is different structurally from the preserved interior, suggesting a cell envelope enclosing the cells' insides, the team says. And nickel levels in the filaments were similar to levels found in modern methane-makers, suggesting the fossils' metal may have come from nickel-containing enzymes in the microbes.

"They can attribute a specific metabolic lifestyle to these early microorganisms," says biogeochemist Dominic Papineau of University College London. The study is "brilliant work," he says.

Yet the search for early life-forms has had its share of false signs (*SN: 2/27/21, p. 6*), and some scientists aren't convinced these fossils are the real deal. In silica-rich hydrothermal environments, the ingredients for cell-mimicking structures mingle and can form life look-alikes, says geobiologist Julie Cosmidis of the University of Oxford. "They fossilize better than actual cells, so I think it could very well be what those things are," she says. Nickel, common on early Earth, clings easily to organic matter, whether it's living or not, she adds. "We don't understand enough [about] the processes that can create false biosignatures."

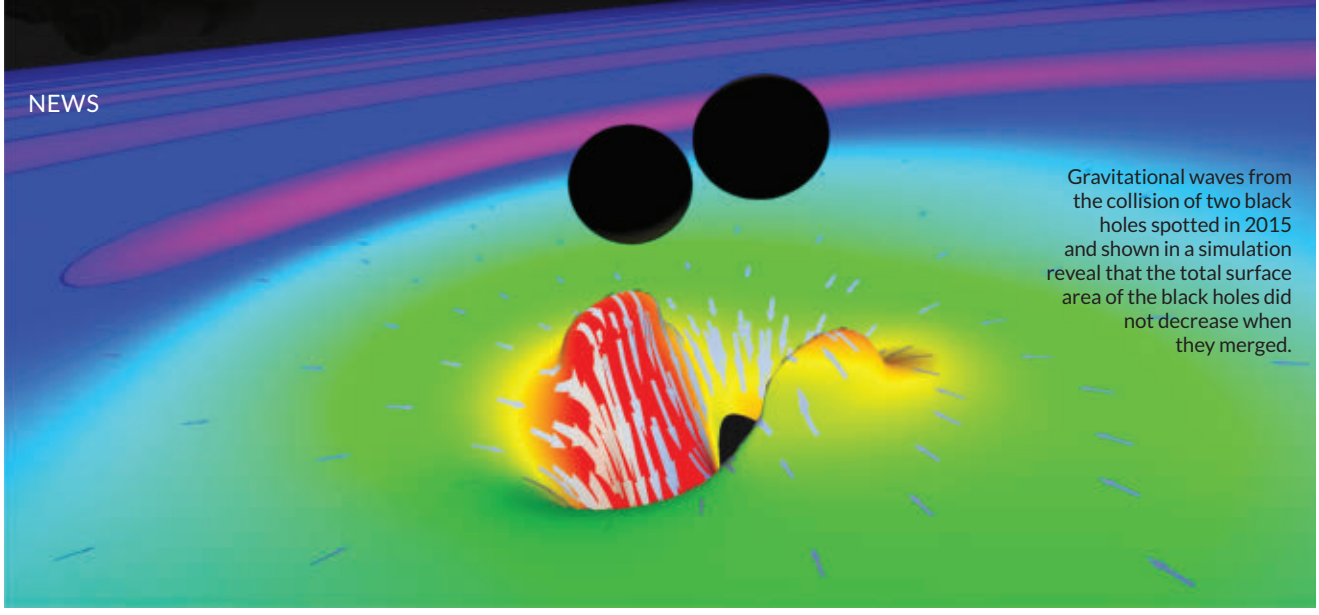


If real, 3.42-billion-year-old fossils of methane-making archaea (above, dark cluster at center and threads nearby) would be the oldest found.

If the strands are ancient archaea, then they'd become the earliest fossil evidence for this domain of life, predating specimens from less than 500 million years ago. And if such microbes evolved so quickly, within around 1 billion years of Earth's origin, then methane-cyclers might be a target in the search for life on other planets where liquid water has been around for a while, Papineau says.

Researchers looking for signs of early life on Earth have explored sediments of surface waters more than deeper hydrothermal systems, where these fossils were found, Cavalazzi says. The discovery, she says, suggests that here and on other planets, scientists should keep scratching below the surface. ■

FROM TOP: P.G.D. MATTHEWS; B. CAVALAZZI



Gravitational waves from the collision of two black holes spotted in 2015 and shown in a simulation reveal that the total surface area of the black holes did not decrease when they merged.

SIMULATING EXTREME SPACETIMES PROJECT

ATOM & COSMOS

# Colliding black holes follow the rules

## Gravitational waves support Stephen Hawking's area law

**BY EMILY CONOVER**

Despite their mysterious nature, black holes are thought to follow certain simple rules. Now, gravitational wave measurements appear to uphold one of the most famous black hole laws predicted by physicist Stephen Hawking.

According to the black hole area theorem, developed by Hawking in the early 1970s, black holes can't decrease in surface area over time. The area theorem fascinates physicists because it mirrors a well-known physics rule that disorder, or entropy, can't decrease over time. Instead, entropy consistently increases (*SN: 7/25/15, p. 15*).

That's "an exciting hint that black hole areas are something fundamental and important," says astrophysicist Will Farr of Stony Brook University and the Flatiron Institute in New York City.

The surface area of a single black hole won't change — after all, nothing can escape from within. However, if you throw something into a black hole, the black hole will gain more mass, increasing its surface area. But the incoming object could also make the black hole spin, which decreases the surface area. The area law says that the increase in surface area due to additional mass will always outstrip the decrease in surface area due to added spin.

To test this area rule, Farr, astrophysicist Maximiliano Isi of MIT and colleagues used ripples in spacetime stirred up by two black holes that spiraled inward and merged into one bigger black hole. A black hole's surface area is defined by its event horizon — the boundary from within which it's impossible to escape. According to the area theorem, the area of the newly formed black hole's event horizon should be at least as big as the areas of the event horizons of the two original black holes combined.

The researchers analyzed data from the first gravitational waves ever spotted, which were detected by the Advanced Laser Interferometer Gravitational-Wave Observatory, LIGO, in 2015 (*SN: 3/5/16, p. 6*). The team split the gravitational wave data into two time segments, before and after the merger, and calculated the surface areas of the black holes in each period. The surface area of the newly formed black hole was greater than that of the two initial black holes combined, upholding the area law with a 95 percent confidence level, the team reports in the July 2 *Physical Review Letters*.

"It's the first time that we can put a number on this," Isi says.

The area theorem is a result of Einstein's general theory of relativity, which describes the physics of black holes and gravitational waves. Previous analyses of gravitational waves have agreed with predictions of general relativity, and thus already hinted that the area law can't be wildly off. But the new study "is a more explicit confirmation" of the area law, says physicist Cecilia Chirenti of the University of Maryland in College Park.

So far, general relativity describes black holes well. But scientists don't fully understand what happens where general relativity — which typically applies to large objects like black holes — meets quantum mechanics, which describes small stuff like atoms and subatomic particles. In the quantum realm, strange things can happen.

For example, black holes can release a faint mist of particles called Hawking radiation (*SN: 11/15/14, p. 14*), another idea developed by Hawking in the 1970s. That effect could allow black holes to shrink, violating the area law, but only over extremely long periods of time. It wouldn't have affected the relatively quick merger of black holes that LIGO detected.

Physicists are looking for an improved theory that will combine the two disciplines into one new theory of quantum gravity. Any failure of black holes to abide by the rules of general relativity could point physicists in the right direction to find that new theory.

Physicists tend to be grumpy about the enduring success of general relativity, Farr says. "We're like, aw, it was right again." ■

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# Mind Games

## From Freud to behavioral economics, figuring out how people think and feel is no simple task

**By Bruce Bower**

One of the most infamous psychology experiments ever conducted involved a carefully planned form of child abuse. The study rested on a simple scheme that would never get approved or funded today. In 1920, two researchers reported that they had repeatedly startled an unsuspecting infant, who came to be known as Little Albert, to see if he could be conditioned like Pavlov's dogs.

Psychologist John Watson of Johns Hopkins University and his graduate student Rosalie Rayner viewed their laboratory fearfest as a step toward strengthening a branch of natural science able to predict and control the behavior of people and other animals.

At first, the 9-month-old boy, identified as Albert B., sat placidly when the researchers placed a white rat in front of him. In tests two months later, one researcher presented the rodent, and just as the child brought his hand to pet it, the other scientist stood behind Albert and clanged a metal rod with a hammer. Their goal: to see if a child could be conditioned to associate an emotionally neutral white rat with a scary noise, just as Russian physiologist Ivan Pavlov had trained dogs to associate the meaningless clicks of a metronome with the joy of being fed.

Pavlov's dogs slobbered at the mere sound of a metronome. Likewise, Little Albert eventually cried and recoiled at the mere sight of a white rat. The boy's conditioned fear wasn't confined to rodents. He got upset when presented with other furry things — a rabbit, a dog, a fur coat and a Santa Claus mask with a fuzzy beard.

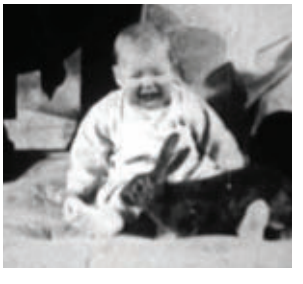
Crucial details of the Little Albert experiment remain unclear or in dispute, such as who the child was, whether he had any neurological conditions and why the boy was removed from the experiment, possibly by his mother, before the researchers could attempt to reverse his learned fears. Also

GLENN HARVEY

J.B. WATSON

uncertain is whether he experienced any long-term effects of his experience.

Although experimental psychology originated in Germany in 1879, Watson's notorious study foreshadowed a messy, contentious approach to the "science of us" that has played out over the last 100 years. Warring scientific tribes armed with clashing assumptions about how people think and behave have struggled for dominance in psychology and other social sciences. Some have achieved great influence and popularity, at least for a while. Others have toiled in relative obscurity. Competing tribes have rarely joined forces to develop or integrate theories about how we think or why we do what we do; such efforts don't attract much attention.



In a questionable experiment published in 1920, researchers conditioned an infant nicknamed Little Albert to fear various furry animals and objects.

But Watson, who had a second career as a successful advertising executive, knew how to grab the spotlight. He pioneered a field dubbed behaviorism, the study of people's external reactions to specific sensations and situations. Only behavior counted in Watson's science. Unobservable thoughts didn't concern him.

Even as behaviorism took center stage — Watson wrote a best-selling book on how to raise children based on conditioning principles — some psychologists addressed mental life. American psychologist Edward Tolman concluded that rats learned the spatial layout of mazes by constructing a "cognitive map" of their surroundings (*SN: 3/29/47, p. 199*). Beginning in the 1910s, Gestalt psychologists studied how we perceive wholes differently than the sum of their parts, such as, depending on your perspective, seeing either a goblet or the profiles of two faces in the foreground of a drawing (*SN: 5/18/29, p. 306*).

And starting at the turn of the 20th century, Sigmund Freud, the founder of psychoanalysis, exerted a major influence on the treatment of psychological ailments through his writings on topics such as unconscious conflicts, neuroses and psychoses (*SN: 7/9/27, p. 21*). Freudian clinicians guided the drafting of the American Psychiatric Association's first official classification system for mental disorders. Later editions of the psychiatric "bible" dropped Freudian concepts as unscientific — he had based his ideas on analyses of himself and his patients, not on lab studies.

Shortly after Freud's intellectual star rose, so did that of Harvard University psychologist B.F. Skinner, who could trace his academic lineage back to Watson's behaviorism. By placing rats and pigeons in conditioning chambers known as Skinner boxes, Skinner studied how the timing and rate of rewards or punishments affect animals' ability to learn new behaviors. He found, for instance, that regular rewards speed up learning, whereas intermittent rewards produce behavior that's hard to extinguish in the lab. He also stirred up controversy by calling free will an illusion and imagining a utopian society in which communities doled out rewards to produce well-behaved citizens.

Skinner's ideas, and behaviorism in general, lost favor by the late 1960s (*SN: 9/11/71, p. 166*). Scientists began to entertain the idea that computations, or statistical calculations, in the brain might enable thinking.

At the same time, some psychologists suspected that human judgments relied on faulty mental shortcuts rather than computer-like data crunching. Research on allegedly rampant flaws in how people make decisions individually and in social situations shot to prominence in the 1970s and remains popular today. In the last few decades, an opposing line of research has reported that instead, people render good judgments by using simple rules of thumb tailored to relevant situations.

Starting in the 1990s, the science of us branched out in new directions. Progress has been made in studying how emotional

## ScienceNews 100

To celebrate our 100th anniversary, we're highlighting some of the biggest advances in science over the last century. To see an expanded version of this story and more from the series, visit the Century of Science site at www.sciencenews.org/century


Psychologist B.F. Skinner (far left) studied how rewards and punishments shape new behaviors in pigeons and other animals. Enclosed chambers known as Skinner boxes, originally used to condition behaviors in nonhuman animals, later became confused with a different Skinner invention that wasn't used for research, a climate-controlled crib for human infants (right).

problems develop over decades, how people in non-Western cultures think and why deaths linked to despair have steadily risen in the United States. Scientific attention has also been redirected to finding new, more precise ways to define mental disorders.

No unified theory of mind and behavior unites these projects. For now, as social psychologists William Swann of the University of Texas at Austin and Jolanda Jetten of the University of Queensland in Australia wrote in 2017, perhaps scientists should broaden their perspectives to "witness the numerous striking and ingenious ways that the human spirit asserts itself."

## Revolution and rationality

Today's focus on studying people's thoughts and feelings as well as their behaviors can be traced to a "cognitive revolution" that began in the mid-20th century.

The rise of increasingly powerful computers motivated the idea that complex programs in the brain guide "information processing" so that we can make sense of the world. These neural programs, or sets of formal rules, provide frameworks for remembering what we've done, learning a native language and performing other mental feats, a new breed of cognitive and computer scientists argued (*SN: 11/26/88, p. 345*).

Economists adapted the cognitive science approach to their own needs. They were already convinced that individuals calculate costs and benefits of every transaction in the most self-serving ways possible — or should do so but can't due to human mental limitations. Financial theorists bought into the latter argument and began creating cost-benefit formulas for investing money that are far too complex for anyone to think up, much less calculate, on their own. Economist Harry Markowitz won the Nobel Memorial Prize in Economic Sciences in 1990 for his set of mathematical rules, introduced in 1952, to allocate an investor's money to different assets, with more cash going to better and safer bets.

But in the 1970s, psychologists began conducting studies documenting that people rarely think according to rational rules of logic beloved by economists. Psychologists Daniel Kahneman of Princeton University, who received the Nobel Memorial Prize in Economic Sciences in 2002, and Amos Tversky of Stanford University founded that area of research, at first called heuristics (meaning mental shortcuts) and biases.

Kahneman and Tversky popularized the notion that decision makers rely on highly fallible mental shortcuts that can have dire consequences. For instance, people bet themselves into bankruptcy at blackjack tables based on what they easily remember — big winners — rather than on the vast majority of losers. University of Chicago economist Richard Thaler applied that idea to the study of financial behavior in the 1980s. He was awarded the 2017 Nobel Memorial Prize in Economic Sciences for his contributions to the field of behavioral economics, which incorporated previous heuristics and biases research. Thaler has championed the practice of nudging, in which government and private institutions find ways to prod people to make decisions deemed to be in their best interest.

Better to nudge, behavioral economists argue, than to leave people to their potentially disastrous mental shortcuts. Nudges have been used, for instance, to enroll employees automatically in retirement savings plans unless they opt out. That tactic is aimed at preventing delays in saving money during prime work years that lead to financial troubles later in life.

Another nudge tactic attempts to reduce overeating of sweets

BOTH: SCIENCE HISTORY IMAGES/ALAMY STOCK PHOTO

## Schools of thought

Researchers have taken a variety of often conflicting, sometimes complementary approaches to the study of human thought and behavior.

**1899**
**Freudian psychoanalysis**
Study and treatment of unconscious mental conflicts

**1912**
**Gestalt psychology**
Study of unified perceptions rather than their parts

**1913**
**John Watson's behaviorism**
Study of the prediction and control of human behavior

**1938**
**B.F. Skinner's behaviorism**
Study of behaviors conditioned by rewards and punishments

**1956**
**Cognitive revolution**
Study of the mind using artificial intelligence and computers

and other unhealthy foods, and perhaps rising obesity rates as well, by redesigning cafeterias and grocery stores so that vegetables and other nutritious foods are easiest to see and reach.

As nudging gained in popularity, Kahneman and Tversky's research also stimulated the growth of an opposing research camp, founded in the 1990s by psychologist Gerd Gigerenzer, now director of the Harding Center for Risk Literacy at the University of Potsdam in Germany (*SN: 7/13/96, p. 24*).

Gigerenzer and colleagues study simple rules of thumb that, when geared toward crucial cues in real-world situations, work remarkably well for decision making. Their approach builds on ideas on decision making in organizations that won economist Herbert Simon the 1978 Nobel Memorial Prize in Economic Sciences (*SN: 10/21/78, p. 277*).

In the real world, people typically possess limited information and have little time to make decisions, Gigerenzer argues. Precise risks can't be known in advance or calculated based on what's happened in the past because many interacting factors can trigger unexpected events in, for example, one's life or the world economy. Amid so much uncertainty, simple but powerful decision tactics can outperform massive number-crunching operations such as Markowitz's investment formula. Using 40 years of U.S. stock market data to predict future returns, one study found that simply distributing money evenly among either 25 or 50 stocks usually yielded more money than 14 complex investment strategies, including Markowitz's (*SN Online: 5/20/11*).

Unlike Markowitz's procedure, dividing funds equally among diverse buys spreads out investment risks without mistaking accidental and random financial patterns in the past for good bets.

Gigerenzer and other investigators of powerful rules of thumb emphasize public education in statistical literacy and effective thinking strategies over nudging schemes. Intended effects of nudges are often weak and short-lived, they contend. Unintended effects can also occur, such as regrets over having accepted the standard investment rate in a company's savings plan because it turns out to be too low for one's retirement needs. "Nudging people without educating them means infantilizing the public," Gigerenzer wrote in 2015.

## Moved to do harm

As studies of irrational decision making took off around 50 years ago, so did a field of research with especially troubling implications. Social psychologists put volunteers into experimental situations that, in their view, exposed a human weakness for following the crowd and obeying authority. With memories of the Nazi campaign to exterminate Europe's Jews still fresh, two such experiments became famous for showing the apparent ease with which people abide by heinous orders and abuse power.

First, Yale psychologist Stanley Milgram reported in 1963 that 65 percent of volunteers obeyed an experimenter's demands to deliver what they thought were increasingly powerful and possibly lethal electric shocks to an unseen person — who was actually working with Milgram — as punishments for erring on word-recall tests. This widely publicized finding appeared to unveil a frightening willingness of average folks to carry out the commands of evil authorities (*SN: 8/20/77, p. 117*).

A disturbing follow-up to Milgram's work was the 1971 Stanford Prison Experiment, which psychologist Philip Zimbardo halted after six days due to escalating chaos among participants. Male college students assigned to play guards in a simulated prison had increasingly abused mock prisoners, stripping them naked and denying them food. Student "prisoners" became withdrawn and depressed.

Zimbardo argued that extreme social situations, such as assuming the role of a prison guard, will overwhelm self-control. Even mild-mannered college kids can get harsh when clad in guards' uniforms and turned loose on their imprisoned peers, he said.

Milgram's and Zimbardo's projects contained human drama and conflict that had widespread, and long-lasting, public appeal. A 1976 made-for-television movie based on Milgram's experiment, titled *The Tenth Level*, starred William Shatner. A 2010 movie inspired by the Stanford Prison Experiment, simply called *The Experiment*, starred Academy Award winners

Above: Amos Tversky (left) and Daniel Kahneman (right) started a popular line of research in the 1970s aimed at uncovering ways in which human decisions go awry.

Left: In the 1990s, psychologist Gerd Gigerenzer and colleagues launched investigations of simple but powerful decision-making shortcuts.

FROM TOP: BARBARA TVERSKY; FRANZ JOHANN MORGENBESSER/FLICKR (CC BY-SA 2.0)

**1971**
**Heuristics and biases (Kahneman and Tversky)**
Study of irrational, mistaken decisions

**1999**
**Ecological rationality (Gigerenzer)**
Study of how mental shortcuts work in the right settings

**2010**
**WEIRD/cross-cultural movement**
Study of how people outside Western cultures think

Volunteers in Stanley Milgram's obedience-to-authority experiments thought they were giving shocks to people who erred on a test, such as the seated man here, who was actually working with Milgram.

When college students assumed the roles of guards (left) and prisoners (right) in the 1971 Stanford Prison Experiment, the group descended into chaos within a few days.

Adrien Brody and Forest Whitaker.

Despite the lasting cultural impact of the obedience-to-authority and prison experiments, some researchers have questioned Milgram's and Zimbardo's conclusions. Milgram conducted 23 obedience experiments, although only one was publicized. Overall, volunteers usually delivered the harshest shocks when encouraged to identify with Milgram's scientific mission to understand human behavior. No one followed the experimenter's order, "You have no other choice, you must go on."

Indeed, people who follow orders to harm others are most likely to do so because they identify with a collective cause that morally justifies their actions, argued psychologists S. Alexander Haslam of the University of Queensland and Stephen Reicher of the University of St. Andrews in Scotland 40 years after the famous obedience study. Rather than blindly following orders, Milgram's volunteers cooperated with an experimenter when they viewed participation as scientifically important — even if, as many later told Milgram, they didn't want to deliver shocks and felt bad after doing so.

Data from the 1994 ethnic genocide in the African nation of Rwanda supported that revised take on Milgram's experiment (*SN: 8/19/17, p. 22*). In a 100-day span, members of Rwanda's majority Hutu population killed roughly 800,000 ethnic Tutsis. Researchers who later examined Rwandan government data on genocide perpetrators estimated that only about 20 percent of Hutu men and a much smaller percentage of Hutu women seriously injured or killed at least one person during the bloody episode. Most Hutus rejected pressure from political and community leaders to join the slaughter.

Neither did Zimbardo's prisoners and guards passively accept their assigned roles. Prisoners at first challenged and rebelled against guards. When prisoners learned from Zimbardo that they would have to forfeit any money they'd already earned if they left before the experiment ended, their solidarity plummeted, and the guards crushed their resistance. Still, a majority of guards refused to wield power tyrannically, favoring tough-but-fair or friendly tactics.

In a second prison experiment conducted by Haslam in 2002, guards were allowed to develop their own prison rules rather than being told to make prisoners feel powerless, as Zimbardo had done. In a rapid chain of events, conflict broke out between one set of guards and prisoners who formed a communal group that shared power and another with guards and prisoners who wanted to institute authoritarian rule. Morale in the communal group sank rapidly. Haslam stopped the experiment after eight days. "It's the breakdown of groups and resulting sense of powerlessness that creates the conditions under which tyranny can triumph," Haslam concluded.

Milgram's and Zimbardo's experiments set the stage for further research alleging that people can't control certain harmful attitudes and behaviors. A test of the speed with which individuals identify positive or negative words and images after being shown white and Black faces has become popular as a marker of unconscious racial bias. Some investigators regard that test as a window into hidden prejudice — and implicit bias training has become common in many workplaces. But other scientists have questioned whether it truly taps into underlying bigotry. Likewise, stereotype threat, the idea that people automatically act consistently with negative beliefs about their race, sex or other traits when subtly reminded of those stereotypes, has also attracted academic supporters and critics.

## Improving lives and life spans

It has taken a public health crisis to stimulate a level of cooperation across disciplines within and even outside the social sciences rarely reached in the last century. After a long stretch of increasing longevity, life spans of Americans have declined in recent years, fueled by drug overdoses and other "deaths of despair" among poor and working-class people plagued by job losses and dim futures.

Economists, psychologists, psychiatrists, sociologists,

epidemiologists and physicians have begun to explore potential reasons for recent longevity losses, with an eye toward stemming a rising tide of early deaths.

Two Princeton University economists, Anne Case and Angus Deaton, highlighted this disturbing trend in 2015. After combing through U.S. death statistics, Case and Deaton observed that mortality rose sharply among middle-aged, non-Hispanic white people starting in the late 1990s. In particular, white, working-class people ages 45 to 54 were increasingly drinking themselves to death with alcohol, succumbing to opioid overdoses and committing suicide.

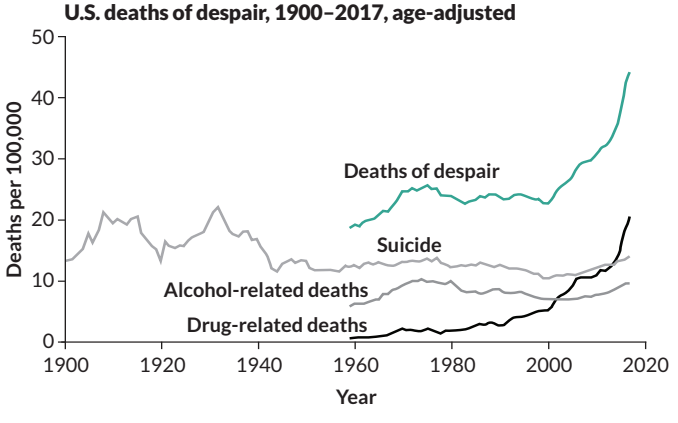
Job losses that resulted as mining declined and manufacturing plants moved offshore, high health care costs, disintegrating families and other stresses rendered more people than ever susceptible to deaths of despair, the economists argued. A similar trend had stoked deaths among inner-city Black people in the 1970s and 1980s.

If Case and Deaton were right, then researchers urgently needed to find a way to measure despair (*SN: 1/30/21, p. 16*). Two big ideas guided their efforts. First, don't assume depression or other diagnoses correspond to despair. Instead, treat despair as a downhearted state of mind. Tragic life circumstances beyond one's control, from sudden unemployment to losses of loved ones felled by COVID-19, can trigger demoralization and grief that have nothing to do with preexisting depression or any other mental disorder.

Second, study people throughout their lives to untangle how despair develops and prompts early deaths. It's reasonable to wonder, for instance, if opioid addiction more often afflicts young adults who have experienced despair since childhood, versus those who first faced despair in the previous year.

One preliminary despair scale consists of seven indicators of this condition, including feeling hopeless and helpless, feeling unloved and worrying often. This scale has shown promise as a way to identify those who are likely to think about or attempt suicide and to abuse opioids and other drugs.

**Self-harm** Social scientists are exploring reasons for rising numbers of "deaths of despair" in the United States, and the rising role played by drug overdoses, as compared with alcohol abuse and suicide.
SOURCE: U.S. CONGRESS JOINT ECONOMIC COMMITTEE 2019




T. TIBBITTS

## Diagnostic disarray

From 1952 to 1980, the *Diagnostic and Statistical Manual of Mental Disorders*, or DSM, divided mental ailments into less-debilitating neuroses and more-debilitating psychoses. Other conditions were grouped under psychosomatic illnesses, personality disorders and brain or nervous system problems. Architects of an update published in 1980, DSM-III, wanted psychiatry to become a biological science, so they emphasized medications over psychotherapy for treating mental disorders. In 2010, scientists dissatisfied with DSM's often fuzzy, symptom-based definitions of mental disorders rebelled and tried to define mental conditions based on brain and behavioral measures. One such approach involves a still-preliminary measure of a susceptibility to mental illness in general, called a p score. This score is thought to reflect a person's "internalizing" liability to develop anxiety and mood disorders, an "externalizing" liability, such as to abuse drugs and break laws, and a propensity to delusions and other forms of psychotic thinking. Researchers hope eventually to use p scores to evaluate how well psychotherapies and psychoactive medications treat and prevent mental disorders. — *Bruce Bower*

Deaths of despair belong to a broader public health and economic crisis, concluded a 12-member National Academies of Sciences, Engineering and Medicine committee in 2021. Since the 1990s, drug overdoses, alcohol abuse, suicides and obesity-related conditions caused the deaths of nearly 6.7 million U.S. adults ages 25 to 64, the committee found. Whether obesity is rarely or often associated with despair is an open question.

Deaths from those causes hit racial minorities and working-class people of all races especially hard from the start. The COVID-19 pandemic further inflamed that mortality trend because people with underlying health conditions were especially vulnerable to the virus.

Perhaps findings with such alarming public health implications can inform policies that go viral, in the best sense of that word. Obesity-prevention programs for young people, expanded drug abuse treatment and stopping the flow of illegal opioids into the United States would be a start.

Whatever the politicians decide, the science of us has come a long way from Watson and Rayner instilling ratty fears in an unsuspecting infant. If Little Albert were alive today, he might smile, no doubt warily, at researchers working to extinguish real-life anguish. ■

### Explore more


- Daniel Kahneman. *Thinking, Fast and Slow*. Farrar, Straus and Giroux, 2013.
- Gerd Gigerenzer. *Risk Savvy*. Penguin Books, 2014.


# A SAFE SYMPHONY OF SOUND

## The science of keeping wind instrumentalists from spreading the coronavirus

**By Betsy Ladyzhets**

Members of the Rude Mechanical Orchestra, based in Brooklyn, N.Y., played at the St. Pat's for All parade in March 2020. It was their last performance before COVID-19 shutdowns.

ERIK MCGREGOR/LIGHTROCKET VIA GETTY IMAGES

The last time I played clarinet with my band was on March 10, 2020. It was a typical Tuesday evening rehearsal: About 10 musicians crowded into a small basement room, sipping beers and chatting between tunes. Brass instruments, woodwinds and drums blared, with bass lines audible from the stairwell.

Since 2004, the Rude Mechanical Orchestra has practiced in the same space, a couple of blocks from the East River in Brooklyn, N.Y. The room is cramped — chairs and music stands crowd every corner, shelves are crammed with instruments and sheet music. With no windows or AC units, air circulation is minimal.

When I walked up the stairs after practice, I had no idea that the space we'd filled with boisterous pop covers and protest tunes would sit quiet for more than a year. The COVID-19 pandemic shut down the world in March 2020, isolating musicians like me from the art we love. Millions of high school and college musicians were barred from their band rooms, children's lessons were canceled and professionals lost performance opportunities and income streams.

Though restrictions are now easing, we still face questions about how our instruments play into infection risk. Wind instruments — brasses as well as woodwinds like my clarinet — produce sound through human breath. And human breath spreads COVID-19. So how can we perform while keeping ourselves and our audiences safe, during the pandemic and beyond? To find answers, wind musicians, including myself, turned to science.

### An ill wind

The hazards of live music hit home when news broke of a superspreader event among members of the Skagit Valley Chorale in Washington state.

On March 10 — the same day as my band's final rehearsal — 61 members had gathered to sing. By the time Gov. Jay Inslee instituted a stay-at-home order two weeks later, 52 members of the choir had either tested positive for the new coronavirus or were assumed to have it. Three singers were hospitalized, and two died.

The group had been careful, avoiding physical contact such as handshakes and hugs, putting plenty of space between their chairs and using hand sanitizer. At that time, the U.S. Centers for Disease Control and Prevention and other public health agencies were primarily telling people to avoid close contact and contaminated surfaces to reduce transmission risks. But many musicians quickly realized that something else was going on.

"When we saw the Skagit Valley choir spread, we knew right away that [the coronavirus] was spreading via aerosol," says Mark Spede, director of bands at Clemson University in South Carolina. He is one of the lead researchers on a coalition that developed COVID-19 protocols for performing arts students. It was "pretty clear," he says, that the virus was spreading through the air. On May 15, 2020, Skagit County health department staff reported in *Morbidity and Mortality Weekly Report* that the "act of singing, itself, might have contributed to transmission through emission of aerosols."

I quickly realized that wind instruments like mine had to pose a similar danger. To play it safe, most wind musicians stopped playing together. My band briefly entertained the idea of practicing outside, but as New York City shut down, we switched to virtual rehearsals. These meetings were a poor substitute for in-person sessions. As anyone who's tried to sing "Happy Birthday" over Zoom can tell you, videocalling platforms just don't cut it for music practice. These platforms are built to highlight one speaker at a time, creating a painful lag in sound when people try to sing or play simultaneously (*SN: 4/24/21, p. 22*).

"School band shut down," recalls 16-year-old Hannah Scheuer, a bandmate of mine and a student in the New York City public school system. Unable to enter the school building for months, classmates who rented instruments from the school couldn't bring them home to practice. A survey conducted in late April by Spede and colleagues revealed that out of 30,000 U.S. high school and college music programs, about one-third had no in-person rehearsals through the end of the 2020–2021 school year.

## Musicians in studies

Facing a lockdown without the camaraderie of rehearsals, musicians wanted answers about the risks their instruments might pose in spreading COVID-19. Some went as far as becoming study subjects to find out.

The Minneapolis-based Minnesota Orchestra, for instance, reached out to Jiarong Hong, a mechanical engineer at the nearby University of Minnesota. A July 2020 release of his study on indoor transmission of the coronavirus had drawn media attention; the study was later published in the January 2021 *Journal of Aerosol Science*. Catching wind of this work, the orchestra asked Hong and colleagues to "provide scientifically driven guidelines to help them get back to their work safely," Hong says. His lab set up experiments with the musicians, which led to one of the first studies on the subject.

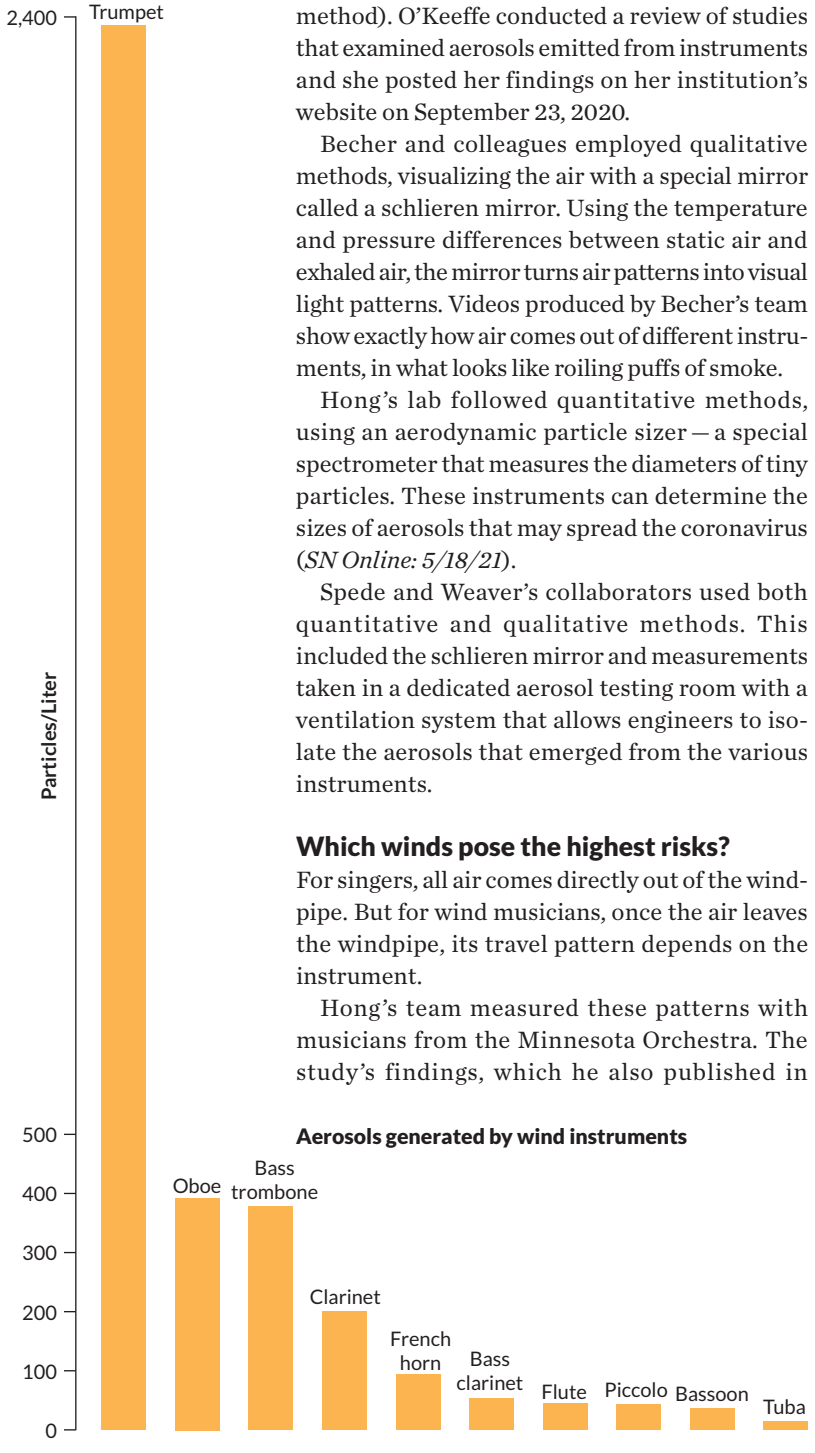
Engineer Lia Becher at the Bauhaus-Universität Weimar in Germany had an experience similar to Hong's. When a colleague's video demonstrating how air spreads after a cough went viral, musicians asked Becher and her lab group how air would spread out of their instruments. So she worked with local musicians to meticulously track the dispersion of air from instruments with mouthpieces.

Meanwhile, Spede and James Weaver, director of performing arts and sports for the National Federation of State High School Associations in Indianapolis, convened a group of concerned music teachers and arts organizations. They worked with mechanical engineers at the University of Colorado Boulder and the University of Maryland in College Park to study the risks posed by different performance activities, in the hopes of bringing students back to classrooms for fall 2020.

While it may seem counterintuitive to wear a mask with a hole, masks like this one worn by a member of the Colerain High School Cardinals marching band in Cincinnati reduce aerosol escape from the side of a musician's mouth.

MICHAEL HICKEY/GETTY IMAGES

**Blowin' in the winds** The air pushed out of a trumpet has the highest concentration of potentially infectious air particles compared with other wind instruments, according to University of Minnesota scientists. SOURCE: R. HE *ET AL/J. AEROSOL SCIENCE* 2021




These studies and others like them fall into two categories, notes Juliette O'Keeffe, an environmental health scientist at the National Collaborating Centre for Environmental Health in Vancouver. Some, she explains, visualize the air coming out of an instrument (a qualitative method), while others measure properties of the air particles that emerge, such as size, concentration and distance traveled (a quantitative method). O'Keeffe conducted a review of studies that examined aerosols emitted from instruments and she posted her findings on her institution's website on September 23, 2020.

Becher and colleagues employed qualitative methods, visualizing the air with a special mirror called a schlieren mirror. Using the temperature and pressure differences between static air and exhaled air, the mirror turns air patterns into visual light patterns. Videos produced by Becher's team show exactly how air comes out of different instruments, in what looks like roiling puffs of smoke.

Hong's lab followed quantitative methods, using an aerodynamic particle sizer — a special spectrometer that measures the diameters of tiny particles. These instruments can determine the sizes of aerosols that may spread the coronavirus (*SN Online: 5/18/21*).

Spede and Weaver's collaborators used both quantitative and qualitative methods. This included the schlieren mirror and measurements taken in a dedicated aerosol testing room with a ventilation system that allows engineers to isolate the aerosols that emerged from the various instruments.

## Which winds pose the highest risks?

For singers, all air comes directly out of the windpipe. But for wind musicians, once the air leaves the windpipe, its travel pattern depends on the instrument.

Hong's team measured these patterns with musicians from the Minnesota Orchestra. The study's findings, which he also published in the January 2021 *Journal of Aerosol Science*, measured risk by comparing the size and concentration of air particles dispersed by musicians with those emitted when a person speaks. Tubas were lowest risk, producing fewer particles than a person speaking. Flutes, French horns and larger woodwinds released similar levels of aerosols as a speaking person. Oboes, trombones and especially trumpets were all higher risk, spreading more aerosols than a person speaking.

Hong's research provides specific aerosol sizes and concentration measurements for individual instruments. But this work, like other studies in this field, used very small sample sizes of one or two musicians to characterize an instrument's air dispersion.

Such a small sample size can be particularly challenging when investigating woodwinds. While brass instruments are easy to evaluate, because all air goes straight from the mouthpiece to the bell, woodwinds get complicated. When I play my clarinet, aerosols have several escape routes: the flared opening at the instrument's end, the keyholes and the space where my lips meet the reed — the thin piece of wood that vibrates against the clarinet's mouthpiece to create sound. What's more, small differences between clarinet players' techniques can have a big impact on the speeds and concentrations of aerosols that players release.

In one trial by Hong's team, one clarinet player produced five times as many aerosols as a second clarinet player. Hong hypothesizes that this difference is because one player used a "harder" clarinet reed, typically used by more experienced musicians. This reed is stiffer and requires more air to produce a sound. The way a clarinet player positions her mouth around her instrument may also affect aerosol generation, Hong explains.

Like Hong's research, Becher's work and preliminary findings from Spede and Weaver's studies suggest that trumpets, trombones, clarinets and oboes spread more aerosols farther out into performance spaces, while larger instruments, particularly tubas, pose lower risks. The long, circuitous tubes in larger instruments trap breath-propelled particles and reduce the speed of those that do escape — in other words, you're less likely to catch COVID-19 if you stand in front of a tuba player than if you stick your head into a tuba's bell.

Although more research is needed, current studies nonetheless suggest that in most cases playing a wind instrument is about as likely (or even less likely) to transmit the coronavirus as loud talking or singing. The air is just traveling

C. CHANG

through your instrument's tubing, rather than going straight out of your mouth. And there are ways to reduce risk.

## Safety tips

While Hong, Becher and other scientists researched particle dispersion from wind instruments, music nonetheless returned to the streets of New York in summer 2020, with many musicians inspired to support Black Lives Matter protests across the city. Eager to join the movement, the Rude Mechanical Orchestra began looking at studies, deliberating how to be safe. I and three other science-minded performers formed a COVID-19 committee.

Evaluating the literature was tricky. In an August 2020 e-mail exchange, committee member Phil Andrews sent the band a preprint from medRxiv.org, which suggested that fabric covers be stretched over brass instruments' bells — the flared openings through which sound emerges. I wrote back with caution, noting that the study included only eight participants. Everything seemed preliminary, and because many of our bandmates have health conditions or families to look after, we opted for more caution. Until we knew more, we'd play only percussion instruments — outside.

Other musicians I spoke with remembered scouring the CDC's website for any mention of wind instruments and carefully reading preprints in subjects that they had never studied. Benjamin Yates, a trombone instructor at the University of Louisiana in Lafayette, recalls an instance of intense research over the summer: "I was sitting at my computer and I had all these tabs open, and I'm looking up really basic terms, like ventilation — what does ventilation actually mean, scientifically?"

Yates' and my efforts to align group practices with scientific recommendations reflected a broader trend across the nation to find safe ways to play music. While some musicians opted to stay in lockdown, others moved rehearsals and performances outside, often using makeshift bell covers or musician masks with space for a mouthpiece. A mask with a hole in it might seem odd, but research led by Spede and Weaver shows that these masks reduce aerosol spread from the sides of musicians' mouths as they blow into their instruments. This is especially key for younger musicians who have less control over their mouth positioning.

Formulating safe strategies for musicians became especially important as U.S. school programs prepared for the 2020 fall semester. For Spede and Weaver, time was ticking on their project to build guidelines for student musicians. Preliminary investigations by engineers at the Universities of Colorado and Maryland provided the information they needed. This study, which included 12 performers playing nine different instruments, was published as a preprint on the University of Colorado's website in April 2021. Before publication, however, Spede and Weaver's team used the findings to devise detailed risk mitigation guidelines (see box above).

At the end of the 2020–2021 school year, Spede and Weaver surveyed U.S. high school and college music programs. Of 3,000 programs that responded, about 2,800 reported using some or all of the guidelines for bands, choirs or orchestras. Among those schools that responded, coronavirus spread was almost nonexistent. Eight programs each reported a case of coronavirus spread between musicians: five in choirs, two in bands and one in an orchestra. Seven of the eight cases involved one person infecting a single other person; two of the cases occurred at schools that did not use any of the recommended safety guidelines.

"With hundreds or thousands of hours of rehearsal and millions of people participating," Weaver says, "the fact that we've had [so few] cases of spread, we're pretty confident in the mitigations." Spede and Weaver believe these protocols could be useful beyond the pandemic, for instance, during cold and flu seasons and other infectious disease outbreaks.

In addition to Spede and Weaver's guidelines, musicians may consider reorganizing where they sit onstage. A modeling study by researchers at the University of Utah in Salt Lake City, based on Hong's measurements, suggests that moving

**Protocols to reduce risk of COVID-19 transmission**

| | |
|---|---|
| **Masks & covers** | Masks on students<br>Bell covers on instruments<br>Surgical mask material or double layers for both |
| **Distance** | 6-foot distance between players<br>Trombone needs 9-by-6-foot distance<br>Applies indoors and outdoors |
| **Time** | 30-minute rehearsal limit indoors/60 minutes outdoors<br>Clear room for minimum of one air change before next rehearsal period |
| **Air flow** | Outdoors is best; open windows and doors if indoors<br>HEPA filtration<br>Maximize air change rates |
| **Hygiene** | Empty spit valves into buckets with alcohol solution<br>Wash hands frequently |

### Safe schools

The vast majority of high school and college bands that followed five recommendations from the National Federation of State and High School Associations rehearsed without spreading the coronavirus between students.

When a musician blows into a trumpet, air particles escape the bell and the musician's mouth, shown here with a schlieren mirror that visualizes temperature and pressure change.

percussion instruments toward the center of the stage and putting the highest-risk winds near vents that pull air from the room can cut aerosol accumulation. The Utah Symphony, which collaborated with the University of Utah researchers on this study, adopted this recommendation for its spring 2021 concert season (*SN Online: 6/23/21*).

O'Keeffe also suggests that musicians monitor COVID-19 transmission rates in their communities, so they know the likelihood that a person with COVID-19 is present. Disease-tracking metrics used by the Brown University School of Public Health in Providence, R.I., indicate that more than 10 new cases a day for every 100,000 people in a region constitutes higher risk. Musicians may feel safer, too, when more than 70 percent of their community is fully vaccinated, adopting the vaccination goal from the White House COVID-19 task force.

## An industry transformed

When I asked musicians how COVID-19 changed their musical activity, their answers reflected both the economic and emotional fallout of last spring's lockdowns.

"Before COVID, I was working at my [former] high school as a school aide while giving lessons there as well," says Elijah Herring, a saxophone student who graduated from New York's Brooklyn College this spring. "Because the school system closed down, I lost my job. I wasn't able to get unemployment benefits until June or July.... I had to street perform to make ends meet, to pay bills, to take care of my mom."

In the short term, COVID-19 was a blow to the music world. Musicians lost income as well as motivation to practice or compose; some left the industry altogether. But in the long term, the pandemic has transformed how many musicians think about their profession.

"Music is a privilege," says Orion White, a saxophone student at the University of Idaho in Moscow. "It's something that really sticks with you; it changes you. It can be almost religious if you let it be, and I took that for granted. Not anymore."

This sentiment is heightened by the layers of added challenge needed to play — any performance, group practice or even informal jam session now requires intensive safety and trust. Before they can start playing, musicians must trust each other with their vaccination status and other health information. I've led discussions in my own band, developing practice guidelines that incorporate health needs and risk comfort levels.

Audiences seem to acknowledge the effort that goes into performing. Andrews and Herring both say that they're getting more money from busking now than they did before the pandemic.

The Rude Mechanical Orchestra had our first pandemic practice that included wind instruments on May 18 this year. We gathered outside, by the river, a few blocks away from our old basement practice space.

We had agreed to strict guidelines — all wind players had to be fully vaccinated, with masks and bell covers on. So only four people opted to play a wind instrument. Still, a tuba, two trombones, a clarinet and a lot of percussion was enough to bring melodies to life. We played through some of our classic tunes, pausing to talk through song structure and enjoy the breeze.

At one point, a small girl with a loose ponytail approached us and began dancing to the music. She didn't know that we were out of practice or that half of the drummers were trained in other instruments. But her dance echoed our joy in being back together. ■

## Explore more

- National Federation of State High School Associations. "COVID-19 mitigation strategies for wind instruments." bit.ly/COVID-19musicguidelines

*Betsy Ladyzhets is a freelance science writer and data journalist based in Brooklyn, N.Y.*

L. BECHER/BAUHAUS-UNIVERSITÄT WEIMAR


**Bright Galaxies, Dark Matter, and Beyond**
*Ashley Jean Yeager*
MIT PRESS, $24.95

INTERVIEW

# Vera Rubin broke new ground in astronomy

Vera Rubin's research forced cosmologists to radically reimagine the cosmos.

In the 1960s and '70s, Rubin's observations of stars whirling around within galaxies revealed the gravitational tug of invisible "dark matter." Although astronomers had detected hints of this enigmatic substance for decades, Rubin's data helped finally convince a skeptical scientific community that dark matter exists.

"Her work was pivotal to redefining the composition of our cosmos," Ashley Yeager, *Science News*' associate news editor, writes in her new book. *Bright Galaxies, Dark Matter, and Beyond* follows Rubin's journey from stargazing child to preeminent astronomer and fierce advocate for women in science.

That journey, Yeager shows, was rife with obstacles. When Rubin was a young astronomer in the 1950s and '60s, many observatories were closed to women, and more established scientists often brushed her off. Much of her early work was met with intense skepticism, but that only made Rubin, who died in 2016 at age 88, a more dogged data collector.

On graphs plotting the speeds of stars swirling around galaxies, Rubin showed that stars farther from galactic centers orbited just as fast as inner stars. That is, the galaxies' rotation curves were flat. Such speedy outer stars must be pulled along by the gravitational grip of dark matter.

*Science News* staff writer Maria Temming spoke with Yeager about Rubin's legacy and what, beyond her pioneering research, made Rubin remarkable. The following discussion has been edited for clarity and brevity.

**What inspired you to tell Rubin's story?**
It all started when I was working at the National Air and Space Museum in Washington, D.C., in 2007. I was walking around the "Explore the Universe" exhibit and noticed there weren't many women featured. But then there was this picture of a woman with big glasses and cropped hair, and I thought, "Who is this?" It was Vera Rubin.

My supervisor was a curator of oral histories. He was working on Rubin's, so I asked him about her. He said, "I have one more oral history interview to do with her. Would you like to come?" So I got to interview her. She was charismatic, kind and curious — not a person who was all about herself, but wanted to know about you. That stuck with me.


Vera Rubin stands by a telescope at Arizona's Lowell Observatory in 1965.

AIP EMILIO SEGRÈ VISUAL ARCHIVES, RUBIN COLLECTION

**You spend much of the book describing evidence for dark matter besides Rubin's research. Why?**
I wanted to make sure I didn't portray Rubin as this lone person who discovered dark matter, because there were a lot of different moving pieces in astronomy and physics that came together in the '70s and early '80s for the scientific community to say, "OK, we really have to take dark matter seriously."

**What made Rubin's work a linchpin for confirming dark matter?**
She really went after nailing down that flat rotation curve in all types of galaxies. Mainly because she did get a lot of pushback, continually, that said, "Oh, that's just a special case in that galaxy, or that's just for those types of galaxies." She studied hundreds of galaxies to double-check that, yes, in fact, the rotation curves are flat. People saying, "We don't believe you," didn't ever really knock her down. She just came back swinging harder.

It helped that she did the work in visible wavelengths of light. There had been a lot of radio astronomy data to suggest flat rotation curves, but because radio astronomy was very new, it was really only once you saw it with the eye that the astronomy community was convinced.

**Why is Rubin's story important to tell now?**
Unfortunately for women and minorities in science, it's still very relevant, in that there are a lot of challenges to pursuing a career in STEM. Her story demonstrates that you have to surround yourself with people who are willing to help you and get away from the people who want to keep you down. Plus her story is also very encouraging: Your curiosity can keep you going and can fuel something way bigger than yourself.

**How did she advocate for women in astronomy?**
She was very outspoken about it. At National Academy of Sciences meetings, the organizers always dreaded her standing up, because she would say, "What are we doing about women in science? We're not doing enough." She was constantly pushing for women to be recognized with awards. She kept tabs on the number of women who had earned Ph.D.s and who had gotten staff positions — and their salaries. She was very data-driven. She'd cull that information and use it to advocate for better representation and recognition of women in astronomy.

**How would you describe Rubin to someone who hasn't met her?**
She was one of the most persistent, gracious and nurturing people that I've ever met. You could strip away all that she did in astronomy and she would still be this incredible figure — the way she carried herself, the way she treated people. Just a beautiful human being. ■


# 100 YEARS OF IMPACT

In 2021, the Society for Science is celebrating 100 years of championing science. Founded in 1921 as Science Service by journalist Edward W. Scripps and zoologist William Ritter, the Society fosters and advances the public understanding of science. In its first century, the organization published accurate, objective journalism in its *Science News* magazine, advised government agencies, cultivated the nation's top young science talent through its competitions and ignited a passion for science in generations of students.

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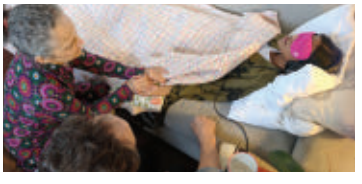
JUNE 19, 2021

SOCIAL MEDIA

## Psychedelic possibilities

Pairing MDMA, the key ingredient in the drug Ecstasy, with intensive talk therapy (below) may relieve symptoms of severe post-traumatic stress disorder, **Laura Sanders** reported in "Psychedelic drug eases severe PTSD" (*SN: 6/19/21, p. 8*). On Twitter, reader **@DrT_Crit_Think** rejoiced: "This discovery is huge for all veterans like my father who suffered decades of nightmares and other terrible effects of war. When science is put in the service of helping people, the possibilities are endless."



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## Rising from the ashes

*Climate change might fuel more wildfires that can survive winter underground and flare up after warmer-than-normal summers, **Jonathan Lambert** reported in "'Zombie' fires could become common" (SN: 6/19/21, p. 7).*

Reader **Mike Roddy** wanted to know if such fires could occur in temperate forests.

Zombie fires typically only happen in boreal forests, which grow at high latitudes between 50° N and 60° N, **Lambert** says. "Most temperate forests, which exist at lower latitudes in both the Northern and Southern hemispheres, lack the carbon-rich peat and soil that fuel zombie fires."

## Crystal clear

*Material formed from the first atomic bomb test contains a quasicrystal, a rare type of matter that has an orderly, nonrepeating structure, **Emily Conover** reported in "Atomic bomb test made a quasicrystal" (SN: 6/19/21, p. 12).*

Reader **Lance N. Franke** asked whether the quasicrystal was radioactive, given it formed during a nuclear explosion.

The researchers did not report any evidence of radioactivity within the quasicrystal itself, **Conover** says. But trinitite, the material in which the quasicrystal was found, is mildly radioactive — though not enough to be dangerous. "You can find within trinitite traces of plutonium, uranium and other radioactive elements that were produced or released in the explosion, but not in very large amounts," she says.

**Franke** also wondered if quasicrystals could have practical uses.

Since quasicrystals are rare outside of the lab and usually extremely tiny, researchers have yet to find a practical use for them, **Conover** says. "Quasicrystals do not follow the same rules of symmetry as normal crystals, which means they could have properties not possible for normal crystals," she says. Researchers are studying lab-made quasicrystals to determine if they could be useful in electronics and other technologies (*SN: 1/21/17, p. 16*).

## Uncovering history

*A century ago, an eruption of racist violence left hundreds dead and destroyed a thriving Black neighborhood in Tulsa, Okla. Now, researchers may have found a mass grave of some of the victims, **Helen Thompson** reported in "Tulsa reckons with the 1921 race massacre" (SN: 6/19/21, p. 22).*

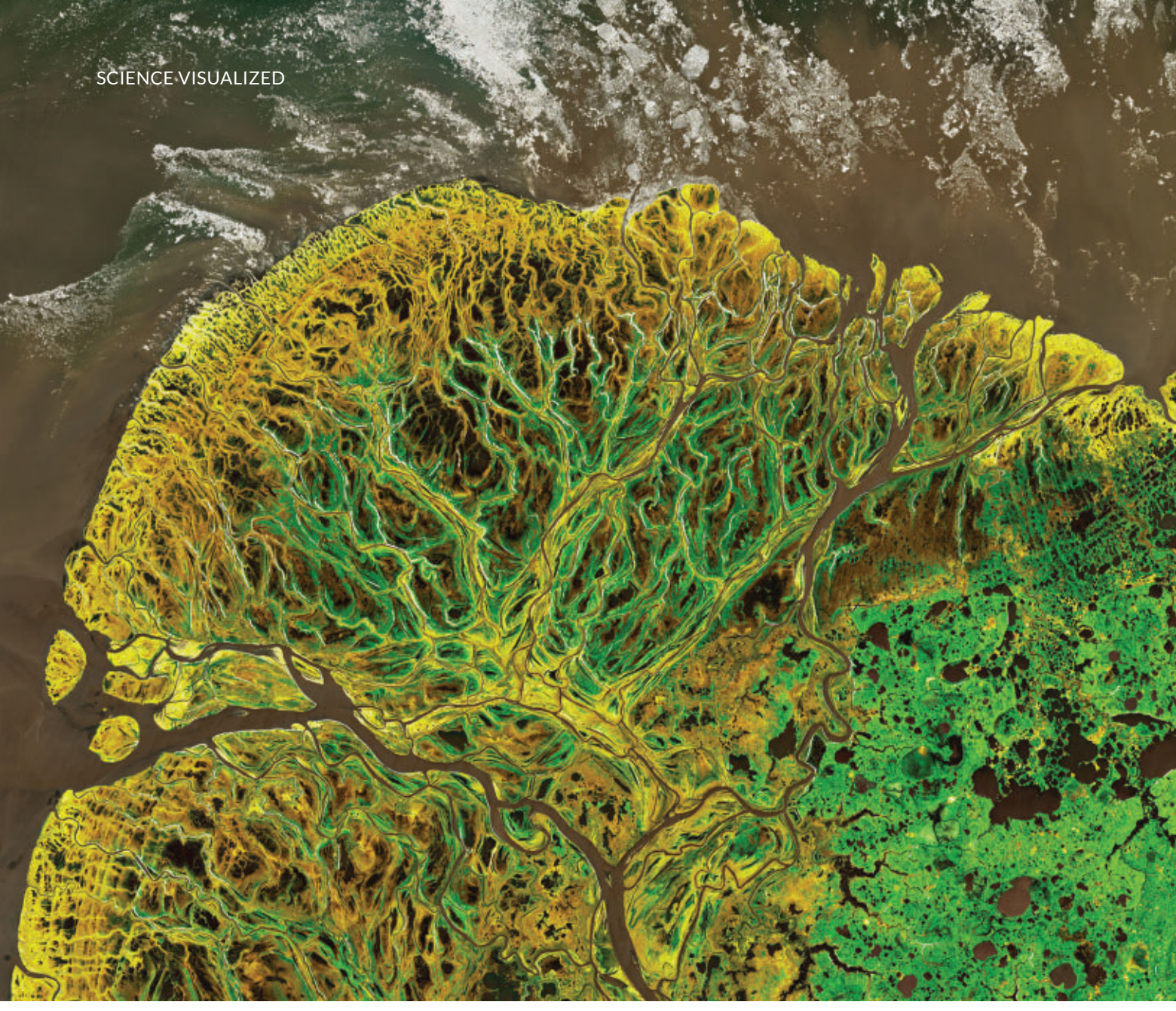
Reader **Norman Dolph** praised **Thompson's** reporting, which prompted him to reflect on his upbringing. "I was born in Tulsa in 1939. My father moved to Tulsa in 1929," **Dolph** wrote. Growing up, "nobody, neither my parents nor any other 'adult' Tulsan, went out of their way to mention this event to me until I was well into college. The event was a secret," he wrote. "Your enlightening research and rendering of the event is a mind-opener."

## Inked up

*Turkey leg bones found at an ancient Tennessee site are the oldest-known tattoo needles, **Bruce Bower** reported in "Ancient Native Americans turned turkey bones into tattooing tools" (SN: 6/19/21, p. 5).*

"How do we know the bones were used for tattooing?" reader **Gary S. Flom** asked. Perhaps the bones were for writing or drawing, **Flom** suggested.

The sharpened bones "show distinctive damage on and near their tips that has been previously observed on experimental tattooing tools," **Bower** says. "Pigment residue on the turkey bones also appears several millimeters from the tips, another feature of experimental tools used to create tattoos."



# Alaska's Yukon Delta is a land in transition

The westward journey of the mighty Yukon River takes it from its headwaters in Canada's British Columbia straight across Alaska. The river has many stories to tell, of generations of Indigenous people hunting on its banks and fishing in its waters, of paddle-wheeled boats and gold panning and pipelines.

Where it meets the Bering Sea, the river fans out into an intricate delta resembling cauliflower lobes of river channels and ponds. The delta has a story to tell too — that of an increasingly green Arctic.

In southern Alaska, such as in the Kenai Peninsula, the Arctic has been getting noticeably greener since the 1980s, as global temperatures climb (*SN: 4/13/19, p. 16*). Now, analyses of Yukon Delta vegetation reveal that more northern areas are getting greener too, researchers report June 1 in *Earth Interactions*. The increasing prevalence of tall willows is one sign of this change. A composite image of the delta's northern lobe (above), taken May 29 by the U.S. Geological Survey's Landsat 8 satellite, shows willow shrublands (colored green) lining river channels that wind toward the sea.

Farther inland, tussock grasses (also in green, at bottom right) carpet the tundra. Grasslike sedge meadows (colored yellow and light brown) populate low-lying wetlands, punctuated by ponds left behind by springtime floods along the riverbanks from snow and ice that have melted upstream.

For the Yukon and other Arctic deltas — where higher floodwaters due to climate change are likely to deposit thicker sediment piles, supporting more greenery — many more changes are likely to come as the planet warms.

*— Carolyn Gramling*

JOSHUA STEVENS/NASA EARTH OBSERVATORY, USGS

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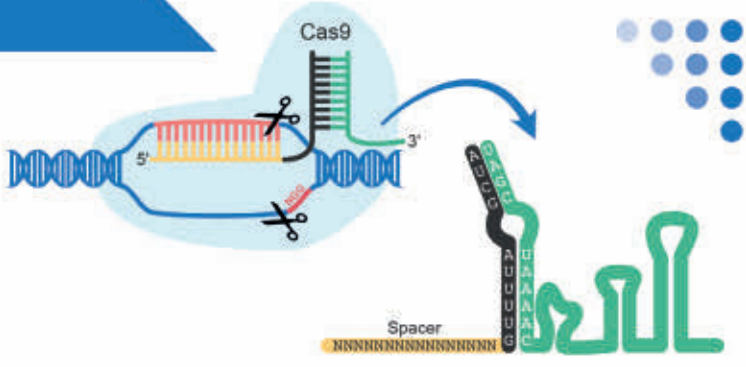


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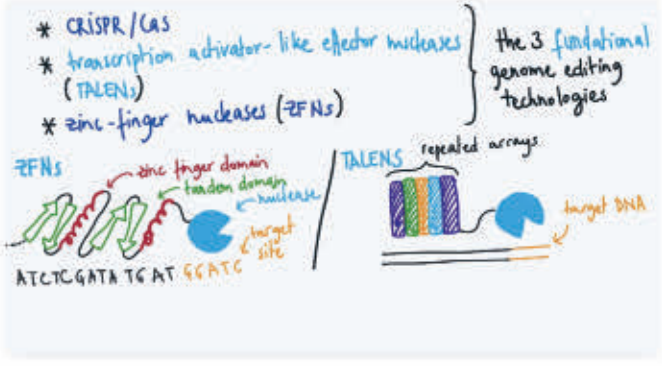


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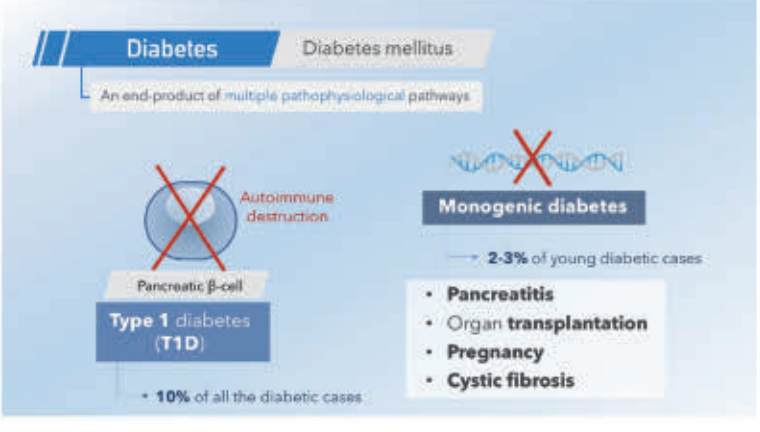


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