First Liquid Magnets | When Mammals Learned to Chew

Science News

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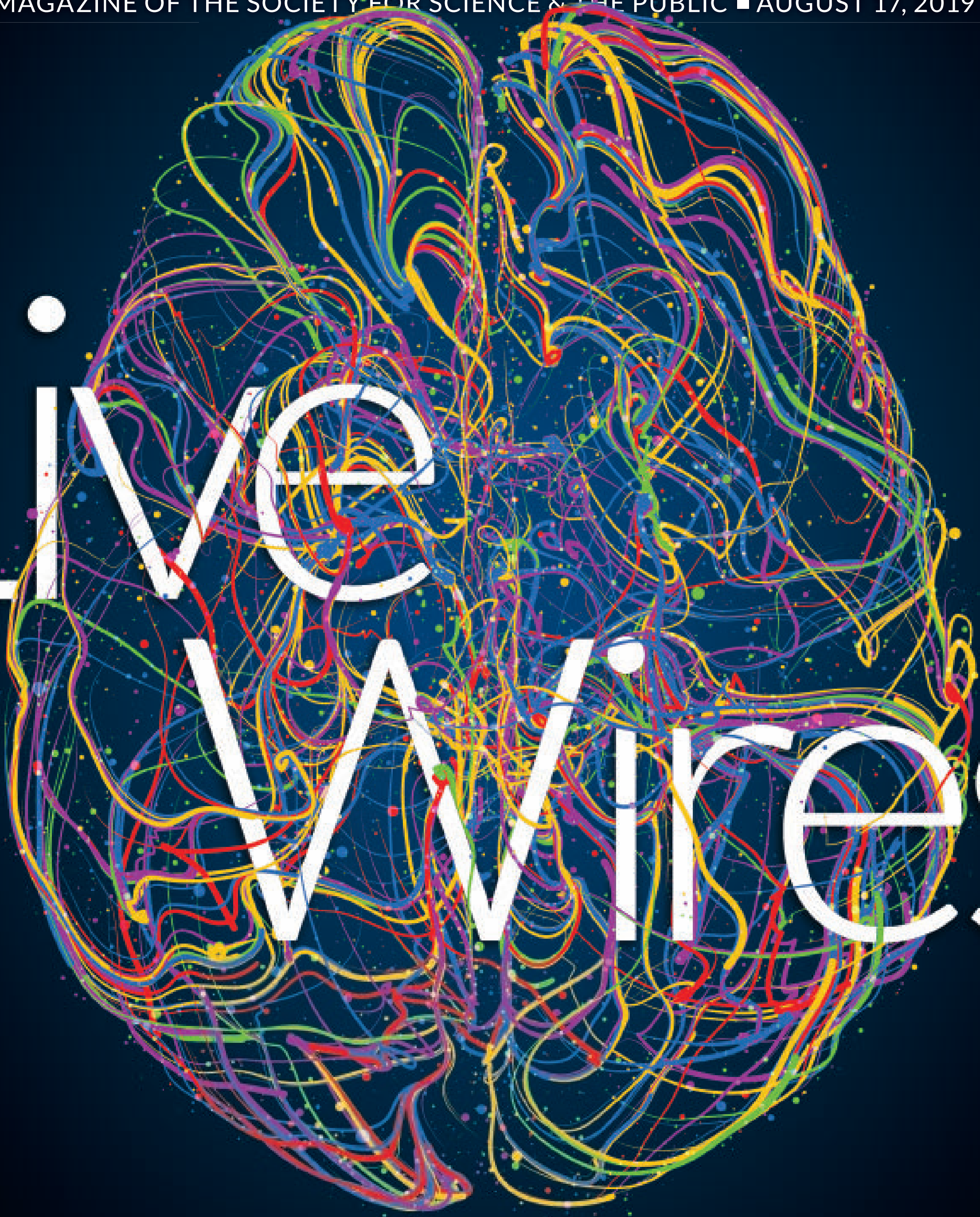

Live Wires

Untangling what makes our brains so powerful

DANIEL STEIGER

Aura Agate 24-Karat Gold Rim Coasters

These beautiful semi-precious naturally formed pieces have been elegantly crafted into beautiful decorative art to brighten up any home!

Naturally /Formed

Sometimes the best creations are formed through nature. This set of four aura agate coasters are created from sliced agate and have been hand crafted by artisans in Brazil. Agate is a naturally formed semi precious stone formed in nodules in volcanic rocks or ancient lavas.

Agate Value

As a semi-precious stones these distinctive, fine, or landscape-like color patterns can command prices into hundreds of dollars. Here at Daniel Steiger we have managed to obtain these rare pieces and can make this special offer for a limited time whilst our stocks last. The perfect gift that you'll want to keep for yourself.

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These coasters are unique! Each individual piece varing slightly in shape, size, color and pattern. They are hand crafted with gold trimming on the sides for an elegant look. You can use them as an art decorative piece or coasters in your home. I absolutely love how the colors bring out any room because each coaster is truly unique and different from the other.

Agate has historically been a symbol of both strength and good luck. Its physical properties embody the classic traits of strength, being long lasting and hard wearing. It has also been considered throughout the ages to bring luck and good fortune to any home it is placed in. The mesmerising shades of color display the majestic beauty of nature in all its creativity.

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News


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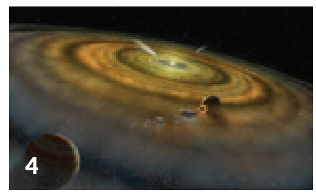
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Departments

COVER Studying the human brain's network of nerve cells in action may reveal how we think and feel. *GarryKillian/iStock/Getty Images Plus*

FROM TOP: YOON S. BYUN, BOSTON GLOBE/GETTY IMAGES; LYNNETTE COOK, FUSE/NASA; Q. WANG

Why this warmer world is not just a passing phase

In the late 1990s, three scientists published a paper charting the Earth's temperatures over the last millennium. For the first 900 years, the trend line was the definition of boring: just little blips up and down. That changed around 1900, when the mean global temperature shot up, and kept rising.

That now-famous trend line, dubbed "the hockey stick" because of its sharp upward slope, is so vivid that it has played a key role in two decades of argument over whether the Earth's atmosphere is warming, and whether those changes are caused by heat-trapping gases generated by human activities.

It's not hard to pick apart a single study's data. Critics of the hockey stick pointed to centuries-long temperature shifts such as the Medieval Climate Anomaly and the Little Ice Age to argue that anomalies in the 20th century were also short-term, natural shifts. Critics also noted the patchwork nature of the pre-1900 data, which didn't rely on direct measurements, and said there was no direct evidence that increased greenhouse gas emissions from the burning of fossil fuels was causing the current temperature rise.

Uncertainty is central to the enterprise of science. It's a rare day when a single study — or dozens, or hundreds — answers a question without a doubt. And because uncertainty almost always remains, scientists have to explain both quantitatively and qualitatively how uncertain they are. That's good science. But climate change naysayers used that uncertainty to say, "The scientists aren't sure." And it meant that when we journalists reported accurately on the science by noting uncertainty, we gave more ammunition to doubters.

Well, scientists are now sure. In 2013, the Intergovernmental Panel on Climate Change, an international consortium convened by the United Nations to evaluate the science of climate, released a report saying there was greater than 95 percent certainty that the substantial warming was due to human activities. And scientists are increasingly linking extreme weather events worldwide, from heat waves to hurricanes, to human-caused climate change (*SN: 1/19/19, p. 7*).

In this issue, we report on how the city of Boston is regularly flooding due to rising sea levels (Page 16). Freelancer Mary Caperton Morton explains how policy makers and scientists are racing to develop responses to keep the venerable city functioning as the water moves inland. And earth and climate writer Carolyn Gramling reports on a startling new study that lays to rest the argument that the warming we're experiencing is just another normal climate shift. This one is clearly different, the data show: Those earlier temperature fluctuations were regional; what's happening now is worldwide (Page 6).

Michael Mann, a climate scientist at Penn State who is one of the researchers who developed the hockey stick data chart, said back in 2005 that he thought that people wouldn't take climate change seriously until they saw it in their own backyards. People in Boston think they're seeing it, as do people in many other communities around the world who are bracing for more extreme heat, rainfall, drought and storms. Our charge at *Science News* is to continue to report on the science while chronicling humankind's responses, for good or ill.
— Nancy Shute, Editor in Chief

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SSP

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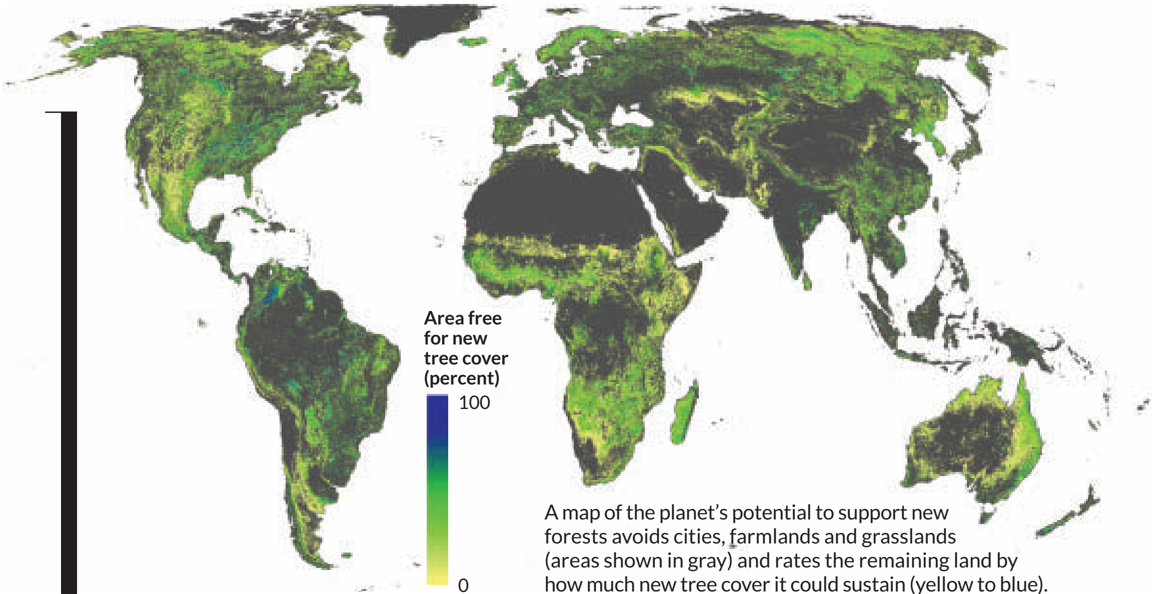
Excerpt from the August 16, 1969 issue of *Science News*

50 YEARS AGO

Bubbles for Batavia

Use by visitors is expected to be especially large at the National Accelerator Laboratory now under construction at Batavia, Ill.... NAL staff and consultants agree that the laboratory will need a large bubble chamber, and it now plans to build one in collaboration with Brookhaven National Laboratory.

UPDATE: NAL was renamed Fermilab in 1974 for physicist Enrico Fermi. The lab's first accelerator produced protons in April 1969, and was shooting subatomic particles into a 76-centimeter bubble chamber filled with liquid hydrogen by 1972. Such chambers track bubble trails left by speeding particles. The lab began upgrading to a 4.5-meter chamber detector in 1973, which helped in the study of neutrinos and turned up evidence for bottom and top quarks. As accelerators modernized, bubble detectors were phased out, and Fermilab's chamber became an art installation. But SNOLAB's bubble chamber in Sudbury, Canada, still searches for weakly interacting massive particles, or WIMPS — a proposed type of dark matter.



A map of the planet's potential to support new forests avoids cities, farmlands and grasslands (areas shown in gray) and rates the remaining land by how much new tree cover it could sustain (yellow to blue).

SCIENCE STATS

Planting forests can buy time to fight climate change

A whopping new estimate of the power of planting trees could rearrange to-do lists for fighting climate change.

Planting trees on 0.9 billion hectares of land could trap about two-thirds of the amount of carbon released by human activities since the start of the Industrial Revolution, a study finds. That's how much tree-friendly land is available on the planet for use. Reforesting these land patches, without knocking down cities or taking over farms or natural grasslands, could build up enough new tree cover to rival the area of the United States, researchers report in the July 5 *Science*.

The new calculation suggests tree planting could help gain time for other efforts to fight climate change, says Tom Crowther, an ecologist at ETH Zurich. Crowther and colleagues used satellite images to see how densely trees grow naturally in various ecosystems, and then extrapolated the amount of forest similar lands could support.

The new trees could capture 205 metric gigatons of carbon in about a century, the analysis shows. That's close to 10 times the carbon savings expected from managing refrigerants, the top climate-fighting strategy according to Project Drawdown, a worldwide nonprofit network of scientists and advocates proposing climate change solutions.

0.9 billion hectares

Total land on Earth suitable for new forests — roughly the area of the United States

But the benefit of tree planting will shrivel if people wait. Earth's climate could change enough by 2050 to shrink the places trees can grow by some 223 million hectares if humankind keeps emitting greenhouse gases as it does now, the analysis suggests.

Still, storing carbon is only one of the ways that trees affect climate, says Cat Scott, an atmospheric scientist at the University of Leeds in England who was not involved in the study. She and colleagues designed computer simulations that showed trees helping to cool a landscape by releasing airborne molecules that invite clouds to form. Meanwhile, even the darkness of tree leaves can change how much heat a landscape absorbs or reflects.

But just how such factors play off each other is not yet clear. Expanding forests into formerly snow-bright, reflective zones in the far north, for example, might warm these regions. But in the tropics, the enhanced cooling from clouds might be the more powerful effect.

Such heroic tree planting, however, "buys us time" in the climate fight, says coauthor Jean-François Bastin, also an ecologist at ETH Zurich. That's time nations can use to cut back greenhouse gas emissions, the real solution to climate change, he says. — *Susan Milius*

CROWTHER LAB/ETH ZURICH

FROM TOP: MELISSA ISHLER, SPECIMEN COLLECTED BY KIMBERLY FLEMING; LYNNETTE COOK, FUSE/NASA

RETHINK

Southern right whale moms and calves whisper in the shallows

Whales don't just belt out sounds in the deep. They also whisper — possibly to hide their location from predators.

Southern right whale (*Eubalaena australis*) moms steer their newborns to shallow waters, where calves are less likely to be picked off by an orca. There, crashing waves mask the quiet calls that a pair makes, researchers report online July 11 in the *Journal of Experimental Biology*.

Most of the whale calls we know about are long-range. "This shows us that whales have a sort of intimate communication" too, says behavioral biologist Mia Nielsen of Aarhus University in Denmark. "It's only meant for the whale right next to you."

Nielsen and colleagues tagged nine mama whales with audio recorders and motion sensors, and recorded ambient noise. When the whales were submerged below the noisy waves, the scientists picked up hushed calls, soft enough to fade into the background noise roughly 200 meters away.

The whispers occurred when the whales were moving, rather than when mothers were stationary, possibly suckling their calves. The whales also stayed within one adult body length of each another, maybe to avoid separation.

An orca "would have to get quite close in the big ocean to be able to detect them," says Peter Tyack, a biologist at the University of St. Andrews in Scotland not involved with the study. Biologists tend to focus on loud animal noises, but animals may have a repertoire "designed only to be audible to a partner who's close by," he says. *— Carolyn Wilke*

Once fungi invade an ant's jaw muscles, the insect spends the rest of its life with its jaws locked on a leaf or twig while the fungi take over (pictured).

MYSTERY SOLVED

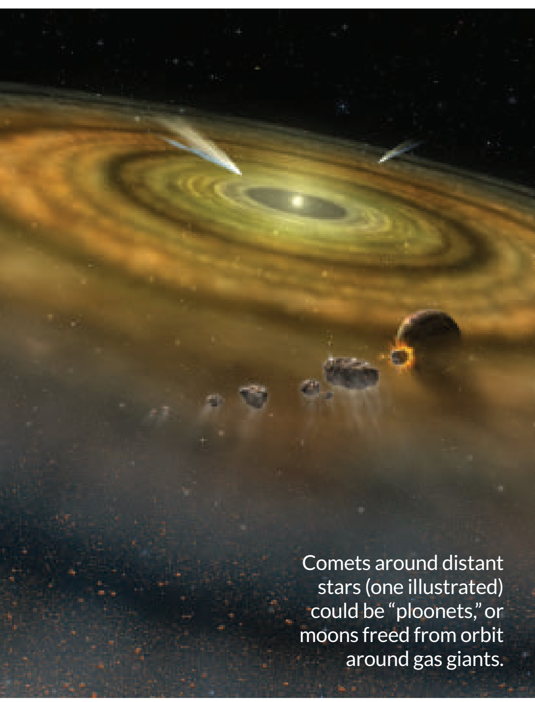
A fungus gives 'zombie' ants lockjaw

Fungus-infected "zombie" ants are known to scale a plant, sink their jaws into a leaf or twig and wait to die while the *Ophiocordyceps unilateralis* fungus feasts on their bodies. In time, a fungal stalk shoots out of the ant's head and releases spores that rain down and infect more ants below.

The ants' behavior may seem dictated by mind control, but the fungi don't colonize the brains. Instead, the fungi force jaw muscles to contract in a death grip, according to a study published online July 17 in the *Journal of Experimental Biology*.

In scanning electron microscopy images of jaw muscles in infected carpenter ants, the muscle fibers "appear really swollen," says molecular biologist Colleen Mangold of Penn State.

Exactly how the fungi induce the death grip is unclear, but the scientists may have a clue: Tiny particles resembling clusters of grapes appear on infected muscle fibers. Mangold and colleagues think these particles may contain molecules, produced by either the invader or the host, holding messages that influence the invasion or the ants' response. *— Carolyn Wilke*



Comets around distant stars (one illustrated) could be "ploonets," or moons freed from orbit around gas giants.

SAY WHAT?

Ploonet \ploo-neht\ n.

Planets of moonish origin

In other star systems, moons might escape their planets and start orbiting their stars instead. These liberated objects have been dubbed "ploonets."

These wayward worlds may be detectable by Earth's telescopes, though astronomers have yet to find any moons outside our solar system, let alone ploonets (*SN Online: 4/30/19*). Scientists simulated what would happen to any moon orbiting a gas giant like Jupiter that migrated from a more distant orbit to one scorchingly close to its star. During the migration, the combined gravitational forces of the planet and the star would inject energy into the moon's orbit, pushing it away from its planet until the moon finally escaped, the researchers report in a paper posted online June 27 at arXiv.org.

"This process should happen in every planetary system composed of a giant planet in a very close-in orbit," says coauthor Mario Sucerquia, an astrophysicist at the University of Antioquia in Medellín, Colombia. "So ploonets should be very frequent."

Some ploonets may be indistinguishable from ordinary planets. Others that stay close to their planet could speed or slow the planet's path, or transit, in front of the star. Ploonethood may be a relatively short-lived phenomenon, though. About half of the ploonets in the researchers' simulations crashed into either their planet or star within half a million years. *— Lisa Grossman*

News

EARTH & ENVIRONMENT

Current warming is unprecedented

Other climate shifts of the last 2,000 years were regional

BY CAROLYN GRAMLING

Temperatures across 98 percent of Earth's surface were hotter at the end of the 20th century than at any time in the previous 2,000 years.

Such nearly universal warming, occurring in lockstep across the planet, is unique to this era, scientists say. Other well-known cold and warm snaps of the past were in fact regional rather than worldwide.

What's more, the rate at which temperatures are increasing now far exceeds any previous temperature fluctuations measured in the last two millennia. Those are the conclusions of a trio of papers examining temperature trends over the last 2,000 years, published July 24 in *Nature* and *Nature Geoscience*. Those previous climate fluctuations were primarily driven by natural causes, rather than human-caused greenhouse gas emissions.

The findings, which are based on newly available global paleoclimate data, reinforce an inescapable conclusion, says Michael Mann, a climate scientist at Penn State who was not involved in the research: "The current period of warmth is unprecedented in its global scope in the last 2,000 years."

In the study in *Nature*, a team led by climate scientist Raphael Neukom of the University of Bern in Switzerland used many types of temperature records from around the world to create thousands of climate reconstructions of the last two millennia, from A.D. 1 to 2000. Those data were collected by an international group of scientists called the PAGES 2k Consortium. The data include proxies for temperatures that were derived from tree rings, ice cores, lake and ocean sediments, corals, cave deposits and historical documents.

Using those data plus climate simulations and direct measurements of temperature collected since the 1800s, the team produced over 15,000 climate reconstructions of global temperatures. Then the team looked at the precise timing of warming or cooling within four known "climate epochs" — the Roman Warm Period from A.D. 1 to 300, the Dark Ages Cold Period from 400 to 800, the Medieval Climate Anomaly from 800 to 1200 and the Little Ice Age from 1300 to 1850.

Though the same datasets informed all of the climate reproductions, the team used different methodologies, varying widely in computational complexity, to process the data and calculate past temperatures. Regardless of method, the story was the same: Past climate epochs were not simultaneous, global events.

The Little Ice Age cold snap, for instance, didn't occur everywhere at the same time, the analysis shows. Northwestern Europe and southeastern North America got their lowest temperatures during the 17th century, while the area encompassing the central and eastern Pacific Ocean were coldest during the 15th century.

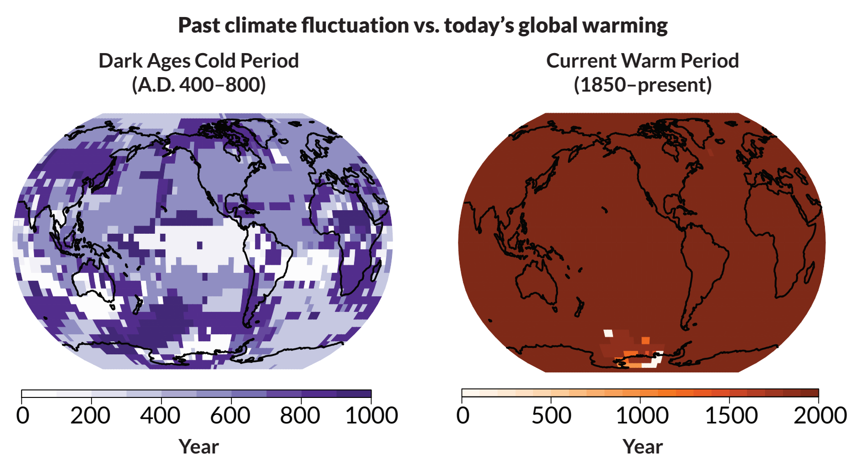
"The traditional understanding is that these [climate epochs] were global-scale phenomena," says study coauthor Nathan Steiger, a Columbia University climate scientist. "That's not the case."

In contrast, the current era of warming is occurring concurrently around the globe, with the highest temperatures found at the end of the 20th century. "It is coherent in a way we didn't experience over the last 2,000 years," Steiger says.

The study's temperature data go up to only 2000. But NASA and the National Oceanic and Atmospheric Administration reported in February that nine of the 10 warmest years on record occurred since 2005, and the last five years were the five hottest on record (*SN Online: 2/6/19*). Human activities have been repeatedly cited as the cause of these record-breaking global average temperatures (*SN Online: 7/2/19*).

A second study, published in *Nature Geoscience*, addresses the question of anthropogenic warming explicitly. The study, authored by Neukom and other members of the PAGES 2k Consortium, used the same temperature proxies as the study published in *Nature* but looked at the average global temperature through time.

Hot and cold Well-known climate fluctuations of the last 2,000 years were thought to be global, but new research shows they were regional. In each map, different colors represent the warmest or coldest century for a given location within the represented time frame. The Dark Ages Cold Period spanned about A.D. 400 to 800. But the lowest temperatures in the Pacific Ocean occurred several hundred years earlier (white to pale purple) and in other areas much later (darker purple). In contrast, for the current era of warming, temperatures were highest at the end of the 20th century for 98 percent of Earth.



R. NEUKOM ET AL/NATURE 2019

That analysis revealed that the current rate of warming is much faster than anything observed in the last 2,000 years that can be attributed to natural variability, Neukom said at a July 22 news conference. "It's another angle to look at the extraordinary nature of current warming."

A third study, also published in *Nature Geoscience*, adds another layer of context to the trends, looking at what natural forces may have shaped past climate epochs.

Led by University of Bern climate scientist Stefan Brönnimann, researchers found that before the mid-1800s, volcanoes were the main engine behind large-scale temperature fluctuations. For instance, five powerful eruptions, including the 1815 Mount Tambora eruption in Indonesia, occurred toward the end of the Little Ice Age, which began around 1300 and ended around 1850.

The eruptions initially led to cooling and climate upheaval, and then a period of recovery as the planet warmed up again. That recovery coincided with the onset of the Industrial Revolution, at which point greenhouse gases became the primary driver for warming, the researchers say.

The ideas that past climate epochs weren't global and that the rate of current warming is unprecedented aren't exactly new, Mann says. In 1998, he and colleagues reported a dramatic upward tick in temperatures at the end of the 20th century — a pattern that, when plotted through time, takes the shape of a hockey stick.

"It's gratifying that independent, international teams using entirely different approaches have come to virtually identical conclusions," Mann says.

Raymond Bradley, a climate scientist at the University of Massachusetts Amherst who coauthored that hockey stick study, agrees. The new studies are a valuable addition, with a "high quality, carefully screened set of data" and powerful simulations that can synthesize and reproduce those past temperatures. "They've done everything right," he says. ■

GENES & CELLS

Droplets could have kick-started life

Small blobs that break apart and re-form can host protein, RNA

BY CARMEN DRAHL

For the origin of life on Earth, ancient puddles or coastlines may have had a major ripple effect.

A new study shows that molecules of a simple type called alpha hydroxy acids form microdroplets when dried and rewetted, as could have taken place at the edges of water sources on an early Earth. These cell-sized compartments can trap RNA, and can merge and break apart. That's behavior that could have encouraged molecules in the primordial soup to give rise to life, researchers report online July 22 in the *Proceedings of the National Academy of Sciences*.

Besides giving clues to how life may have gotten started on the planet, the work might have additional implications for both medicine and the search for extraterrestrial life.

Present-day biology relies on cells to concentrate nutrients and protect genetic information, so many scientists think compartments could have been important for life to begin. But no one knows whether the first microenclosures on Earth were related to modern cells.

"The early Earth was certainly a messy place chemically," with simple molecules such as alpha hydroxy acids potentially having roles in the emergence of life alongside biomolecules like RNA and their precursors, says biochemist Tony Jia of Tokyo Institute of Technology's Earth-Life Science Institute.

Jia's team focused on mixtures of alpha hydroxy acids, some of which are common in cosmetics. Though not as prominent as their chemical relatives amino acids, alpha hydroxy acids are plausible players in origin-of-life happenings because they frequently show up in meteorites as well as in experiments mimicking early Earth chemistry.

In 2018, a team led by geochemists Kuhan Chandru and H. James Cleaves, both of the Earth-Life Science Institute, demonstrated that, just through drying, alpha hydroxy acids form repeating chains of molecules called polymers. In the new study, Chandru, Cleaves, Jia and colleagues found that rewetting the polymers leads to the formation of microdroplets about the same diameter as bacterial cells.

Previous studies have shown that simple molecules can form droplets (*SN: 4/15/17, p. 11*). The new work goes further, showing "that possibly prebiotically relevant molecules can form droplets," says artificial-cell expert Dora Tang of the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden, Germany.

"The early Earth was certainly a messy place chemically."

TONY JIA

In the lab, the researchers demonstrated that droplets could trap and host molecules essential to life, such as RNA. The team also observed that a protein retained its function within the droplets and that fatty acids could assemble around droplets.

Still, those findings don't mean microdroplets were Earth's first cells or ancestors of them, Chandru cautions. Instead, he says, the droplets could have helped along reactions in emerging biochemical systems in the lead-up to life.

Though the study's focus was on the origin of life, Jia points out that the microdroplets could potentially be engineered to deliver medications. The researchers note in their paper that they may submit a patent related to the work within the next year but did not specify an application.

The new research may also hold an important lesson for the search for extraterrestrial life. "We need to not only focus on detection of modern biomolecules and their precursors, but also other relevant nonbiomolecules" that, like alpha hydroxy acids, might have played supporting roles in the emergence of life, Jia says, on Earth or elsewhere. ■

LIFE & EVOLUTION

Chewing goes way back in mammals

Flexible hyoid bones may have helped the animals diversify

BY CAROLYN GRAMLING

Chew on this: Millions of years before the emergence of true mammals, an early relative had a flexible, saddle-shaped complex of bones connected to the jaw that was thought to belong to mammals alone. Those bones, scientists say, help all mammals chew and swallow, and ultimately was one secret to mammals' success.

That relative: *Microdocodon gracilis*, which lived about 165 million years ago in what's now China. While examining a fossil of the shrew-sized species, scientists led by vertebrate paleontologist Chang-Fu Zhou of the Paleontological Museum of Liaoning in Shenyang, China, found a hyoid that looks like modern mammals' hyoid, the team says in the July 19 *Science*.

When it comes to food, mammals have staked claims across many environments.

A fossil of the shrew-sized mammal relative *Microdocodon gracilis*, which lived roughly 165 million years ago, preserves a modern-looking hyoid (arrow), which is important for chewing.

But chewing is one thing all mammals have in common. That's unlike, say, reptiles, which tend to swallow food whole. "The food transport and the swallowing of the chewed-up food is all controlled by muscle related to this highly mobile bone," says vertebrate paleontologist Zhe-Xi Luo of the University of Chicago.

All jawed vertebrates have a hyoid, but the mammalian hyoid is uniquely mobile. Luo likens it to a backyard swing. The hyoid "can bend and is flexible, like a kid swinging back and forth," he says.

Whether the evolution of a flexible hyoid predated true mammals or came later was unknown. Enter *M. gracilis*. The species was a mammaliaform, a group that includes modern mammals and their closest extinct relatives. *M. gracilis* represents a key stage between primitive ancestors with a rigid hyoid and the later burst of mammalian diversity that began 65 million years ago. By then, mammals had the mobile hyoid.

The fossil is the first mammaliaform from the Jurassic Period, 201 million to 145 million years ago, with a well-preserved hyoid. "Once we knew what to look for, we started to search for corroboration of similar structures in other

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BODY & BRAIN

Gut microbes may play a role in ALS

Bacteria that make vitamin B3 improved symptoms in mice

BY TINA HESMAN SAEY

A friendly gut bacterium can help lessen ALS symptoms, a study of mice suggests.

Mice that develop a degenerative nerve disease similar to ALS — amyotrophic lateral sclerosis, or Lou Gehrig's disease — fared better when bacteria making vitamin B3 were living in their intestines, researchers report online July 22 in *Nature*. Those results suggest that the gut microbes make molecules that can slow disease progression.

The results may be important for people with ALS but are too preliminary to inform any changes in treating the disease, says microbiome researcher Eran Elinav of the Weizmann Institute of Science in Rehovot, Israel. "With respect to ALS, the jury is still out," he says. "We have to prove that what we found in mice is reproducibly found in humans."

At any given time ALS affects about 5 in every 100,000 people, or about 19,000 people in the United States.

Elinav and colleagues examined the gut microbiomes — the microbes that live in the large intestine — of mice that produce large amounts of a mutated form of SOD1 protein. In the mice, as in ALS patients, faulty SOD1 proteins clump together and lead to nerve cell death.

Microbiomes of ALS mice had almost no *Akkermansia muciniphila* bacteria. Restoring *A. muciniphila* in ALS mice slowed disease progression, and mice lived longer than untreated mice.

Akkermansia has a mixed record when it comes to human health. It's been linked to protecting against type 2 diabetes that comes with aging (*SN: 12/22/18, p. 14*), lowering cholesterol levels in the blood and relieving inflammatory bowel disease symptoms. But studies of Alzheimer's dementia, Parkinson's disease and multiple sclerosis (*SN: 12/9/17, p. 20*) have associated increased *Akkermansia* with worse symptoms, says microbiologist Brett Finlay of the University of British Columbia in Vancouver. "So I was surprised to see a beneficial effect of *Akkermansia* in a brain disease."

Elinav's team investigated what *Akkermansia* does to relieve symptoms that hamper a mouse's ability, for example, to grip a wire. The team focused on metabolites the bacteria produce, including B3.

Giving nicotinamide, a water soluble form of B3 found in foods and dietary

Z.-X. LUO/UNIV. OF CHICAGO

extinct mammal lineages," Luo says. "We found them left and right."

Given that the structure was common among Jurassic mammaliaforms, the hyoid may have been important to mammals' ability to diversify. "Mammals just chewed and swallowed themselves into evolutionary success," Luo says.

The findings also hint that a mobile hyoid predates another mammal trait: the evolution of the three middle ear bones and their separation from the jaw. Those bones enable sharp hearing. Some scientists suspected the bones' separation led to evolution of the mobile hyoid. The new evidence suggests that these two adaptations weren't directly related.

That aspect of the discovery was particularly interesting, says vertebrate paleontologist Simone Hoffmann of the New York Institute of Technology in Old Westbury. "The hyoid is used for chewing, but also for suckling milk," says Hoffmann, who coauthored a commentary in the same issue of *Science*. This fossil "suggests the hyoid bone may have developed way before mammals themselves. It might change our understanding of what attributes we typically think of as mammal attributes." ■

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supplements, to ALS mice improved some symptoms. But unlike mice with boosted *Akkermansia* numbers, the vitamin-supplemented mice didn't live longer than untreated mice. That finding may mean that the bacteria make other substances or work with other microbes to affect symptoms, says Jun Sun, a medical microbiologist at the University of Illinois in Chicago. "Usually you don't expect one miracle metabolite can rescue the mice completely."

Elinav's group also looked at whether *Akkermansia* may play a role in human ALS. In a small study of 37 ALS patients and 29 healthy family members, people with ALS had lower levels of *Akkermansia* in their stool. Levels of nicotinamide in ALS patients' blood and cerebrospinal fluid were also lower. The lower the levels of nicotinamide in the blood, the more severe the patient's symptoms. ■

Q. WANG

HUMANS & SOCIETY

Ancient reshaped skulls found in China

Fossils may be some of the oldest examples of the practice

BY BRUCE BOWER

Tombs in China have produced what may be some of the oldest known human skulls that were intentionally reshaped.

At a site called Houtaomuga, scientists found 25 skeletons dating from about 12,000 to 5,000 years ago. Eleven had artificially elongated braincases and flattened bones at the front and back of the head, the researchers report in the August issue of the *American Journal of Physical Anthropology*. Skull modification occurred over a longer stretch of time there than at any other site, the team says.

Permanent reshaping of a skull early in life, when the bones are soft, can be achieved by compressing an infant's head with one's hands. Binding the head with hard, flat surfaces or tightly wrapping the head in cloth also remodel the bones. Specific head modifications may have been signs of social status.

Intentionally modified skulls have been found in many parts of the world. The earliest signs of cranial modification date to between about 13,000 and 10,000 years ago in western Asia, southeastern Australia and, now, East Asia.

"It is too early to tell whether intentional cranial modification first emerged in East Asia and spread elsewhere or originated independently in different places," says paleoanthropologist Qian Wang of Texas A&M University in Dallas.

Radiocarbon dating puts one man's modified skull at about 12,000 years old. Two sediment layers dating to between 6,300 and 5,000 years old contained the other 10 reshaped skulls at Houtaomuga.

The site holds clues that reshaping was reserved for high-status individuals or certain families, Wang, bioarchaeologist Quanchao Zhang of Jilin University in Changchun, China, and colleagues report. A 3-year-old with a reshaped braincase was buried with a lot of pottery and other artifacts, suggesting that the youngster came from a rich family. Numerous shell ornaments placed on a woman with an

Intentionally modified human skulls discovered at Chinese archaeological sites include this roughly 6,000-year-old skull from a child.

elongated skull probably denoted her high status. An adult and adolescent with modified skulls were buried together, perhaps because the two were family.

While those individuals clearly had modified skulls, the oldest skull has a slightly elongated braincase that probably wasn't modified, says Xijun Ni, a paleoanthropologist at the Chinese Academy of Sciences in Beijing. That cranial shape characterizes some Asians today, Ni contends. The tops of such skulls often include a slight depression near the back, as on the 12,000-year-old skull, he adds. Wang disagrees. The extent of bone flattening on the braincase exceeds any naturally occurring variations, he argues.

A human skull discovered by workers at an underwater sand mine in China displays intentionally flattened bones, Ni and colleagues reported January 26 at bioRxiv.org. Radiocarbon dating indicates the skull is about 11,200 years old.

Chinese findings expand the known distribution of ancient skull reshaping, says archaeologist Maria Mednikova of the Russian Academy of Sciences in Moscow. Unlike Ni, Mednikova thinks the oldest Houtaomuga skull was intentionally remodeled. The latest report "on cranial deformations in China draws a picture of an entrenched tradition that continued for millennia." ■

GENES & CELLS

Longevity gene comes with trade-offs

TCER-1 may help nematodes live longer but not healthier

BY TINA HESMAN SAEY

Long life and good health don't always go hand in hand.

A gene that lengthens nematodes' lives and is necessary for reproduction also makes the worms more susceptible to infection and stress, researchers report July 17 in *Nature Communications*. That's unusual. Longevity-promoting genes generally help organisms deal with stress, says Arjumand Ghazi, a geneticist at the University of Pittsburgh.

Ghazi and colleagues had previously found that the gene *TCER-1* increases life span and is needed for *Caenorhabditis elegans* worms to make eggs and healthy offspring. The researchers expected that deleting the gene would make worms prone to infection. Instead, worms missing *TCER-1* fought off an infection for nearly twice as long as worms with the gene, says Francis Amrit, a molecular biologist in Ghazi's lab.

In nematodes, a protein called TCER-1 (green in a microscope image of a worm's gut and reproductive cells) helps strike a balance between immunity, fertility and longevity.

The team also found that worms that made more TCER-1 protein than usual overcame fertility declines caused by exposure to a pathogen but succumbed to infection faster. When functioning normally, the gene appears to suppress immune responses so more resources can be used for reproduction.

"In a lot of ways, reproduction and longevity are opposite one another, and this is underscored by these findings," says Coleen Murphy, a biologist at Princeton University.

Worms missing *TCER-1* were also resistant to stressors such as heat and radiation. Those advantages continued only as long as worms were of egg-laying age. Older worms were equally susceptible to infection or stress regardless of whether they had the gene. Together, the results indicate that *TCER-1* helps regulate survival — balancing stress responses, reproduction and life span, Amrit says.

TCER-1 protein works with other proteins to achieve that balance, the study found. But details of how the protein senses stress and regulates fertility, longevity and stress responses are unknown.

People have a version of *TCER-1*, but the work is unlikely to affect human health any time soon. The findings do offer a warning about antiaging therapies, says aging researcher Shin-Ichiro Imai of Washington University School of Medicine in St. Louis. Even antiaging therapies that seem to work well may lead to unexpected frailty. ■

BODY & BRAIN

Lasers make mice hallucinate

Scientists manipulate neurons to create a visual perception

BY LAURA SANDERS

Aiming lasers into the brain can make a mouse "see" lines that aren't there. The feat, described online July 18 in *Science*, is the first time a specific visual perception has been made with lab trickery.

The work is "technically amazing," says neuroscientist and psychiatrist Conor Liston of Weill Cornell Medicine in New York City. The ability to monitor and control precise collections of nerve cells, or neurons, could help unravel big questions, including how certain groups of neurons create experiences.

The study used optogenetics, in which laser light activates neurons in the brain. The neurons are genetically tweaked to carry a protein that prompts them to send a signal in response to the light.

When optogenetics debuted about 15 years ago, everyone was hoping to achieve this level of precise control over perception, says neuroscientist and psychiatrist Karl Deisseroth, who helped pioneer the technique. "It's exciting to get to this point," says Deisseroth, a Howard Hughes Medical Institute investigator at Stanford University.

Deisseroth and colleagues monitored neurons in mice that were viewing either horizontal or vertical lines. Each mouse was trained to lick water from a spout when the mouse saw the orientation of lines it was trained on. The team then set out to artificially evoke the vision of the lines. Initially, mice were shown faint real lines. When the lines became so faint that mice floundered, optogenetic stimulation via laser improved their performance.

Then the team tested the mice in total darkness, with no visual input whatsoever, and found that a perception of the lines could be created solely with lasers. Stimulating about 20 of the neurons that responded to the real sight caused mice to "see" the right vision, and lick as a result.

Artificially stimulated neurons kicked off cascades of other neurons firing in a way that suggested that the visual part of the brain was responding as it normally would to a sight.

Two key advances led to the experiment's success, Deisseroth says: Precise lasers that were carefully controlled by liquid crystals and the discovery of a new light-responsive protein, called ChRmine. Even dim lasers can activate this protein, a helpful trait because too much light can damage the brain.

Similar approaches could let scientists create other perceptions, such as smells and touches, Deisseroth says. The method could even be applied to complex tasks such as memory, Liston adds. ■

F. AMRIT AND A. GHAZI/UNIV. OF PITTSBURGH

ATOM & COSMOS

Source of gaps in stellar disks debated

Rings in the gas around stars may not point to developing planets

BY LISA GROSSMAN

The photo album of baby planets may be emptier than astronomers thought.

New research is prompting debate about the theory that gaps in planet-forming disks around young stars mark where planets are forming. Planets that simulations suggest would grow in these gaps don't resemble the full-grown planets observed around more mature stars.

So maybe the gaps don't point to the formation of planets — or at least, not the most common kinds of planets that telescopes can see. "The question we raised, and we put it boldly, is whether those gaps in rings are really caused by planets or … by other things," says astrophysicist Nelson Ndugu of Mbarara University of Science and Technology in Uganda. "Right now, it is too early to take a side."

Planet formation is thought to start with a cloud of gas and dust, which collapses into a star surrounded by a rotating disk (*SN: 5/12/18, p. 28*). Gravity draws the gas and dust into pebble-sized clumps, which cluster into boulders. Eventually boulders grow large and gravitationally powerful enough to hoover up nearby gas, growing into gas giants. The whole process should take about 10 million years to build a Jupiter, for example, theoretical models find.

In 2014, astronomers got what looked like their first glimpse of the process in action. The Atacama Large Millimeter/submillimeter Array in Chile, or ALMA, snapped a shot of the star HL Tau, about 450 light-years from Earth in the Taurus constellation, that showed a disk interrupted by dark gaps (*SN: 11/29/14, p. 32*).

Scientists attributed the gaps to newborn planets that scooped up disk gas as they grew. Then in 2018, astronomers reported the first infant planet spotted in a disk gap, around the star PDS 70, about 370 light-years away in the Centaurus constellation (*SN: 8/4/18, p. 5*). Later observations found a second planet orbiting the star.

Trouble is, the planets orbiting PDS 70 are still the only examples. And the theory didn't quite fit for HL Tau: The star was only 1 million years old, too young to have gotten so far in forming planets.

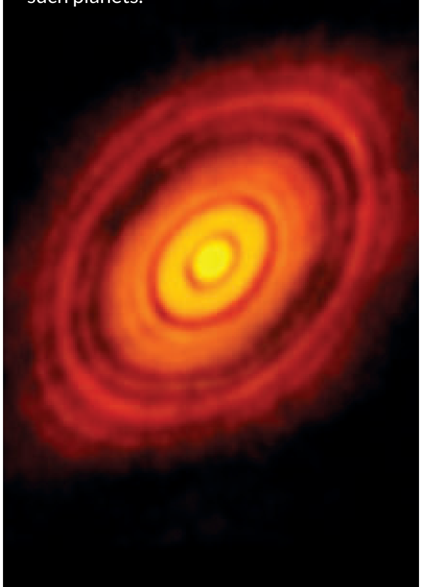
"It didn't really make sense," says astrophysicist Nienke van der Marel of the Herzberg Institute for Astrophysics in Victoria, Canada. In February in the *Astrophysical Journal*, she and colleagues published a survey of 16 other protoplanetary disks, with ages from less than half a million years to more than 10 million. All of the disks had gaps and rings.

"That is hard to explain if it's caused by planets," she says. If all the gaps mark spots of planet formation, that would mean "planets must form extremely fast."

Even if planets were responsible for all the gaps, things still don't add up, Ndugu and colleagues argue in a paper posted online June 27 at arXiv.org. The team ran computer simulations of planets growing up and compared the resulting protoplanetary disks with ALMA observations of 20 real-life disks from a 2018 survey called DSHARP.

"We took this [survey] as a middle step for our formation simulations to see what actually happens," says astrophysicist Bertram Bitsch of the Max Planck Institute for Astronomy in Heidelberg, Germany. The team then let the simulations run until the disk was gone, either coalesced into planets or blown away by the star's radiation.

Rings that break up the planet-forming disk around the star HL Tau were thought to be sculpted by planets growing inside the gaps. But HL Tau is too young to have such planets.



ALMA/ESO, NAOJ AND NRAO

The results deviated from observations. First, the simulations suggested that the outer reaches of disks needed about 2,000 times Earth's mass in pebbles to grow planets that could open up the observed gaps. But most disks don't have that much material in their outer reaches.

Assuming the gaps in the DSHARP disks were due to planets, the simulations indicated those planets would have grown into gas giants orbiting at least as far from their stars as Uranus does from the sun. Such planets should be bright enough for telescopes to find, but out of the more than 4,000 mature exoplanets discovered to date, only a few are such distant gas giants. "We predict a certain population of planets which would be observable, but we don't see them," Bitsch says.

It's possible, of course, that the studied disks are exceptions to the rule. The DSHARP images focused on the biggest, brightest disks because they are easiest to spot, says survey team member Jane Huang of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass. Comparing those disks' potential planets with the entire exoplanet population is not a fair comparison, she says.

Astronomers are also looking for other ways that gaps might be made in a disk. "Maybe there's some exotic physics going on in the disks that doesn't require planets," van der Marel says. Her study ruled out one theory: that gaps represent "snow lines" around a star where various chemical elements condense from a gas to a solid. But there are still options involving magnetic fields, drifting currents or gravitational weirdness.

Those more exotic possibilities can't explain gaps in every disk, though. It's not even clear those processes always happen in disks. So the planet-building theory of gaps, for all its shortcomings, may still be the best bet. "One of the advantages of the planet explanation," Huang says, "is that we know planets exist." ■

MATTER & ENERGY

Stable liquid magnets become a reality

Droplets could prove useful in robotics, medicine and more

BY MARIA TEMMING

The rules about what makes a good magnet may not be as rigid as once thought. Using a mixture containing magnetic nanoparticles, researchers have made liquid droplets that behave like bar magnets.

The magnets, described in the July 19 *Science*, could be used to build soft robots or capsules that can be magnetically steered through the body to deliver drugs.

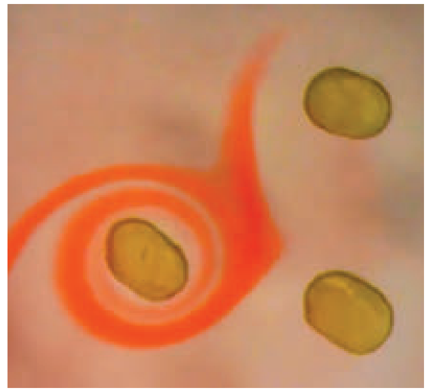
Magnets that generate persistent magnetic fields typically are composed of solids like iron, where the magnetic poles of densely packed atoms are all locked in the same direction. Though some liquids containing magnetic particles can become magnetized when put in a magnetic field, the magnetic orientations of those free-floating particles tend to get jumbled when the field goes away, causing the liquid to lose its magnetism.

Adding certain polymers to the recipe has now resulted in permanently magnetized liquid droplets. Researchers submerged millimeter-sized droplets of a watery solution containing iron oxide nanoparticles in oil peppered with polymers. Those polymers drew many of the magnetic nanoparticles to the droplets' surfaces and pinned them there, forming a densely packed shell of nanoparticles around each particle-rich droplet.

Exposing a droplet to a magnetic field forced the magnetic poles of the nanoparticles to point in the same direction. Nanoparticles on the droplet's surface were crowded so closely that when the magnetic field was shut off, the magnetic orientations could not lose alignment.

The collective magnetism of the surface particles is strong enough to keep free-floating nanoparticles in the rest of the droplet in line. "So the whole droplet behaves like a solid magnet," says coauthor Xubo Liu, a materials scientist at Beijing University of Chemical Technology.

Liquid magnets could help soft robots get around, says Rémi Dreyfus, a chemical physicist with the French national research agency CNRS who is currently at a joint CNRS–Solvay–University of Pennsylvania lab in Bristol, Pa. Rather than relying on inflatable air pouches or electric current to move — which tether robots to wires or tubes — bots injected with liquid magnetic material could be remotely controlled with magnetic fields.



Under the influence of a rotating magnetic field, magnetized liquid droplets (yellow) twirl in oil, wrapping themselves in orange dye.

X. LIU ET AL/SCIENCE 2019

Droplets might also be combined to make new kinds of materials, such as magnetic sponges or stretchy polymers, says Dreyfus, who wrote a commentary on the study in the same issue of *Science*. "I'm sure people will have many ideas." ■

MATH & TECHNOLOGY

AI card shark conquers poker

Algorithm named Pluribus beats pros in multiplayer games

BY MARIA TEMMING

Artificial intelligence has passed the last major milestone in mastering poker: An AI dubbed Pluribus has outplayed more than a dozen elite professionals at six-player no-limit Texas Hold'em, scientists report online July 11 in *Science*.

Games like poker, with hidden cards and players who bluff, present a greater challenge to AI than games in which every player can see the whole board. Computers have aced one-on-one poker, but multiplayer games take that complexity to the next level. Algorithms that can plot against several adversaries using spotty info could be good negotiators, political strategists or cybersecurity watchdogs.

Pluribus first honed its strategy by playing against copies of itself, starting with random moves and learning which actions helped to win. The AI used that intuition for when to hold and when to fold during the first betting round of each hand against five human players.

During subsequent betting rounds, Pluribus fine-tuned its strategy by imagining how the game might play out if it took different actions. Unlike AI trained for two-player poker (*SN: 4/1/17, p. 12*), Pluribus didn't speculate all the way to the end of the game, which would require too many computations. Instead, the AI imagined several moves ahead and decided what to do based on those hypothetical futures and different strategies that players could adopt.

In each of 10,000 hands of the game, Pluribus competed against five contestants from a pool of 13 professionals. Every 100 hands, Pluribus raked in, on average, about $480 from competitors.

"This is roughly the amount that elite human professionals aspire to beat weaker players by," implying that the AI was savvier than its opponents, says one of Pluribus' creators, Noam Brown of Facebook AI Research in New York City.

Now that AI has poker in the bag, the strategic reasoning of algorithms could be tested in games with more complex hidden information, says computer scientist Viliam Lisý of the Czech Technical University in Prague. In games such as kriegspiel, a chess spin-off where players can't see each other's pieces, the unknowns can become far more complicated than a few cards held close to the chest, Lisý says. ■

BODY & BRAIN

Botox may relieve pelvic pain associated with endometriosis

For some women with endometriosis, the pain doesn't stop after surgery and hormonal treatments. Pain can persist, triggered by muscle spasms that ripple through the pelvic floor. Now, a small study suggests that Botox, best known for smoothing wrinkles, could quell spasms.

Thirteen women diagnosed with the disorder, in which tissue similar to the uterus lining grows elsewhere in the body, had the botulinum toxin injected into their pelvic floor muscles.

All of the women, ages 21 to 51, reported a reduction in pain four to eight weeks after treatment. Eleven rated their pain as mild or completely gone, researchers at the National Institutes of Health in Bethesda, Md., report online July 8 in *Regional Anesthesia & Pain Medicine*. Relief lasted from five to 11 months in seven of the 11 women followed for up to a year.

Before the study, participants had had surgery to remove lesions and hormone treatments, but pain persisted.

Botulinum toxin is produced by the microbe that causes the food poisoning illness botulism. As Botox, the toxin is used to calm overactive muscles in neck spasms and bladder conditions.

Larger studies that compare the treatment with a placebo are necessary to evaluate how safe and effective the treatment is. *— Aimee Cunningham*

ATOM & COSMOS

Hayabusa2 makes second grab for pieces of an asteroid

The Hayabusa2 spacecraft has made its second and final attempt to grab a pinch of dust from asteroid Ryugu. On July 10, the Japanese spacecraft briefly touched down near an artificial crater that it had previously blasted into the 4.5-billion-year-old asteroid's surface. If all went well, the spacecraft is the first to collect a sample from an asteroid's interior.

Hayabusa2 made its first contact with Ryugu in February in a seemingly successful data grab. The spacecraft fired a bullet at close range into the surface to kick up and collect dust (*SN: 1/19/19, p. 20*).

To grab deeper material, the spacecraft dropped a two-kilogram cylinder onto the surface in April to blast an artificial crater about 10 meters wide and 2 meters deep.

The Japanese space agency aimed Hayabusa2 at an area about 20 meters north of the crater's center, where material from the crater appeared to land. After reaching the surface, Hayabusa2 briefly tapped the targeted spot and fired another bullet, creating a spray of pebbles.

Hayabusa2 will leave Ryugu late this year and is expected to arrive back at Earth in 2020. Studying any material collected from the asteroid may let scientists tease out details of the asteroid's history and the early history of the solar system (*SN: 4/13/19, p. 11*). *— Lisa Grossman*

After blasting a crater into the asteroid Ryugu, the Hayabusa2 spacecraft touched down about 20 meters away to gather some of the debris.

EARTH & ENVIRONMENT

U.S. wells are pumping up water from increasing depths

Residential, agricultural and industrial wells are being dug deeper and deeper in search of freshwater, according to the first nationwide assessment of U.S. groundwater wells. But scientists warn that the practice is not a sustainable way to address future water needs.

In the United States, groundwater provides drinking water to more than 120 million people and supplies nearly half of the country's water for crop irrigation. But water levels are dropping in many major aquifers.

Digging deeper wells is one response. To learn how widespread that practice is, water resources engineer Debra Perrone and hydrologist Scott Jasechko, both of the University of California, Santa Barbara, compiled data on about 11.8 million wells drilled from 1950 to 2015. During that time, wells got deeper across 79 percent of the country, the team says July 22 in *Nature Sustainability*.

Relative to a shallow well, sinking a deeper well is more expensive and requires more energy to pump the water out. Deeper wells can also tap into saltier water, requiring desalination. Less-wealthy areas may struggle to keep up with the race to reach and treat water pumped from greater depths, the researchers warn. *— Carolyn Gramling*

MATTER & ENERGY

Increased control over ion motions may improve quantum computers

Physicists are taking their quantum powers to the next level — the next energy level, that is.

Researchers have controlled the motion of a trapped ion, an electrically charged atom, better than ever before, manipulating the energy level of the ion's oscillation within an electromagnetic field. A single ion of beryllium, trapped by electromagnetic fields, was made to oscillate according to scientists' bidding, the team reports online July 22 in *Nature*.

In quantum mechanics, energy comes in discrete amounts, packets known as quanta. Using lasers to tweak the ion's energy, physicist Katie McCormick of the University of Washington in Seattle and colleagues set the ion oscillating within the electromagnetic field that confined it, with any number of quanta up to 100, breaking previously published records of about 17 quanta.

The researchers also put the ion in a superposition, in which the ion is simultaneously in two energy states at once, making it ultrasensitive to any stray electromagnetic fields. The larger the difference in the two energy levels of the superposition, the more sensitive the ion is. The team put the ion in a superposition between a state with no quanta of energy and one with 18. Such ions could be used as precise sensors to locate electromagnetic fields.

The newly demonstrated prowess with ions could also be used to build better quantum computers. Some quantum computers store and process information via ions confined in traps, with lasers used to perform operations on the quantum data. *— Emily Conover*

JAXA

Boston is taking action to adapt to sea level rise

By Mary Caperton Morton

Bostonians are getting used to flooding. Morrissey Boulevard (shown), near the campus of University of Massachusetts Boston, gets hit several times a year during high tides.

Boston dodged a disaster in 2012. After Hurricane Sandy devastated parts of New Jersey and New York, the superstorm hit Boston near low tide, causing minimal damage. If Sandy had arrived four hours earlier, many Bostonians would have been ankle to hip deep in seawater.

Across the globe, sea levels are rising, delivering bigger storm surges and higher tides to coastal cities. In Boston, the most persistent reminder comes in the form of regular "nuisance" flooding — when seawater spills onto roads and sidewalks during high tides. Those nuisance events are harbingers of a wetter future, when extreme high tides are predicted to become a daily occurrence.

"The East Coast has been riding a post-Sandy mentality of preparing and responding before the next big one," says Robert Freudenberg, an environmental planner at the Regional Plan Association, an urban research and advocacy firm based in New York City. But a more enduring kind of threat looms. "Sea level rise is the flooding that doesn't go away," he says. "Not that far in the future, some of our most developed places may be permanently inundated."

And Boston, for one, is not waiting to get disastrously wet to act. In the seven years since Hurricane Sandy's close call, the city-run Climate Ready Boston initiative has devised a comprehensive, science-driven master plan to protect infrastructure, property and people from the increasingly inevitable future of storm surges and rising seas. The famously feisty city intends to be ready for the next Sandy as well as the nuisance tides that promise to become the new normal, while other U.S. coastal cities are trying to keep up.

Water always wins

British colonists founded Boston in 1630 next to a freshwater spring on the heavily forested Shawmut Peninsula. By the 1800s, the trees had been replaced by a bustling trading port. As the population grew, industrious residents began filling in tidal flats and marshland with rocks, dirt and trash to create more buildable space. By the early 1900s, the city had tripled in geographic land area. The South End, Charlestown, East

DAVID L. RYAN/BOSTON GLOBE/GETTY IMAGES

Boston, Back Bay and downtown neighborhoods, including attractions like historic Faneuil Hall and the New England Aquarium, are all built on landfill. Even Logan International Airport is built atop a filled-in tidal flat that was once five islands.

Of course, early Bostonians had no idea that rising seas would one day threaten former lowlands. With more filled-in land area than most major U.S. cities and 75 kilometers of shoreline, Boston is the fifth most vulnerable coastal city to flooding from sea level rise in the United States — after Miami, New York City, New Orleans and Tampa — and the eighth most vulnerable city in the world, in terms of overall cost of potential damage, according to the World Bank.

When it comes to coastal flooding, Boston has a lot stacked against it. The city's official elevation is 14 meters above sea level, but its lowest areas sit at sea level.

Over the last century, sea level in Boston Harbor rose by about 28 centimeters, due to both thermal expansion of seawater as the oceans warm (*SN Online: 9/28/18*) and the melting of distant ice sheets. Conservative projections for Boston place sea level about 15 centimeters higher by 2030, 33 centimeters higher by 2050 and 149 centimeters higher by 2100. In a worst-case scenario, if greenhouse gas emissions continue at the current pace, sea level could rise by as much as three meters by 2100.

New England and the eastern shore of Canada have a unique combination of geographic factors that push water farther inland in response to high tides: The region's shallow seafloor topography tends to funnel water higher inland, and its proximity to the Gulf Stream — a major ocean current that runs from the Gulf of Mexico up along the East Coast — also helps magnify tides. Due to rising ocean temperatures, the Gulf Stream is slowing down, causing even more water to pile up along the East Coast and boosting high tides, physical oceanographer Tal Ezer of Old Dominion University in Norfolk, Va., reported in June in *Earth's Future*.

In 2017, Boston racked up a record 22 nuisance tides (defined in Boston as tides over 3.8 meters above average sea level), according to a 2018 report by the National Oceanic and Atmospheric Administration. As sea level creeps higher, the Seaport and some other areas of Boston could see daily tidal flooding by midcentury, says Kirk Bosma, a coastal engineer with the Woods Hole Group in Massachusetts.

Flooding during extreme high tides, when there's no storm in sight, already happens in East Boston, Charlestown and the downtown waterfront (*SN Online: 7/15/19*). David Cash, an environmental policy expert at the University of Massachusetts Boston, has witnessed high tide flooding from his office overlooking Dorchester Bay and Morrissey Boulevard, a major thoroughfare and the primary road to the campus. "Morrissey Boulevard now floods several times a year at high tide on blue sky days," Cash says.

If a storm hits at high tide, its effects can be greatly magnified, creating a storm tide, Bosma says. Boston lies in the path of both winter nor'easters and Atlantic hurricanes, which are increasing in intensity, NOAA reported in July in an overview of current research on global warming and hurricanes. When storm surges and heavy rain or snow hit coastal cities with more concrete than absorptive marshland, the combination can overwhelm urban drainage systems and cause flooding.

The winter of 2018 was stormy, even by New England standards. In January, winter storm Grayson dumped more than 40 centimeters of snow on Boston. Streets were flooded deep enough to float large dumpsters in the dark, icy water.

"During the storm, the high tide came right up over the seawall, across the street and poured into my office building's parking garage," says Joel Carpenter, an equity trader at Congress Asset Management in the Seaport. As massive plow trucks drove through about a meter of seawater, pushing huge ice chunks out of the way, Carpenter wondered how he would get home. "Public transport was shut down." He had to walk through ankle-deep water to a spot several blocks from his office, where an Uber was willing to pick him up.

When the ocean surged 4.6 meters above the high tide mark, Grayson broke the record set in 1978 for the highest storm tide. Just two months later, in March, winter storm Riley delivered

Creating space Boston's original coastline (green) includes the Shawmut Peninsula, where the city was founded in 1630. Much of the current city is built on landfill (brown), once marshlands and tidal flats.

THE MURIEL G. AND NORMAN B. LEVENTHAL FAMILY FOUNDATION another record storm surge. Like it did in 2012, the city got lucky: Riley didn't hit at high tide, Bosma says. "If Riley had occurred with hide tide, it would have been disastrous."

As it was, public transportation ground to a halt and the National Guard had to come in to help evacuate stranded motorists and residents. "These storm events are a real wake-up call," Cash says. "Our future is going to be wet."

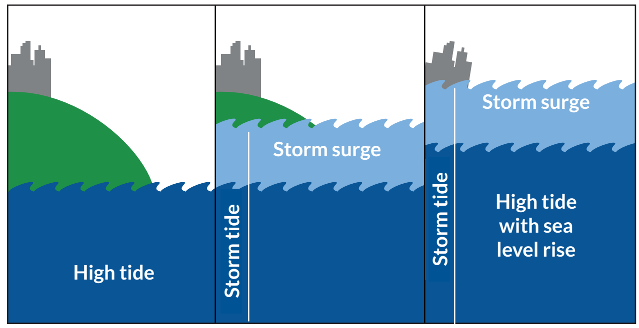
Heads together

By the time those winter storms hit, Boston was already getting serious about protecting itself against flooding. In 2015, officials assembled BRAG, the Boston Research Advisory Group, to bring Boston-based researchers together to guide science-based decision-making for Climate Ready Boston.

"BRAG is like a mini Intergovernmental Panel on Climate Change just for Boston," says BRAG member Ellen Douglas, a hydrologist at the University of Massachusetts Boston. BRAG combines peer-reviewed literature and locally sourced published data to project Boston-specific impacts of heat waves, storms and sea level rise.

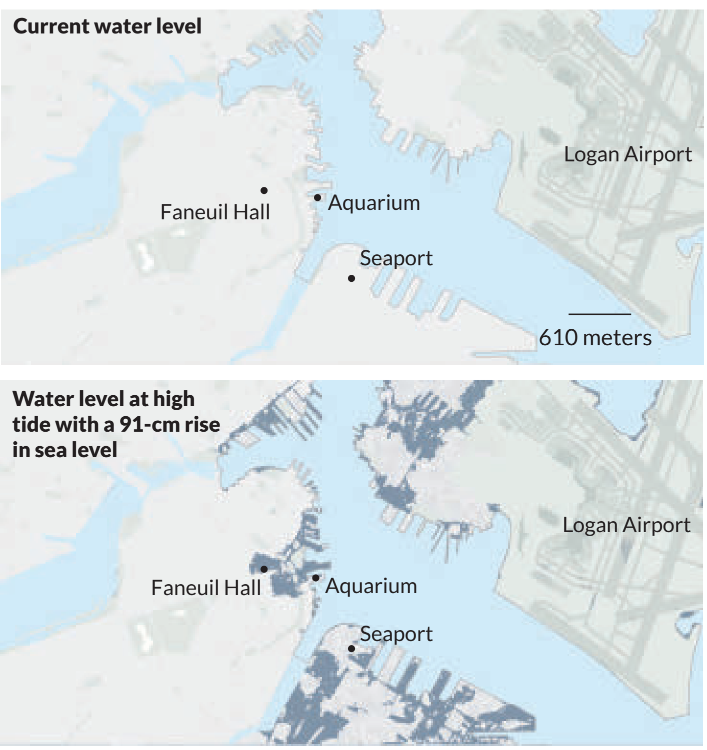
In 2016, BRAG released its first report, "Climate Change and Sea Level Rise Projections for Boston." The references run long, citing more than 100 studies.

Based on the probabilities of the various sea level rise scenarios outlined in the report, Boston is preparing for up to 100 centimeters of sea level rise. Future zoning and coastal resilience projects — those intended to protect people and keep property from flooding — will need to safeguard against at least 100 centimeters, about a yardstick's worth, of sea level rise.



Combined dangers As sea level rises, so does high tide. When storms hit at high tide, the combination of storm surge and high tide is a storm tide. In Boston Harbor, the highest recorded storm tide crested at 4.6 meters above sea level in January 2018, causing extensive flooding.

Rising waters Several Boston neighborhoods and public institutions are on low-lying landfill (top). Climate Ready Boston is preparing the city for about 100 centimeters of sea level rise (bottom), which will flood several areas (blue) if no action is taken.



"We did a full citywide vulnerability assessment [of] how, when and where the city would be affected over different time frames," using BRAG's sea level rise estimates, says Bud Ris, a senior member of the Green Ribbon Commission, a consortium of business, institutional and civic leaders that advises Climate Ready Boston.

Boston is ranked eighth worldwide for expected economic losses due to coastal flooding, estimated at $237 million per year in 2005 and $741 million annually by 2050, according to a 2013 study in *Nature Climate Change*. "Those kind of numbers frame the upfront costs and the call to action pretty starkly," Ris says. "If we don't do the work now, we are going to pay even more later."

The cost of adaptation is daunting; estimates range into the billions of dollars over the next 50 years. In April, Boston Mayor Martin Walsh pledged 10 percent of the city's $3.49 billion capital budget in 2020 to fund resiliency projects, such as raising major roadways and replacing existing concrete structures and pavement along coastlines with floodable green spaces.

Though much more money will be needed, Massachusetts has a history of coming up with funds for staggeringly expensive public works projects, Ris says. Cleaning up the infamously filthy Boston Harbor cost taxpayers about $5 billion over two decades. The city spent $22 billion on the Big Dig, the country's most expensive highway project that took two decades to reroute the city's formerly elevated Central Artery into a tunnel system completed in 2007. "If we come up with a workable plan, the money will come from somewhere," Ris predicts.

Blue Boston

One of the first steps toward building a more flood-resilient Boston was to map where the water will go, Douglas says.

"The first set of maps we put out [in 2011] showed what the coastline of Boston will look like by the year 2100 with sea level rise and a large storm surge. The map got a lot of

FROM TOP: CLIMATE COUNCIL OF AUSTRALIA, ADAPTED BY T. TIBBITTS; CITY OF BOSTON, ESRI, HERE, GARMIN, NGA, USGS, ADAPTED BY T. TIBBITTS

This high tide flood along Boston's waterfront occurred in October 2016. NOAA estimates that Boston will see between 12 and 19 days of high tide flooding between May 2019 and April 2020.

attention because it was so blue."

With 100 centimeters of sea level rise, much of Boston's fill land will be inundated by the harbor, returning the remaining landmass to the original shape of the Shawmut Peninsula. Low-lying city landmarks such as North Station, Faneuil Hall and the aquarium would be permanently awash in blue.

The Boston Harbor Flood Risk model, released in 2015, shows how flooding in and around Boston Harbor will change over time under various scenarios.

"We looked at thousands of different [historical and simulated] storm events combined with sea level rise, waves and tides, and determined the movement of floodwaters out of the harbor and into the streets," says Bosma, who led the modeling project. The model identified the financial district, Fort Point Channel and the Blackstone Block Historic District as among the city's most vulnerable areas.

"If you just look at the 2100 maps, [preparing for flooding] can seem pretty hopeless," Bosma admits. "But the models show where we need to focus our money and efforts right now and where we can plan for future projects in 2030, 2050 and beyond."

The city government has also been working on making more detailed street-by-street maps of Boston's many neighborhoods, says Carl Spector, Boston's commissioner of the Environment Department.

"We started with East Boston and Charlestown, because they are already seeing flooding," he says. That report was released in 2017, followed by a report for South Boston in 2018. The city is now evaluating the downtown and North End districts. "These reports have priority lists and recommended timelines for when projects should be started and completed over the next 30 years," Spector says.

Concrete vs. green space

Protecting individual buildings from flooding usually involves waterproofing lower floors, raising electrical equipment and installing pumps to remove floodwater. But on a citywide

PHOTO: BOSTON HARBOR NOW; ICONS: T. TIBBITTS

U.S. cities at risk

Boston is fifth in line among the U.S. cities most at risk from coastal flooding. At greater risk are Miami, New York City, New Orleans and Tampa. Here's where their flood resilience efforts stand:

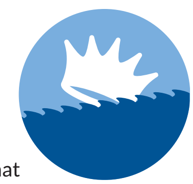
Miami

Florida's flooding risk comes not just from storms and high tides but also from water seeping up through the porous limestone that underlies much of the state. After 2017's Hurricane Irma caused more than $50 billion in damage, Miami residents voted in favor of a new tax to fund coastal flooding resilience projects across the city. The first project, in the city's low-lying Fair Isle neighborhood, broke ground in March and will construct a drainage-collection system and raise roadways.

New York City

In 2012, Hurricane Sandy hit New York City with a 3.4-meter storm tide, causing over $19 billion in damage. Although there are now several programs to guide rebuilding and resiliency efforts, few adaptation projects have come to fruition, says Robert Freudenberg, an environmental planner with the Regional Plan Association in New York City. In March, the New York City Panel on Climate Change released a report and new flooding maps. In May, the city's Office of Emergency Management began installing sandbags around lower Manhattan as a temporary measure to protect the waterfront while more permanent solutions are considered.

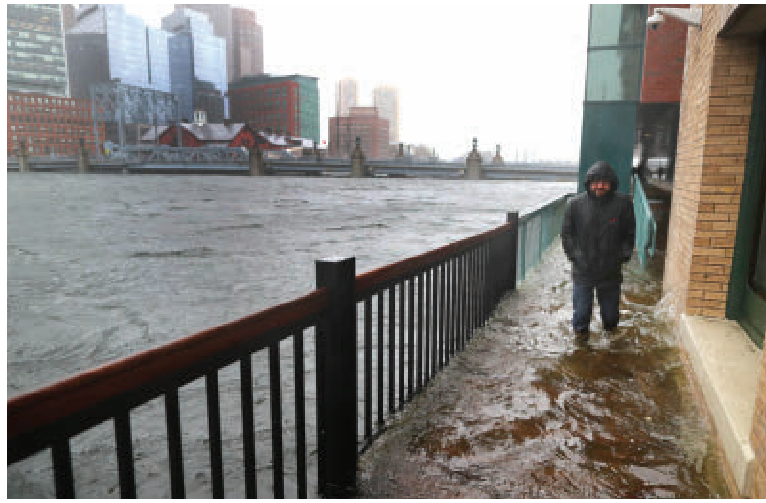
New Orleans



Louisiana is one of the most flood-prone states, thanks to a combination of rising sea level, sinking landmass and the flood-prone natures of the Mississippi and Atchafalaya rivers. Sinking in particular is a major problem as the river sediments that once replenished coastal land are blocked by levees, unable to refill riverbanks and estuaries. Since 1930, nearly 5,000 square kilometers of land have been inundated with water, with 10,000 square kilometers imperiled in the next 50 years. This loss of protective marshland leaves New Orleans more exposed to Gulf storms and flooding. In May, Louisiana released a $40 billion plan called LA SAFE to build needed levees, restore shorelines and, if necessary, relocate entire communities at risk from flooding. The first LA SAFE projects are slated for completion in 2022.

Tampa

Like much of southern Florida, the Tampa Bay region already sees regular flooding during high tides and storms. Since 1952, sea levels in Tampa Bay are up by about 18 centimeters. In April, Tampa's Climate Science Advisory Panel recommended that the city begin preparing for seas to rise an extra 30 to 76 centimeters by 2050 and 60 to 260 centimeters by 2100. Those ranges are NOAA's predictions for sea level rise, depending on different climate change scenarios. A timeline for starting adaptation projects hasn't been announced.



Clockwise from top left: Evan Arvedon checks out his car during a 2013 flash flood on Charles Street. A man wades through knee-deep seawater on a Congress Street sidewalk in the Seaport in March 2018. A nor'easter propelled seawater from Boston Harbor onto Long Wharf, near the aquarium, in October 2018.

ALL: BOSTON GLOBE/GETTY IMAGES; PHOTOGRAPHERS, CLOCKWISE FROM TOP LEFT: YOON S. BYUN, JOHN TLUMACKI, CRAIG F. WALKER

scale, flood protection starts at the coastline. The most efficient way to prioritize resiliency projects is by focusing on efforts that can protect entire neighborhoods, rather than single buildings, Bosma says. "Boston is not flat; it actually has quite a bit of topography that directs water in certain ways. We look to the coast and try to come up with more regional solutions — whether that be a floodwall or a berm or a park — that can protect a whole slew of inland assets all at once."

So why not build a concrete seawall around Boston Harbor to protect the entire city? BRAG and the Sustainable Solutions Lab at the University of Massachusetts analyzed the feasibility of installing a pair of barriers across the harbor. "It doesn't make a lot of sense from both financial and operational standpoints," Bosma says. A permanent barrier would cost as much as $20 billion and require intensive maintenance. Plus it could limit the size and frequency of ships coming and going from the harbor as well as impede the flow of water needed to maintain water quality.

Building a dynamic harbor barrier, with gates that open and close to allow for shipping and water flow, is feasible from an engineering standpoint, Bosma says. But by 2040 or 2050, sea level will probably be high enough that such gates would need to be closed for almost every high tide to prevent flooding. "The size and magnitude of the gates required would take six to eight hours to open or close," he says. "They'd have to be almost constantly moving."

Shore-based solutions that buffer against high tides and storm surges make more sense, the analysis found. Nature-based coastal adaptations such as parks and wetlands that can absorb the flooding are not only effective but also bring added benefits such as native habitat restoration, tourism and recreational opportunities, according to a study conducted on the Gulf Coast and published in 2018 in *PLOS ONE*.

"As much as possible, we're using nature-based solutions that are flexible and can be adjusted over time to conditions depending on what happens with sea level rise," Bosma says.

Infrastructure's tangled web

Resilience is about more than keeping buildings dry. "We may be able to protect Boston's buildings, but if people can't turn on the lights and can't flush the toilets and they can't get to work via public transportation and they can't call for help because the phones don't work, we're going to be in deep trouble," says John Cleveland, executive director of the Green Ribbon Commission.

Outages in the power grid, as well as telecommunications, water and gas services — which rely on the power grid — can cascade inland to places that never actually get wet, says Rae Zimmerman, an urban infrastructure planner at New York University.

For convenience, fiber optics, gas mains, water mains and electric power distribution lines often share the same underground conduits. "It's cheaper to install and maintain them that way, but it also means that when one system goes haywire, they all go," Zimmerman says.

Climate Ready Boston is behind in this arena. "As far as I know, the city hasn't started coordinating its strategy around its infrastructure for transportation, energy, water, wastewater and communications," Bosma says. "We need to be embedding resilient design standards into ongoing infrastructure investments."

For example, when the city overhauled its stormwater and wastewater sewer systems 30 years ago, "we didn't foresee the problem of sea level rise," says John Sullivan, chief engineer of the Boston Water and Sewer Commission. During flood events, partially shared wastewater and stormwater drainage systems make keeping seawater out of Boston's wastewater treatment plants a challenge.

The city is now researching strategies for storing influxes of stormwater using existing natural depressions in the landscape and even parking garages, so that saltwater does not get into the wastewater treatment plants and wreak havoc on the microbes that help process the waste. One goal is to incorporate backup systems that flow with gravity and don't require pumping. "If we can avoid having to pump, which requires electricity, we'll be better off in the event of a power outage," Sullivan says.

Last summer, a team led by computer scientist Paul Barford of the University of Wisconsin–Madison released a series of maps that overlapped the physical internet — fiber-optic cables, hubs and data centers — with projections of sea level rise in major U.S. coastal cities. Just like with the water systems, nobody was thinking seriously about sea level rise when the infrastructure that runs with the internet was installed 20 years ago, Barford says. "Now we have thousands of miles of cables and major data centers that are susceptible to damage during coastal flooding events." Waterproofing vulnerable components of the physical internet may help, but the most critical infrastructure may need to be moved inland away from the coasts, he says.

Pipes, conduits and power lines follow existing roadways, so some utilities may be able to piggyback on the maps and strategies developed for the Massachusetts Department of Transportation and the Massachusetts Bay Transportation Authority, Douglas says.

"MassDOT has taken all of our reports very seriously," she says. "They have a lot of infrastructure in the way of sea level rise." Perhaps the biggest challenge is to keep the Big Dig highways open for traffic while protecting the tunnels from flooding, Douglas says. "You can't just close off the tunnels. They are important evacuation routes during emergencies, but they were not built to tolerate any amount of flooding."

Resiliency projects

Not so long ago, sea level rise was considered a distant problem, something to deal with a hundred years or more from now. But sea level rise is already lapping at U.S. shores. Boston may be among the oldest cities in the country, but it also might prove to be one of the most resilient.

An artist's rendering of flood-resilience updates to Ryan Playground on the Mystic River in the south part of Boston includes elevating pathways and plazas plus adding green space to help drain floodwater.

STOSS LANDSCAPE URBANISM, CLIMATE READY BOSTON

The Climate Ready Boston plan is well under way, with completed district-level projects in East Boston, Charlestown and South Boston. Work includes installing a deployable floodwall along the East Boston Greenway, elevating a section of Main Street in Charlestown to protect a large swath of the neighborhood and removing concrete to restore floodable parks and green space in South Boston and the Seaport.

With momentum building in Boston, the resiliency project is expanding to the rest of the state; Massachusetts has over 300 kilometers of coastline to protect, including the curled arm of Cape Cod. This spring, Massachusetts Speaker of the House Robert DeLeo and Governor Charlie Baker each pledged $1 billion in grants for resilient infrastructure and climate adaptation projects across the state.

When it comes to implementing climate adaptation strategies, other cities, including New York, can learn from Boston, says Freudenberg, the environmental planner in New York. "Developing a vision for climate adaptation is easy. Implementing that vision is much harder," he says. "At some point, once we've considered the science and all the available strategies, we have to start building. It's been seven years since Sandy and seas are rising. It's time to take action." ■

Explore more

- Climate Ready Boston: www.boston.gov/departments/environment/climate-ready-boston

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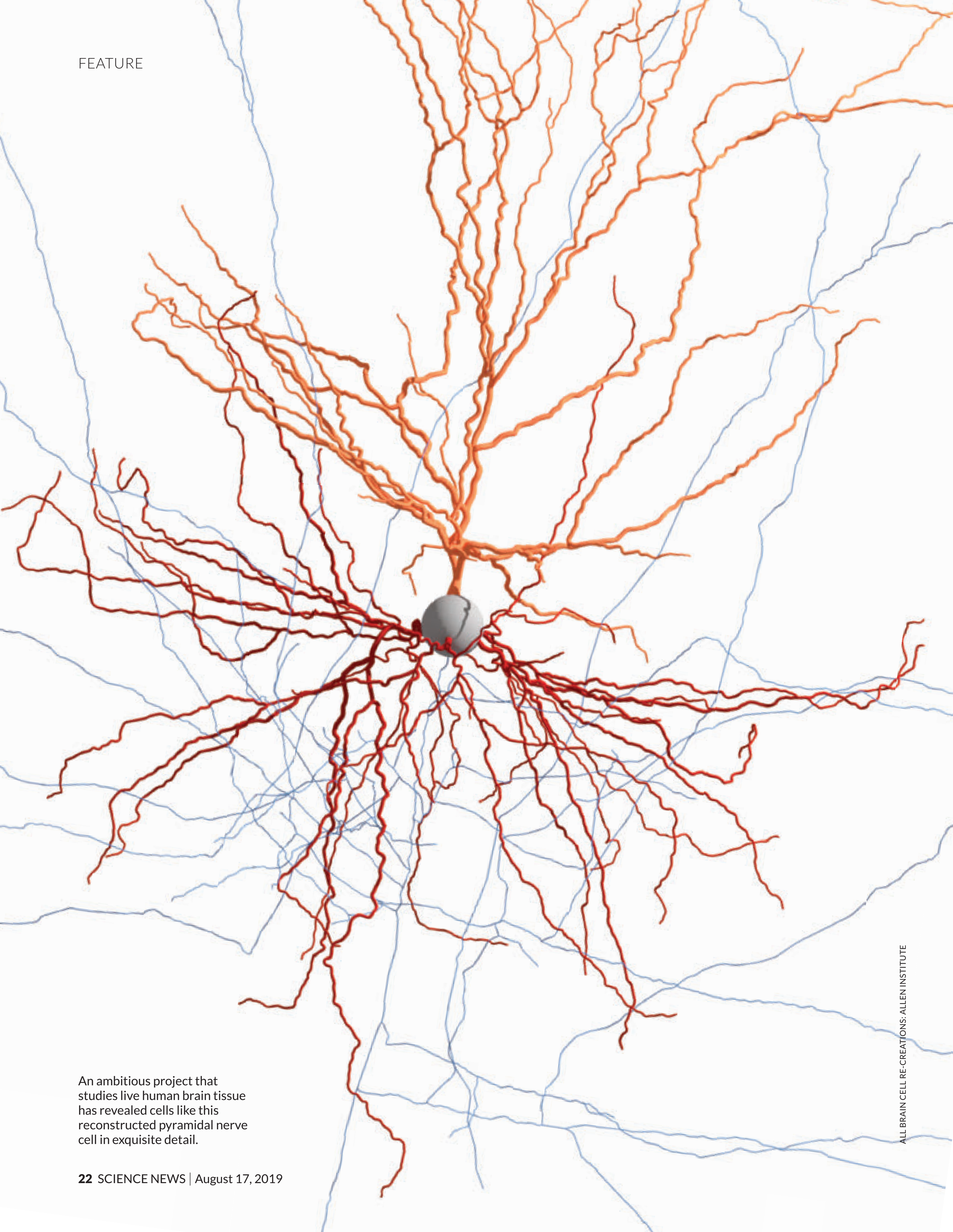
Mary Caperton Morton is a freelance science writer based in California's Sierra Nevada mountains. She was born in Boston.



An ambitious project that studies live human brain tissue has revealed cells like this reconstructed pyramidal nerve cell in exquisite detail.

ALL BRAIN CELL RE-CREATIONS: ALLEN INSTITUTE

A Menagerie of Neurons

Studies of living brain cells aim to determine what sets humans apart

By Laura Sanders

The golf ball–sized chunk of brain is not cooperating. It's thicker than usual, and bloodier. One side has a swath of tissue that looks, to my untrained eye, like gristle.

Nick Dee, the neuroscientist charged with quickly cutting the chunk into neat pieces, confers with his colleagues. "We can trim off that ugliness on the side," he says. The "ugliness" is the brain's connective tissue called white matter.

To produce useful slices for experiments, the brain tissue must be trimmed, superglued to a lipstick-sized base and then fed into a lab version of a deli slicer. But this difficult chunk isn't cutting nicely. Dee and colleagues pull it off the base, trim it again and reglue.

Half an hour earlier, this piece of neural tissue was tucked inside a 41-year-old woman's head, on her left side, just above the ear. Surgeons removed the tissue to reach a deeper part of her brain thought to be causing severe seizures. Privacy rules prevent me from knowing much about her; I don't know her name, much less her first memory, favorite meal or sense of humor. But within this piece of tissue, which the patient generously donated, are clues to how her brain — all of our brains, really — create the mind.

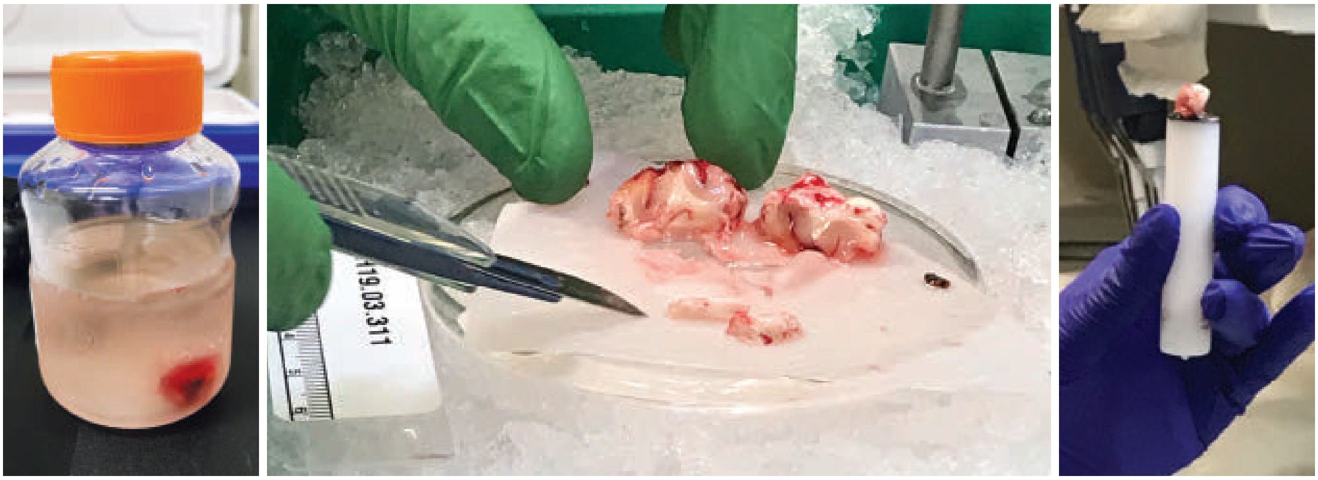
Dee's team is working fast because this piece of brain is alive. Some of the cells can still behave as if they are a part of a person's brain, which means they hold enormous potential for scientists who want to understand how we remember, plan, behave and feel. After Dee and his team do their part, pieces of the woman's brain will be whisked into the hands of eager scientists, where the cells will be photographed, zapped with electricity, relieved of their genetic material and even infected with viruses that make them glow green and red.

It's all part of a project at the Seattle-based Allen Institute for Brain Science, funded largely by private money plus some U.S. government grants. Now in its sixth year, the project relies on a network of scientists, neurosurgeons and patients who are willing to donate brain tissue removed during surgery. The ultimate aim is to answer one of the biggest questions in neuroscience: What makes us human?

The answer won't be simple. But already, the project has turned up hints about what makes the human brain so powerful. Live-tissue experiments have revealed cellular quirks that may be specific to primates and have turned up new details about a mysterious type of nerve cell, or neuron. Other tantalizing discoveries show that humans and mice have very similar numbers of neuron types.

These slices of human brain tissue are kept alive by artificial cerebrospinal fluid bubbled with a mix of carbon dioxide and oxygen.

THIS PAGE: ALLEN INSTITUTE; ALL OTHER PHOTOS: MOLLY TELFER



A chilled jar (left) holds a sample of brain tissue minutes after it was removed during a May 14 surgery for epilepsy in Seattle. At a lab across town, the sample is trimmed and cut on ice (middle). Once trimmed, it is glued onto a holder the size of a lipstick tube for more slicing (right).

From brain to lab

Allen Institute scientists fly into action when a brain sample arrives from a nearby hospital, wringing as much information as they can out of the precious tissue. What the researchers learn about the cells' behavior, shape and genetic activity is shared publicly in the Allen Brain Atlas. (Bold text shows each step's duration).

1 to 3 minutes
Surgery Brain tissue is removed at a Seattle hospital — usually within minutes of a surgeon opening the patient's skull — and placed into a jar with chilled artificial cerebrospinal fluid bubbling with oxygen and carbon dioxide.

15 to 30 minutes
Transport A specially equipped van speeds the tissue from the hospital to the Allen Institute.

30 to 60 minutes
Slice The sample is placed on a dish in a bucket of ice, trimmed and sliced into anywhere from six to more than 30 flakes that are each 0.35 millimeters thick.

Distribute From each sample, one slice goes into the freezer for future analyses. Every fifth slice is fixed in preservative. The rest are kept alive for more same-day experiments.

1 hour
Rest Live cells recover from the trauma of surgery.

Observe behavior Rested cells move to the electrophysiology lab, where "rig" operators study cell behavior with 30 minutes of electrical prodding.

Map cell shape Filling some neurons with dye, researchers can see the elaborate projections.

Study the genes Thin glass pipettes pull out the nucleus of some neurons so researchers can see which genes were active just before the cells died.

Weeks to months
Manipulation Other tests attempt to insert genetic material into cells that stay alive longer than expected. The cells glow for better visibility.

This kind of detailed cellular reckoning is a necessary early step on the path to understanding human thoughts, behaviors and abilities.

"We want a complete description of all the types of neurons," says Christof Koch, chief scientist and president of the Allen Institute for Brain Science. Steady progress over the last six years shows that answers are within reach. Once order is given to the tangle of neurons that populate our brains, scientists can turn their sights to the bigger mysteries, like how those cells create our memories, emotions and even consciousness itself.

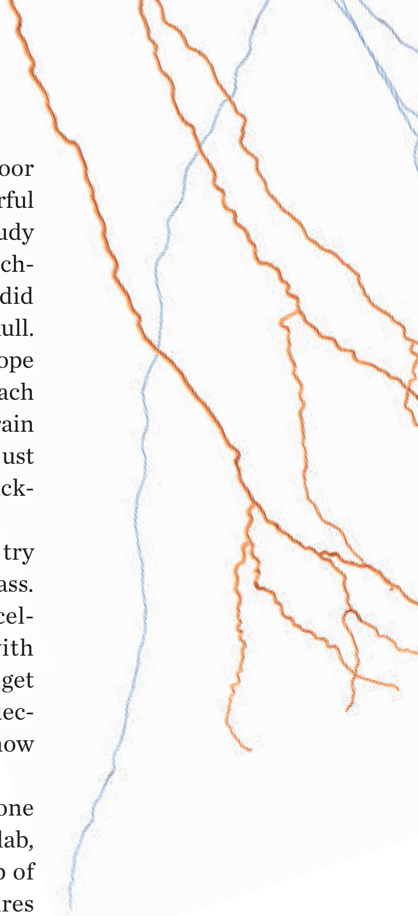
Rush hour

On the morning of May 14, I waited outside of a basement operating room at the University of Washington's Harborview Medical Center. Inside, a neurosurgeon was cutting deep into the woman's brain. At 10:15, the wide swinging doors opened, and a doctor carried out a clear plastic jar with an orange cap.

Settled at the bottom of the liquid inside was a bit of brain, gently sloshing around with the motion. Tissue-procurement team member Tamara Casper was ready with a cart that carried a blue cooler (the same kind I have in my garage) on the top and two gas canisters below. The piece of brain had tinged the clear solution pink.

It was a colorful reminder that this tissue had, minutes earlier, been inside a skull, where it was helping to create a woman's mind.

Scientists have other methods to mimic human brains: Brain organoids, small balls of neural tissue that are grown from stem cells (*SN: 3/3/18, p. 22*), and animals raised in labs have been immensely helpful to neuroscientists. "There's real value



there," says Allen Institute neurobiologist Ed Lein. "But what they're not good for is studying the specifics of the final product in the mature brain."

This particular sample submerged in the pink liquid had spent 41 years piloting a woman's life. "It's hard to emphasize how different this is," Lein says of the project. Other laboratories have studied live tissue removed from human brains, but none have scaled up and systematized the process as much as this group in Seattle.

"To me, it's almost mind-blowing that we can study the human brain outside of the human brain," says Ryder Gwinn, a neurosurgeon at Swedish Medical Center in Seattle who collaborates with Allen Institute scientists.

Gwinn treats people with epilepsy. Medication doesn't always stop his patients' seizures. In severe cases, surgery can be a patient's best bet. In some of these operations, a surgeon cuts away healthy brain tissue to reach the spot deeper in the brain where seizures first spark. Surgeons peel away the skin and remove a cookie-shaped piece of skull, exposing the temporal lobe of the brain, a stretch of the outermost layer called the cortex. Often, a large piece of the temporal lobe comes out, Gwinn says. Some of that neural tissue goes to pathologists. The rest is typically tossed as medical waste — unless Allen Institute scientists can get their hands on it.

"The tissue is terribly scarce," Koch says. Early on, colleagues, including many Allen Institute researchers, were skeptical that enough samples could be found and brought to the lab in good shape. But after about 140 surgeries, more than 30 this year alone, it's clear that these brain samples survive the journey beautifully.

As soon as the sample came out of the OR, Casper hooked up the oxygen and carbon dioxide gas to keep the tissue alive in the liquid, an artificial cerebrospinal fluid. Then she was off, pushing the cart through the hospital with one hand and texting the Allen Institute team with the other. The cart was loaded into a white van modified to safely hold combustible gas canisters. And with that, the bubbling brain bit was on its way. The van threaded through heavy, rain-soaked Seattle traffic back to the lab, where Dee was ready, scalpel in hand.

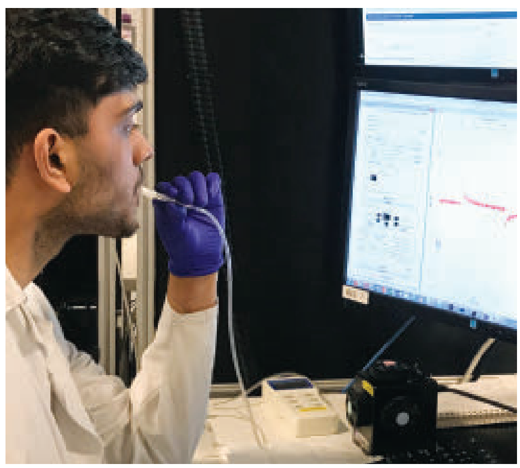
Cross talk

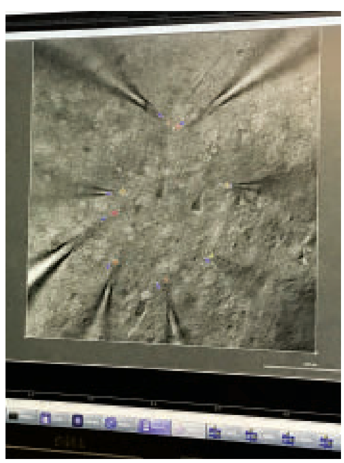
After that frustrating start with the uncooperative piece of brain, Dee finally gets enough slices for multiple experiments. A one-hour rest helps the cells recover from the trauma of being separated from the brain. The slices go up to a second-floor lab, where some slices are placed under a powerful microscope and prodded with electricity to study how these live human cells behave. The researchers hope the behavior mimics what the cells did while they were inside their former owner's skull.

Six scientists sit at "rigs," each one a microscope mounted inside a black three-sided box. At each rig, a researcher hunts through the woman's brain tissue for healthy cells — nice and plump, with just the right amount of visibility against the background tissue.

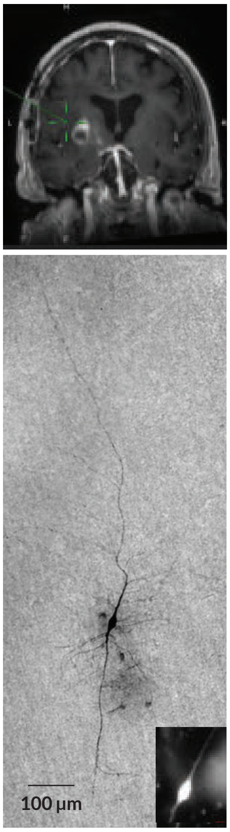
Once they find a good one, the researchers try to latch on with an impossibly thin tube of glass. Called patch-clamp, the technique forces a cellular conversation, which is carried out with electrical signals that move between cells. To get the conversation going requires injecting an electric current into a cell, and then measuring how the cell responds to the artificial message.

Most of these rigs measure the reactions of one neuron at a time. But in the back part of the lab, researcher Lisa Kim pilots a futuristic setup of glistening metal, tangles of blue and black wires

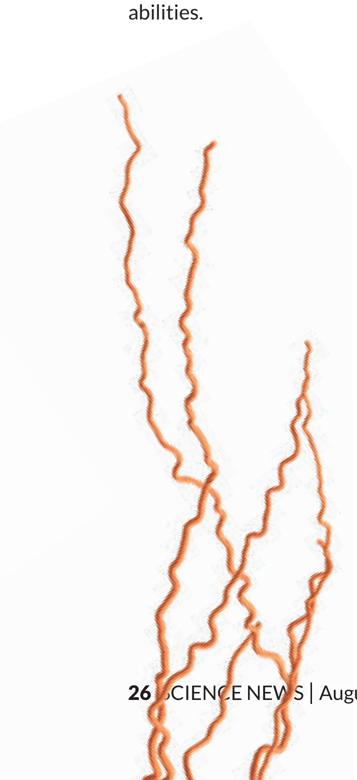




Ramkumar Rajanbabu of the Allen Institute uses a suction tube to get a good seal on a single live neuron's membrane so he can see how cells behave. Scientists can observe neighboring neurons (bottom left shows up to eight pipettes, each touching a cell's nucleus) to reveal complex cellular conversations (bottom right).



A piece of brain taken from a surgery patient (scan, top) contained what may be a rare von Economo neuron. These large, spindly cells (bottom and inset, shown with different dyes) might enable some of humans' sophisticated abilities.



and eight needle mounts, all pointing at a different part of a brain slice. While I'm there, this mega-rig is eavesdropping on a kind of party line between seven live neurons. Kim is zipping electricity into each one in turn to see how the signal transmits to its neural neighbors.

The electrical zings of these neurons offer clues about their identities and their relationships; one of the seven cells responds when a neighboring cell gets an electrical zap, a hint that those cells communicated while inside the woman's head. Other clues come from information about the neurons' elaborate, gangly shapes created by the signal-sending axons and receiving dendrites. Each neuron reminds me of an impossibly complex map of river tributaries.

An even stronger sense of a cell's function comes at the end of the patch-clamp experiments. Working the thin glass tube again, a researcher can suck out the nucleus of each live cell. The theft kills the cell but obtains a record of which genes were active when the cell was alive. After Kim finished the game of electrical telephone, she carefully slurped out the nucleus from each of the seven neurons.

All the information gathered from these rigs can help researchers identify neurons that might play a special role in making the human mind. Such scrutiny, for instance, revealed what researchers think is a rare cell called a von Economo neuron, named for the Austrian neurologist who first described the cell type in the 1920s.

The extra-long, extra-spindly neuron was found in live brain tissue donated by a 68-year-old woman who had surgery to remove a tumor. The neuron displayed an unusual electrical response to the current applied to it, Allen Institute scientists and colleagues reported online May 7 at bioRxiv.org. The result was tantalizing, because problems with von Economo neurons are suspected of playing a role in psychiatric conditions and Alzheimer's disease.

Studies on live human cells also turned up an important difference between humans and mice: A certain kind of human neuron is covered with a protein called an h-channel; in mice, those channels are rare. H-channels help cells respond to electrical signals and can be affected by drugs, including one for epilepsy.

This basic difference, described in 2018 in *Neuron*, might explain why certain kinds of drugs work differently in the brains of mice and people. More broadly, these newly discovered properties of human neurons might be the things that enable some of the most sophisticated features of our brains.

Taking stock of live human neurons "is essential," and not just to satisfy humans' navel-gazing curiosity, says Nenad Sestan, a Yale School of Medicine neuroscientist. Discovering the quirks of human brains "might lead to us understanding one day why we suffer from certain disorders," Sestan says. Imprecise animal models have stymied research on schizophrenia, autism and Alzheimer's disease, he says. That's why studying live, human tissue is so crucial.

A blow to the ego

But human brains aren't always so unique. A new result might disappoint people who think that our brains are teeming with specialized neurons that let us talk and think in ways other animals can't. The overall number of cell types in the human cortex and in the mouse cortex is roughly the same, says a study led by Allen Institute researchers that is in press at *Nature*. Koch calls the finding "the biggest result, to my mind."

"People, including scientists, have this strong need [for] human exceptionalism," Koch says. But the fact that the overall resident population of the human brain and mouse brain is remarkably similar — based on brain tissue from surgeries as well as postmortem tissue — adds to the list of blows to the human ego.

First, Darwin downgraded humans to just another animal on the tree of life. Then, the

Using a multistation rig at the Allen Institute, researchers can observe a group chat among a handful of live neurons in response to an injected electric current.

BRAIN AND NEURON IMAGES: R.D. HODGE/BIORXIV.ORG 2019

Human Genome Project shocked us with the news that we have a similar number of genes as mice (and fewer than water fleas). Now, add brain cell types to the list of things that make people more like other mammals.

The paper coming out in *Nature* is "historic," says coauthor Rafael Yuste, a neuroscientist at Columbia University. In terms of understanding how humans compare with other animals, "it's going to be a before-this and after-this."

These similarities don't surprise Suzana Herculano-Houzel, a neurobiologist at Vanderbilt University in Nashville. "We are not special," she says. Finding that humans and mice have similar types of cells in their brains makes a lot of sense, as does the idea that some cell types and some genes will be species-specific. The question is, she says: "Which of those differences are actually meaningful?"

The explanation for why we're so smart, then, is not that our brains are teeming with specialized, human-specific neurons. The answer must be found elsewhere. Perhaps it really is in small numbers of rare neurons such as von Economo neurons, or in neurons that haven't yet been discovered. Still other scientists think that our brainpower might come, in part, from cells in the brain that aren't neurons, such as the glial cells that perform a range of basic brain jobs that scientists are just beginning to understand (*SN: 8/22/15, p. 18*).

Or maybe, as Yuste suspects, the answer is the sheer size of our brains compared with our relatively small bodies. Or perhaps our "smarts" are a result of our long life span and the fact that we are immersed in cultures rich with language, literature and customs, as Herculano-Houzel points out.

"The brain is by far, by far the most complex, highly organized piece of active matter anywhere in the universe."

CHRISTOF KOCH

Mind fix

As Dee did his slicing, neurobiologist Jonathan Ting waited eagerly for his bit of brain. Ting runs experiments that deliver genes to live cells — and he's kept his cells alive a surprisingly long time.

In his fourth-floor lab, Ting is not happy with the piece he got, calling it "kind of a bloody mess." But he cuts it up some more and returns the resulting slices to the bubbling solution. Then he pulls what looks like a baking tray out of a nearby incubator, makes a Martha Stewart joke and shows me live brain samples that are weeks old. Some have survived for several months, a hardiness that shocked the researchers when they first began these experiments.

To make it easier to find rare cell types, scientists infect live human brain slices with viruses engineered to cause certain groups of neurons to glow red or green under a microscope's laser.

This kind of durability comes in handy as Ting tinkers with how best to infect the cells with viruses. His goal is to use the viruses to deliver genes that make certain groups of live human cells glow. The glow makes it easier to study the cells and, ultimately, to figure out how to change their behavior. To Ting's delight, he discovered that the virus and its luminescent cargo can be delivered simply by dropping virus-laden liquid on the live brain slices.

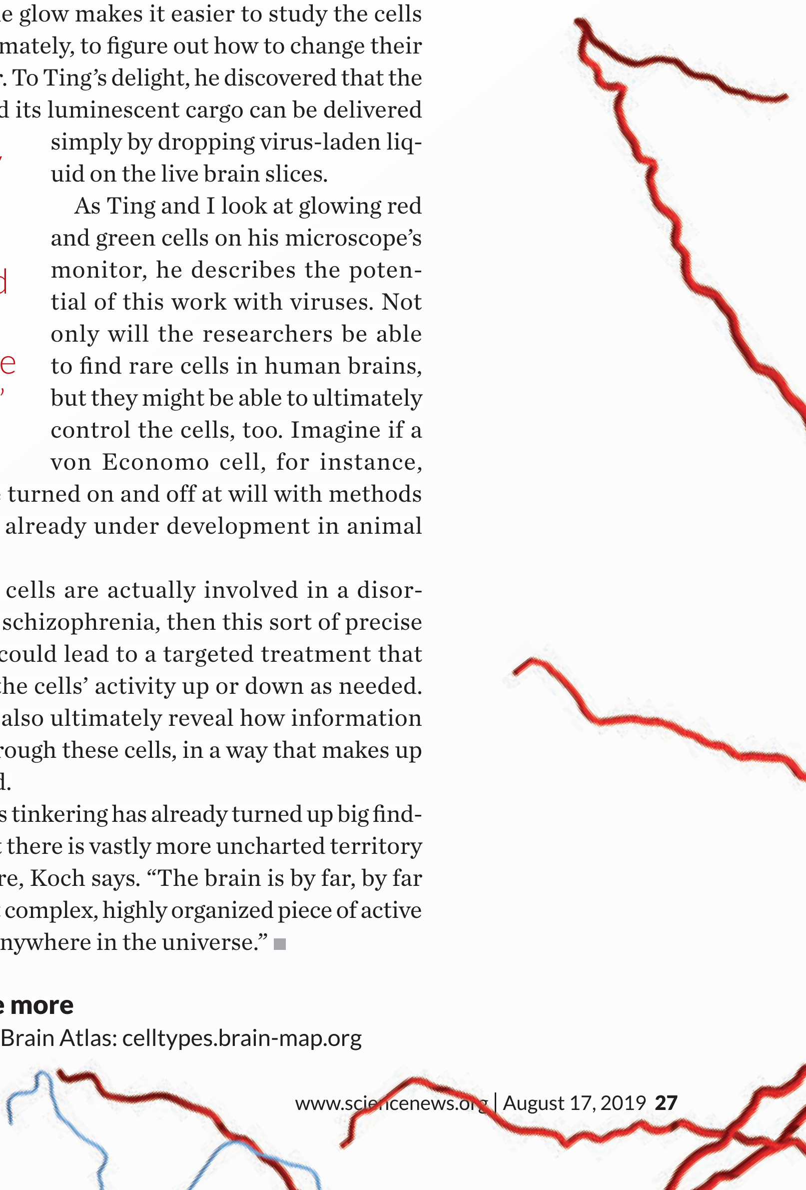
As Ting and I look at glowing red and green cells on his microscope's monitor, he describes the potential of this work with viruses. Not only will the researchers be able to find rare cells in human brains, but they might be able to ultimately control the cells, too. Imagine if a von Economo cell, for instance, could be turned on and off at will with methods that are already under development in animal models.

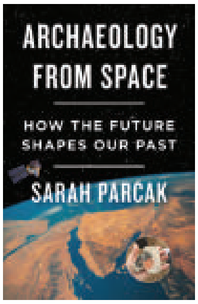
If the cells are actually involved in a disorder, say, schizophrenia, then this sort of precise control could lead to a targeted treatment that toggles the cells' activity up or down as needed. It could also ultimately reveal how information flows through these cells, in a way that makes up the mind.

All this tinkering has already turned up big findings. But there is vastly more uncharted territory to explore, Koch says. "The brain is by far, by far the most complex, highly organized piece of active matter anywhere in the universe." ■

Explore more

- Allen Brain Atlas: celltypes.brain-map.org





Archaeology from Space
Sarah Parcak
HENRY HOLT AND CO., $30

BOOKSHELF

Search for ancient ruins gets off the ground

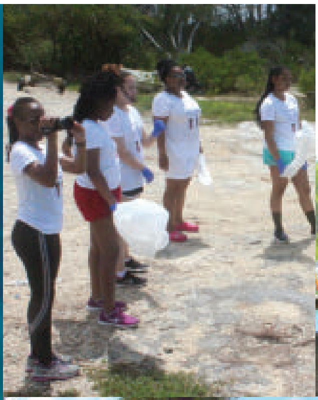
The term "space archaeology" may conjure up images of astronauts hunting for artifacts from little green men, but the field is much more down to Earth. Space archaeologists use satellite imagery and other remote-sensing techniques to look for ancient sites on our planet. As archaeologist Sarah Parcak explains in her new book, *Archaeology from Space*, these tools have transformed studies of antiquity. "We've gone from mapping a few dozen ancient sites in one summer-long archaeological season to mapping hundreds, if not thousands, of sites in weeks," she writes.

With the witty Parcak as a guide, the book offers a lively, inspiring trip around the world, back in time and even into the future. Parcak begins with the basics of space archaeology, explaining how, for example, satellite images can reveal the locations of walls or the foundation of a former building. Even long-buried ruins can leave a mark on the surface, affecting the growth of vegetation and so resulting in "crop marks." These outlines become apparent from high above and with instruments attuned to certain wavelengths of light.

In example after example, Parcak demonstrates the capabilities of different technologies. (Of course, old-fashioned digging is still integral to confirming what's in the ground.) Many of the book's anecdotes and tales of fieldwork focus on what Parcak and colleagues have learned about ancient Egypt. While studies of monuments and tombs have revealed aspects of everyday Egyptian life — "Like us, they wrote on walls and obsessed over cats" — satellite data have filled in some bigger-picture details. In the first survey of large-scale settlement patterns in the ancient Nile Delta, Parcak's team discovered that people largely abandoned the region near the end of Egypt's Old Kingdom some 4,000 years ago. Reading about how environmental changes, and droughts in this case, contributed to the Old Kingdom's demise feels remarkably timely in this era of climate change. Parcak notes that part of archaeology's value lies in learning lessons in resiliency from past societies.

Looking to the future, Parcak predicts artificial intelligence will be the next big thing in space archaeology. She estimates that only about 10 percent of Earth's land has been mapped for archaeological sites, and machines will scan satellite data much faster than humans. For now, citizen scientists can help via Parcak's online platform GlobalXplorer.

Parcak is a natural storyteller whose enthusiasm is infectious. By the end of the book, I was wishing I had paid more attention in my college archaeology courses. — *Erin Wayman*



Clockwise from top right: One student conducts a pH test on a water sample. With scuba gear on, students head out to their diving location. Participants dive in Andros, Bahamas. The girls take part in a beach cleanup.

ALL: BLACK GIRLS DIVE FOUNDATION

DIVE IN

Society's STEM Action Grant Program supports Black Girls Dive Foundation

Historically, a number of societal and systemic barriers have prevented black men and women from enjoying an activity as simple as swimming. According to the USA Swimming Foundation, 64 percent of black children don't know how to swim. There are similar barriers for many black children who want to learn more about science, technology, engineering and math, or STEM, fields. To address both of these issues, Nevada Winrow, a neuropsychologist working in education, started the Black Girls Dive Foundation based in Owings Mills, Md. The organization is dedicated to providing underserved and under-resourced girls between the ages of 9 and 17 with valuable skills in STEM and aquatic-based recreation.

In June, the foundation was one of 20 community-driven nonprofits that received a STEM Action Grant from Society for Science & the Public. The STEM Action Grant Program aims to support organizations that are working to enhance the public's understanding of science and increase participation of underrepresented populations in STEM fields.

Through her organization, Winrow is influencing a new generation of women to take up STEM. "Because of the Society's support, 75 people have been able to explore their STEM identities through engagement in STEM activities and mentorship from leading experts in their field," Winrow says. "Postsurvey results even showed that participants saw themselves as scientists, as opposed to the presurvey where they reported that they did not see themselves as scientists."

This is the foundation's second $5,000 grant from the Society. In 2018, the foundation received $5,000 to support a program called STREAMS, for science, technology, robotics, engineering, art and mathematics with scuba diving. Participants cultivate science-literacy skills and engage in activities such as building underwater remotely operated vehicles, taking scuba lessons and starting conservation initiatives at the local and international levels. The 2019 grant will help the foundation fund supplies and equipment, provide staff training and support participants' capstone projects.

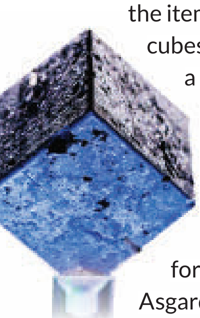
Students have raved about STREAMS. "This program is the best thing ever. I get to brag that I know how to scuba dive, and I can identify many kinds of fish," says one participant.

A total of $65,000 was awarded this year through the STEM Action Grant Program, with $30,500 going to 10 organizations that previously received support. To date, the Society has given $170,000 to 29 organizations seeking to improve access to STEM education.

JUNE 22, 2019

Name that cube

A mysterious uranium cube that came into a physicist's possession in 2013 was once part of an attempt to build a nuclear reactor in Nazi Germany, **Emily Conover** reported in "Uranium cube traced back to the Nazis" (*SN: 6/22/19, p. 16*). Readers online noticed the item's resemblance to iconic cubes in popular culture. "That's a Tesseract," **CatO9Ales** joked, referring to a device featured in Marvel comics and related movies, such as *The Avengers* and *Thor.* "If you know what's good for you, you'll move it to Asgard right away," **CatO9Ales** wrote. Online reader **stargene** thought it looked like a spaceship belonging to the Borg, an alien hive mind in the television show *Star Trek: The Next Generation*.



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Lyme light

Lyme disease is hard to detect, but scientists are investigating new diagnostic approaches that could help people get treated for the tickborne illness sooner, ***Laura Beil*** *reported in "The trouble with Lyme disease testing"* (SN: 6/22/19, p. 22).

"I found the info in a recent issue about better ways to detect Lyme disease to be very interesting," reader **Hazel Beeler** wrote. "But a gram of prevention is worth a kilogram of detection and treatment." **Beeler** noted that there is a Lyme vaccine for dogs and wondered about a vaccine for people.

A Lyme vaccine for people was available in the United States from 1998 until 2002. The vaccine was effective, but its maker voluntarily removed it from shelves partly over public concerns that the vaccine triggered arthritis. At least 1.4 million doses of the vaccine were doled out before it was taken off the market, according to a review published in *Clinical Infectious Diseases* in 2011. About 100 vaccinated people reported developing arthritis, researchers found.

Now, no human Lyme vaccines are available in the United States, but at least one is in development, **Beil** says. Called VLA15, the vaccine candidate is in Phase II clinical testing, which assesses a drug's efficacy. Researchers expect to publish results in 2020.

The U.S. Centers for Disease Control and Prevention estimates that it takes 36 to 48 hours for bacteria that cause Lyme disease to make their way from a tick into a person's body, **Beil** reported in the story. Reader **Tania Hanson-De Young** doubted that timeline and thought it was possible for a tick to transmit the bacteria within a day.

It's very unlikely that Lyme-causing bacteria could infect a person in less than 36 hours, says **Charles Chiu**, an infectious disease physician and microbiologist at the University of California, San Francisco. Data from multiple studies in rodents support the CDC timeline, he says. And a study in humans, published in 2001 in the *New England Journal of Medicine*, "provides empirical evidence that transmission at less than 24 hours is extremely rare," **Chiu** says.

Of course, there are factors that may affect transmission time in people, he says. Some of those factors include the maturity of the tick and the number of feeding ticks on a person.

Ancient split

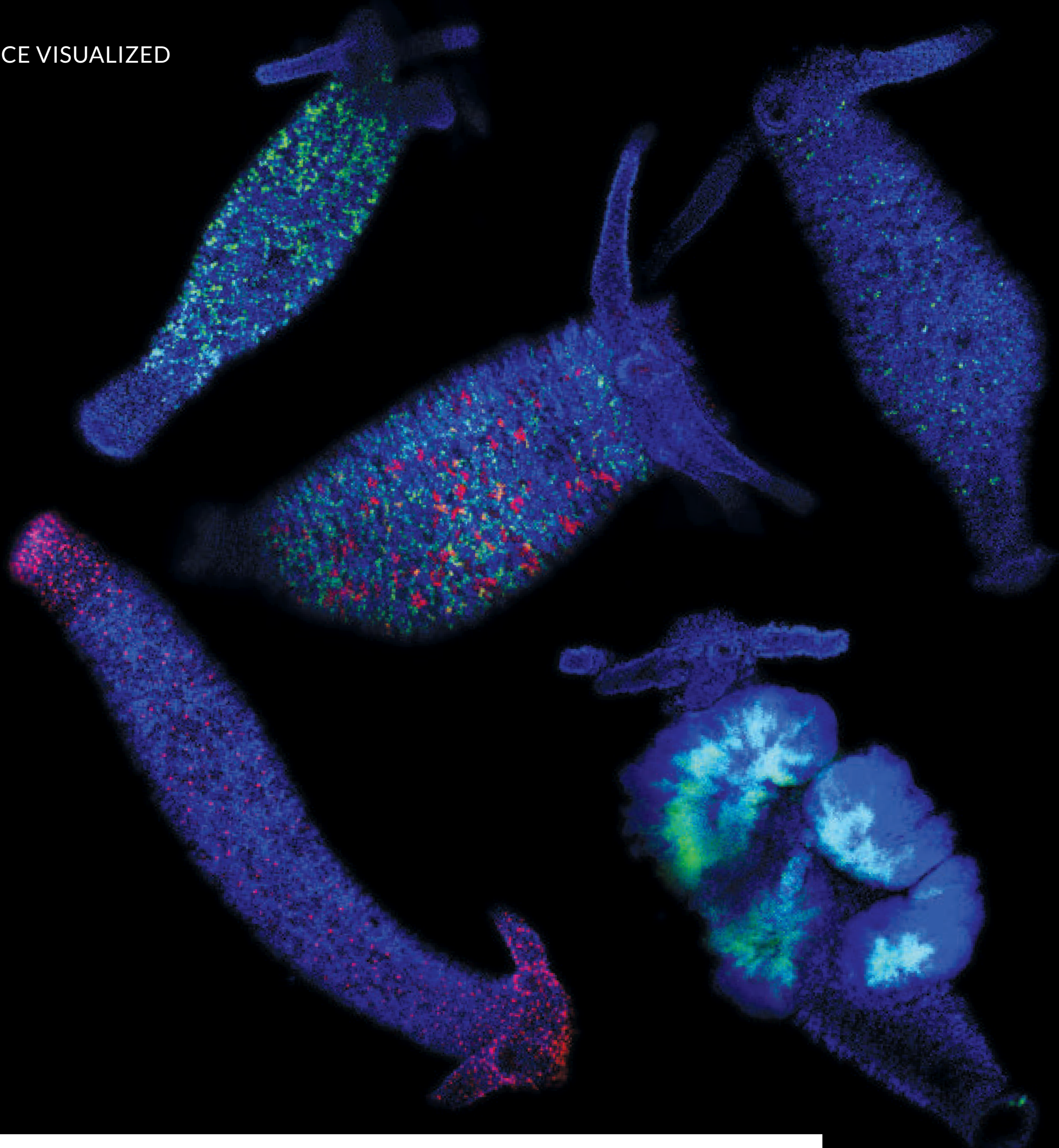
Fossil teeth found in Spain suggest that Neandertals and humans split from a common ancestor nearly 1 million years ago, ***Bruce Bower*** *reported in "Neandertal split came earlier"* (SN: 6/22/19, p. 8).

Reddit user **idriveataco** wondered why Neandertals aren't considered part of the human species. "We were able to breed with them and have viable offspring. Isn't that a determinant of speciation?" **idriveataco** asked.

The traditional definition of "species" as a group of organisms that can breed only among their own kind doesn't always hold up (*SN: 11/11/17, p. 22*). Many closely related animal species interbreed, as do plants, **Bower** says.

"Anthropologists have argued for decades about whether Neandertals were a separate species called *Homo neanderthalensis,* or were a big-boned, slope-jawed version of *Homo sapiens,*" he says. Some scientists have used ancient DNA studies to argue for Neandertals as a separate species, which is the most popular view. "It's still not clear, though, how many DNA differences are enough to establish without doubt that … Neandertals belonged to a species apart from *Homo sapiens,*" **Bower** says. "Stay tuned."

JOHN T. CONSOLI/UNIV. OF MARYLAND



Glowing hydras hint at mysteries of regeneration

Hydras seem to have found the fountain of youth. The tiny freshwater invertebrates (one shown at right) can regrow their entire bodies from a scrap of tissue and perpetually renew their cells. "Every 20 days, it's basically a completely new animal," says Celina Juliano, a developmental biologist at the University of California, Davis.

The animal's regenerative superpowers hinge on three groups of stem cells that develop into the cells of the hydra's nerves, glands and other tissues. Scientists now have the best views yet of which genes turn on as those cells journey toward their fates, Juliano and colleagues report in the July 26 *Science*.

The team analyzed nearly 25,000 cells from the roughly 1-centimeter-tall hydras. Creating fluorescent markers that latched onto RNA in cells illuminated which genes were activated as the animals' stem cells developed into specific cell types. One hydra (at center above), for example, shows gene activity involved in two stages of development of the animal's stinging cells (early, green; late, red). Other hydras reveal gene activity in fully developed nerve cells (bottom left; red) and sperm cells (bottom right; green). Two more hydra (top left and right) show gene activity in stem cells (green).

The work could reveal fundamental principles of how regeneration works, and may aid research on regenerating tissue in humans. *— Carolyn Wilke*

TOP IMAGES: STEFAN SIEBERT AND YASHODARA ABEYKOON/JULIANO LAB/UC DAVIS; INSET: S. SIEBERT/JULIANO LAB/UC DAVIS

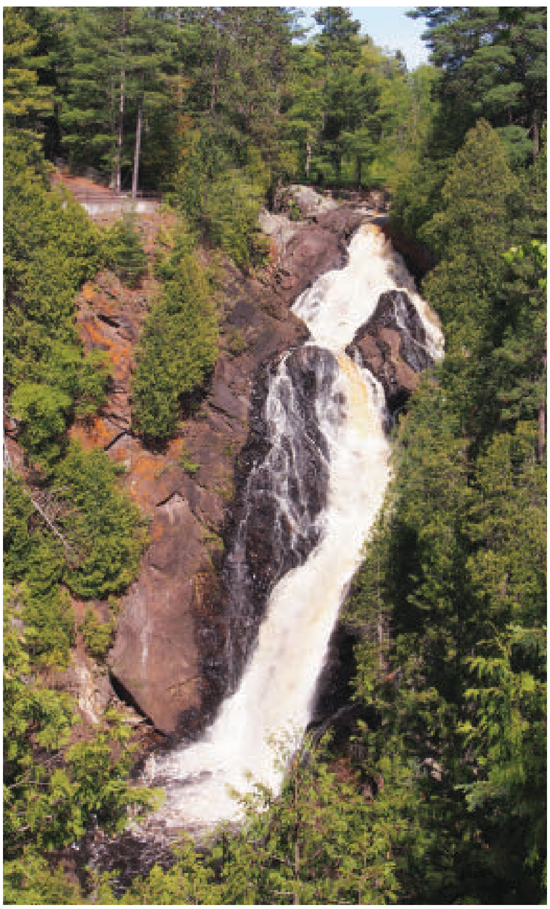
GEOLOGIC ROAD TRIP OF THE MONTH

PATTISON STATE PARK

The chief attraction at Pattison State Park is Big Manitou Falls, Wisconsin's highest waterfall and the fourth highest east of the Rocky Mountains. The Black River, one of several relatively short rivers that drain the Northern Highlands and flow into Lake Superior, plummets 165 feet where it crosses the Douglas Fault. The escarpment along the fault is made of basalt more than 1 billion years old that was heaved up above the much younger sandstone to the north. The basalt walls near the waterfall have a noticeably brownish color—the stain of oxidation caused largely by limonite, a commonly occurring iron oxide.

As the Wisconsin ice sheet retreated north more than 10,000 years ago, it left behind a moraine—a pile of glacial debris that accumulated at the margin of the glacier. The moraine lay parallel to the south shore of Lake Superior and covered the Douglas Fault escarpment. Glacial Lake Duluth also covered the escarpment, leaving behind a thick layer of lake bed clay. The Black River, flush with glacial meltwater, rapidly cut through the clay and moraine and then went to work eroding the bedrock. The river found a route along a cross fault, a short fault lying at an angle to the main Douglas Fault. The zone of breccia along the cross fault, shards of basalt shattered by the faulting action and cemented together over time, is less resistant than the surrounding mass of basalt, so the falls has migrated upstream along it to the main fault. About 1.5 miles upstream of Big Manitou Falls is Little Manitou Falls, which plunges over a 31-foot-tall ledge of basalt into another breccia zone along another small fault associated with the Douglas Fault system.

Upstream from the big falls, Little Manitou Falls flows over dark basalt. The Black River's root beer color is due to tannins and other organic acids in the river, picked up in vast wetlands in its headwaters.



Big Manitou Falls cascades down the basalt escarpment upstream from the Douglas Fault.

Downstream of the fault and Big Manitou Falls, the river created a 100-to-170-foot gorge in the bedded sandstone of the Bayfield Group, which is much younger than the basalt ledge at the Douglas Fault. At one of the vantage points on the park's geology walk (for which a guidebook is available in the park office), visitors can see where the fault is located—downstream from the big falls, which has since migrated upstream.

Before European immigration, the Native Americans in the area were the Ojibwe, who called the falls Gitchi Monido, for the Great Spirit whose voice they heard in the roar of the falls. Manitou is a variation of that name, probably invented by an early French explorer. Native American groups collected copper from the park area between 6,000 and 500 years ago, using it for decorative items, tools, and weapons. Later, European immigrants attempted to mine copper commercially without much success.

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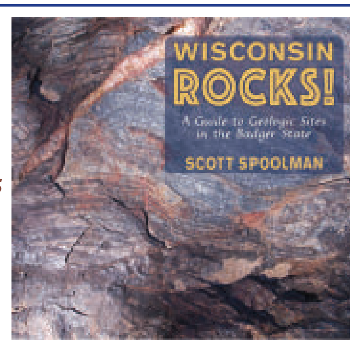

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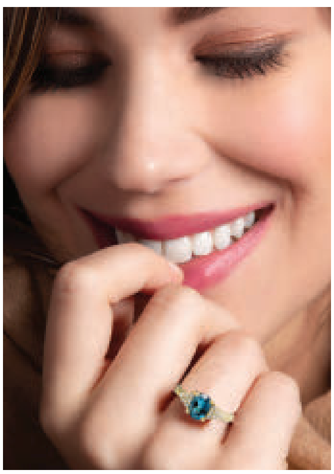

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