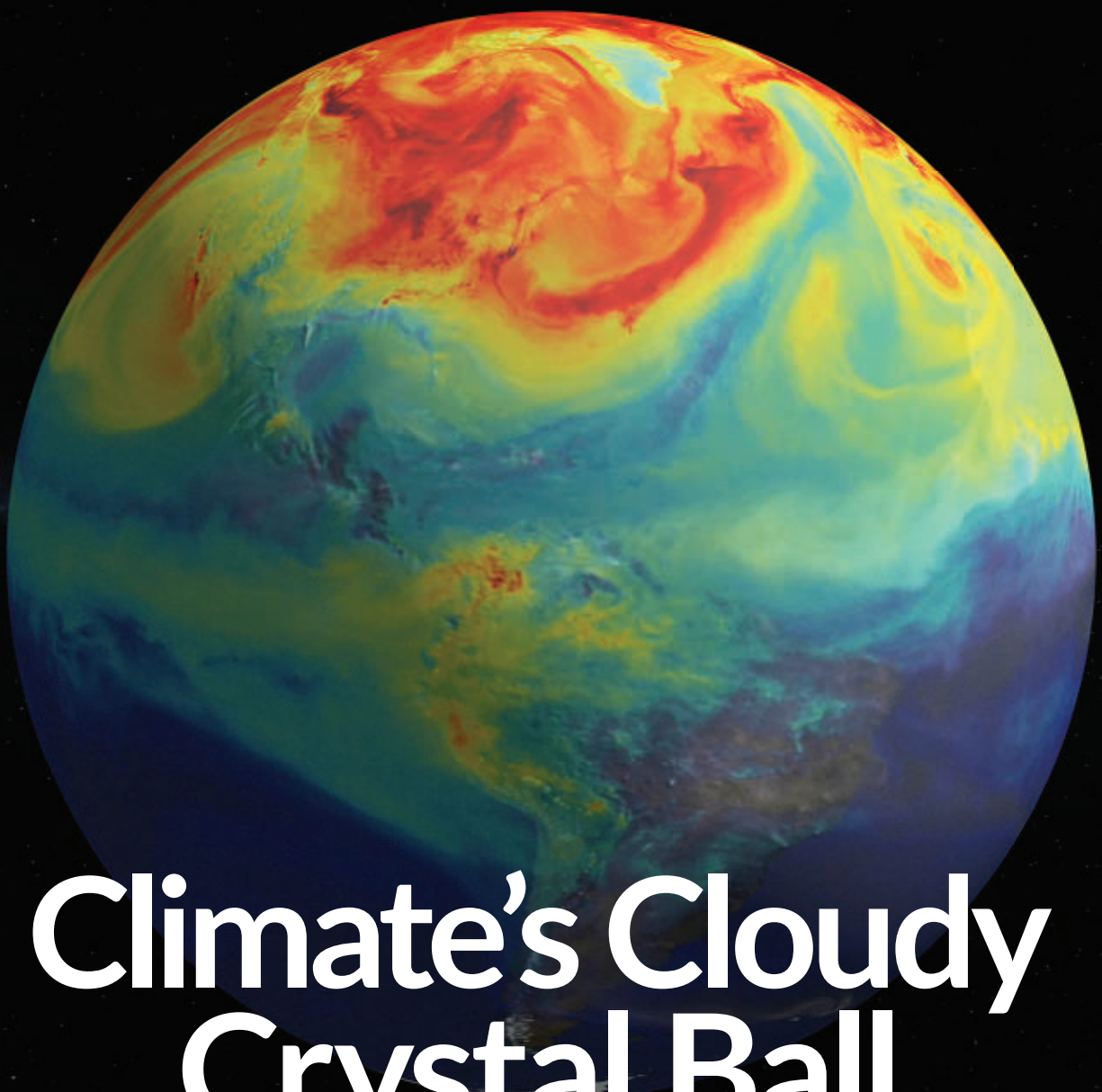
Misbehaving Kaons | Spitzer Space Telescope's Farewell

ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC ■ FEBRUARY 29, 2020



Climate's Cloudy Crystal Ball

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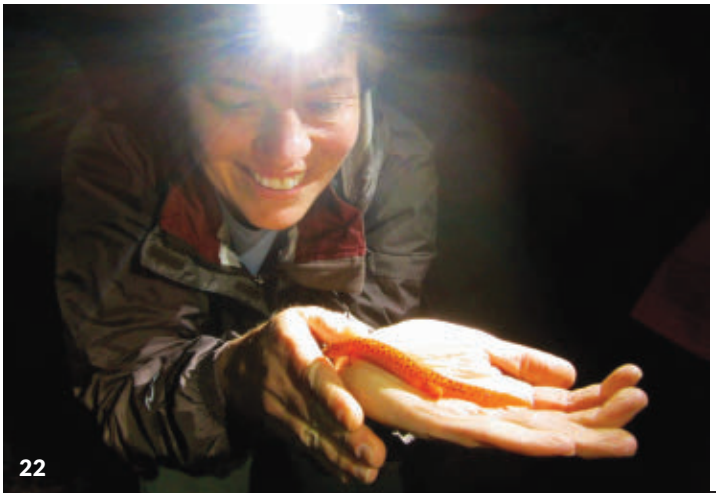
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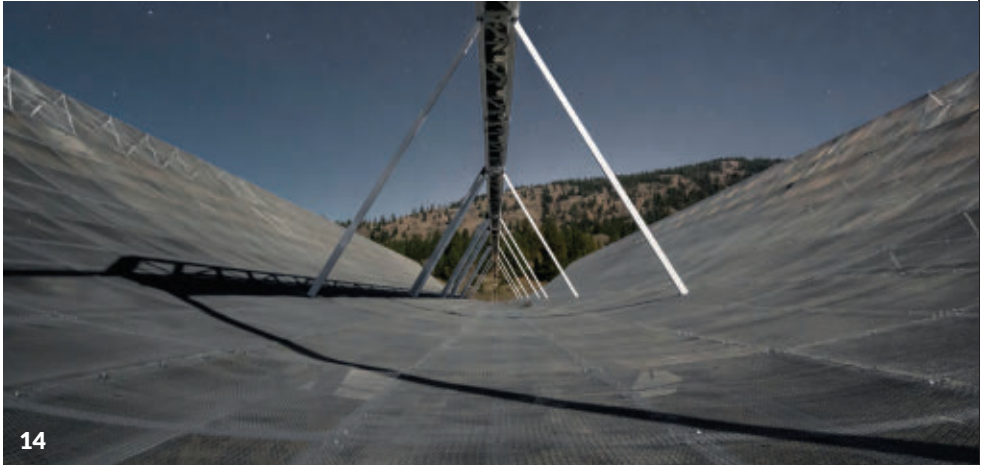
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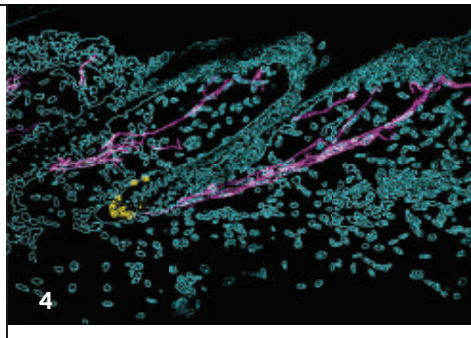
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Departments

COVER Atmospheric carbon dioxide (higher levels are red in this simulation) is a driver of global warming. *slavemotion/iStock/Getty Images Plus*

FROM TOP: CARLY MULETZ WOLZ; BING ZHANG, YA-CHIEH HSU; CHIME COLLABORATION

Modern-day oracles with a supercomputer

Humans have always sought to see the future and have called on many aids, from the movements of the stars to the fuzzy midsection of a woolly bear caterpillar (a wider brown band supposedly meant a milder winter). Sometimes the divination is all in fun; remember those paper "cootie catcher" fortune-tellers from childhood? But at other times, our lives depend on it.

For millennia, humans have closely observed changes in the weather in an attempt to deduce patterns that might help predict the next drought, flood or hurricane. By about 650 B.C., the Babylonians had developed weather predictions based on the appearance of clouds and other atmospheric phenomena. Aristotle followed with *Meteorologica*, a treatise based on his observations of the weather as well as his study of astronomy and chemistry.

Starting in the Renaissance, scientists invented tools to more precisely monitor weather, forming the basis of atmospheric physics. Nicholas of Cusa designed a hygrometer for measuring humidity in the 15th century; Galileo followed with an early version of a thermometer. By 1643, Evangelista Torricelli had invented a barometer to measure atmospheric pressure.

As people around the world shared observations and data, atmospheric patterns emerged, but prediction remained a challenge. In 1922, mathematician Lewis Fry Richardson tried to calculate a forecast eight hours into the future — and it took him six weeks. He then estimated that it would take 64,000 human "computers" working together in one room to provide timely weather forecasts.

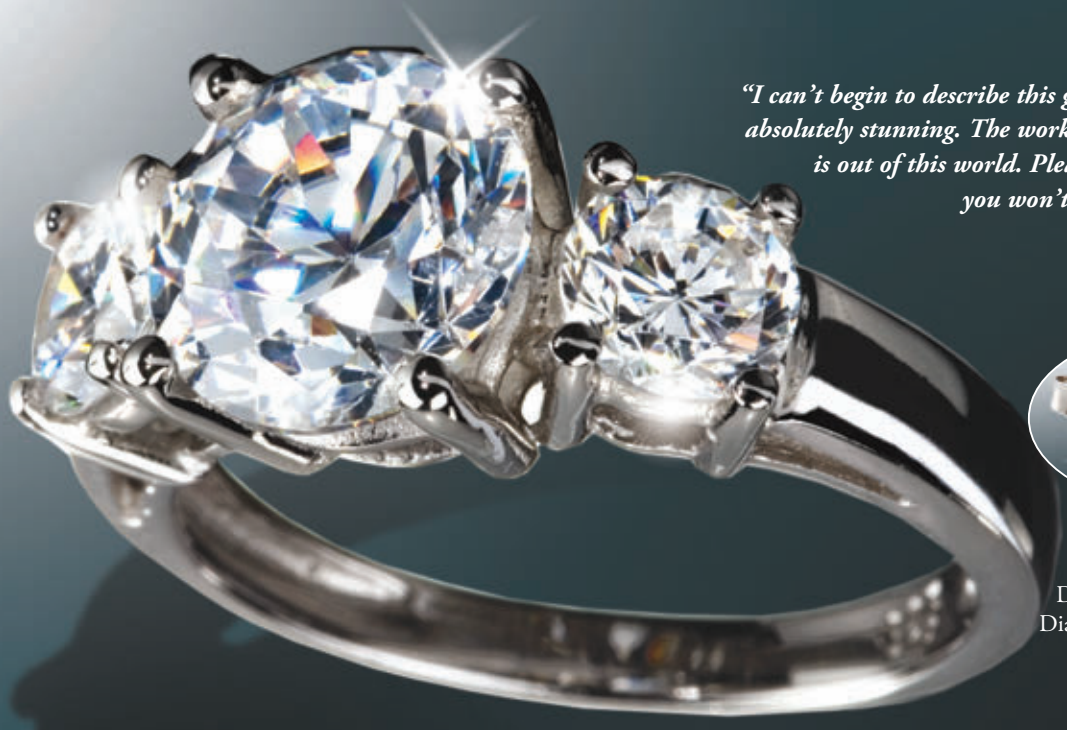
Today, a supercomputer can whip through much more daunting calculations in the blink of an eye, taking in data from around the world and cranking out startlingly accurate forecasts five days out. But we also have a much larger challenge at hand — predicting years, even decades out how increases in atmospheric carbon dioxide will reshape our world.

For more than half a century, scientists have been building computer programs called climate models to try to figure that out. Beginning in the late 1950s, models looked separately at discrete parts of the planet, such as the atmosphere or oceans. Today's models powered by supercomputers can bundle together these factors, while also incorporating global data on vegetation, sea ice, dust, sea spray and marine ecosystems. Some track how society, via population or economic growth and global conflict, may affect the climate.

Recent models are delivering surprises, earth and climate writer Carolyn Gramling reports (Page 18). "The better they get, the more we realize there are more complexities, and we need more data," Gramling says. That means more experiments with the models and more data gathered in the field. "These people are really brilliant, and they're all engaged in trying to solve this problem right now," Gramling says of the scientists. "It gives me hope, that we have these really wonderful minds hard at work on the problem."

Considering how much progress we've made since Richardson's imagined room crammed with 64,000 human calculators, there's room for optimism.

— Nancy Shute, Editor in Chief



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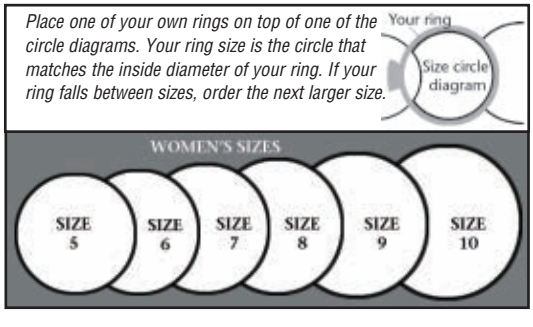

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Excerpt from the February 28, 1970 issue of *Science News*

50 YEARS AGO

Solar eclipse

This year's eclipse [offers] an important opportunity for observation.... The temperature of the main body of the sun is about 6,000° Celsius, but the temperature in the corona goes up to millions of degrees. Some observers will seek to determine ... the nature of the heating mechanism and the possible role of magnetic fields in keeping hot regions separated from cool ones.

UPDATE: We still don't know how the corona, the sun's outer atmosphere, reaches such extreme temperatures. Theories suggest the sun's magnetic field somehow shifts solar energy to the corona, more than 2,000 kilometers above the sun's surface. Plasma tendrils erupting from near the sun's surface might transfer energy to the corona in conjunction with magnetic field realignments (*SN: 12/7/19, p. 14*). NASA's Parker Solar Probe, launched in 2018, will measure the magnetic field from within 6 million kilometers of the sun's surface (*SN: 7/21/18, p. 12*). Until then, a detailed infrared image of the corona taken during the 2017 solar eclipse could shed more light on the magnetic field.

IT'S ALIVE

Texas has its own rodeo ant queens

Alex Wild has found new rodeo ants in, of course, Texas. These *Solenopsis* ants grip tight and ride the backs of bigger queen ants of a different species. It's not, however, just random piggyback fun.

The shiny little riders hang on with mouthparts that have evolved a snug fit around the waist of the much larger queen, says Wild, a naturalist who curates the insect collections for the University of Texas at Austin. The hangers-on are queens themselves, but Wild has yet to find workers of the new rodeo ant species he identified. These royal rodeos might let a parasitic queen skip having to create her own entourage, allowing her to live off food scammed from the bigger queen's colony.

Scams are a risk of social living. "We humans build cities," Wild says. "All sorts of things come to hang around." It's the same for ant nests; queen-riding unlocks those riches for grifters.

Wild coined the nickname "rodeo ant." But biologists already knew of a few species that hugged the backs of other species' queens and probably sneaked food. *Tetramorium inquilinum*, a parasitic ant first found in the Swiss Alps, grows large claws and a concave rear underside that fits a big queen's back.

That clinging freeloader isn't a waist-grabber, but Florida researchers found two different kinds that are. Specimens are sparse, though. A single queen, shorter than a rice grain, turned up in 1992, mouth-clamped around the waist of an unrelated big-headed *Pheidole* ant. After 14 years without finding another specimen, the team described the lone find and gave her a name, *Solenopsis phoretica*. Then, two years later, a different group of Florida researchers named a second species, *S. enigmatica*, based on two queens and a few workers from the Caribbean island of Dominica.

Wild unexpectedly joined the quest for these elusive queen-riding ants one morning in March 2017 while walking along trails near the Brackenridge Field Laboratory, an urban field station reachable by Austin city bus. As an ant biologist, he routinely flips over stones to "see what's nesting under them," he says. Under one stone scurried a colony of big-headed ants and, surprisingly, "something on the back of the queen."

That something was the new Texas rodeo ant, a mouth-clamping *Solenopsis* species yet to be formally named, Wild reported November 17 in St. Louis at the 2019 meeting of the Entomological Society of America. Her head shape and notched mouthparts allow a snug grip around the waist of the species she rode.

Wild urged his students to leave no Brackenridge stone unturned, and Jen Schlauch found a small, reddish ant riding a darker queen different from the big-headed ant parasitized by Wild's queen. Under the microscope, the rider also looked different from Wild's rider, suggesting there's yet another species of rodeo ant living in Texas. — *Susan Milius*

Meet a rodeo ant. The little ant on the big one's back is a queen of a species discovered in Austin, Texas. It has the right mouthparts and head shape to grip the waist and ride a queen of the bigger species shown here.

A. WILD

RETHINK

Mount Vesuvius victims likely suffocated

When Mount Vesuvius erupted in A.D. 79, the blast didn't vaporize everyone nearby, as previously suggested. People in Herculaneum, a seaside outpost near Pompeii, likely suffocated and baked in stone boathouses used as shelter, researchers report online January 23 in *Antiquity*, based on an analysis of skeletons in the boathouses.

Collagen levels in ribs from 152 of the individuals were higher than if those people had been vaporized by volcanic gases and ash, the team found. Microstructures in the victims' rib bones also suggest people were exposed to lower temperatures when they died than those caught out in the open, where air sizzled at up to 480° Celsius.

The results hint at a grisly scenario in which Herculaneum residents hid for protection, only to suffocate on volcanic gas and overheat in their sanctuary. Most of those victims were women and children. Many found on a nearby beach were men, possibly having dragged out boats to escape the eruption. — *Erin Garcia de Jesus*

Evidence suggests some victims of Mount Vesuvius' eruption suffocated and faced ovenlike conditions in stone shelters.

FOR DAILY USE

The trick to brewing a better espresso shot

New research challenges conventional wisdom that brewing an espresso shot requires very finely ground coffee beans.

In brewing espresso and running computer simulations of the process, researchers found that using finer grounds generally allowed water to absorb a higher percentage of the dried coffee, but only to a point. When filtered through beans ground to the finest settings on a standard machine, the hot water extracted a lower percentage of coffee than water filtered through slightly coarser grounds, researchers report online January 22 in *Matter*.

The experiments and simulations showed that, with the finest grounds, very small coffee particles wedge into gaps between other particles, says study coauthor Jamie Foster, a mathematician at the University of Portsmouth in England. That means water flows unevenly through the grounds, oversampling some parts while missing others, which wastes coffee and produces inconsistent flavor.

In tasting fine-ground espresso, coauthor and chemist Christopher Hendon of the University of Oregon in Eugene says he detected both the bitter notes of overextracted coffee and the sour hints of underextracted grounds. "That's a really strange flavor profile."

The coarser grounds eliminated the clogging issue and created more consistent taste. "You've extracted [coffee] more efficiently," Foster says, so "you can afford to use less coffee."

A café in Eugene helped test this strategy for a year starting in September 2018. Brewing espresso shots with 15 grams of coarser grounds rather than 20 grams of fine grounds saved more than $3,600. — *Maria Temming*

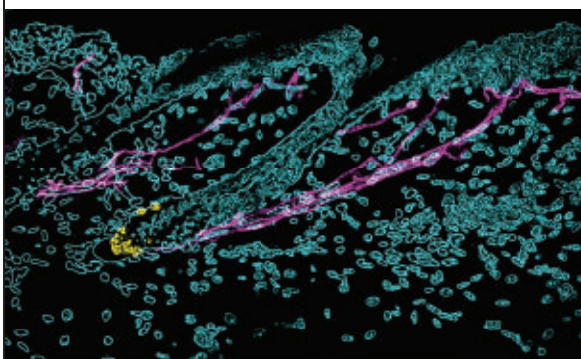
MYSTERY SOLVED

Here's how stress can make hair go gray

Stress has long been suspected of turning hair gray. Just think of U.S. presidents before and after their time in office. Now, scientists have figured out how that works. Stress triggers the body's fight-or-flight response, which causes pigment-producing cells that give hair color to go into a frenzy and dwindle in number, researchers report in the Jan. 30 *Nature*. Once the pigment cells are gone, so is the color.

The researchers stressed mice by injecting them with a compound related to capsaicin, the ingredient that makes chili peppers hot. Within five days, the mice's hair turned white, and part of the nervous system was depleting pigment cells from hair, the team found.

Melanocyte stem cells in hair follicles convert into pigment-producing cells, giving hair its color. Since the body can't replenish stem cells, color vanishes as the cells are used up. The sensory stress in the experiment triggered the mouse sympathetic nervous system to release the neurotransmitter norepinephrine. That compound overactivates the stem cells, setting off a flurry of conversion into pigment-producing cells. And that rapidly uses up the stem cell supply. The work raises questions about whether the stress-related graying process is the same in aging. — *Erin Garcia de Jesus*



Stress triggers nerves (pink) in the sympathetic nervous system to deplete hair-coloring stem cells (yellow) at the bottom of hair follicles. Teal marks other cells' nuclei.

CLOCKWISE FROM TOP: R. MARTYN *ET AL*/*ANTIQUITY* 2020; BING ZHANG, YA-CHIEH HSU; NATHAN DUMLAO/UNSPLASH

HUMANS & SOCIETY

Africans carry Neandertal genes too

Ancient migrations from Europe probably introduced the DNA

Ancient humans living in Europe (example of a *Homo sapiens* skull, left) interbred with Neandertals (right) before migrating back into Africa and spreading Neandertal genes to humans living on that continent.

FROM LEFT: THE NATURAL HISTORY MUSEUM/ALAMY STOCK PHOTO; SABENA JANE BLACKBIRD/ALAMY STOCK PHOTO

BY BRUCE BOWER

Africans today possess more Neandertal ancestry than previously thought, a new analysis shows, though still not as much as most people outside of Africa.

People who migrated out of Africa about 60,000 to 80,000 years ago mated with Neandertals. That set the stage for some human groups to return to Africa carrying Neandertal genes that spread throughout the continent, apparently because those genes were beneficial, scientists report online January 30 in *Cell*.

Sets of Neandertal gene variants inherited by modern Africans include genes involved in bolstering the immune system and modifying sensitivity to ultraviolet radiation, Princeton University geneticist Joshua Akey and colleagues found. A new statistical approach for detecting ancient genetic material that's still present in modern DNA, developed by Akey's team, enabled this discovery of genetic inheritance that had gone unnoticed until now.

The team also detected an earlier migration of *Homo sapiens* out of Africa about 100,000 to 150,000 years ago during which Neandertals acquired human genes via interbreeding. In the study, some African people's DNA that appeared at first to have been inherited from Neandertals actually came from those ancient migrating humans, the researchers determined.

"Our work highlights how humans and Neandertals interacted for hundreds of thousands of years, with populations dispersing out of and back into Africa," Akey says. "Remnants of Neandertal DNA survive in every modern human population studied to date."

Akey's team compared DNA from 2,504 present-day Africans, Europeans, East Asians and Americans with DNA extracted from Neandertal fossils found in Siberia and southeastern Europe.

The new statistical program calculates the probability that specific segments of a person's DNA represent an inheritance of Neandertal DNA segments. In contrast, previous approaches compared living people's DNA with that of Neandertals and a modern African group assumed to lack Neandertal ancestry. But if those reference groups actually possess Neandertal DNA, as indicated by the new report, then earlier studies underestimated Neandertals' genetic legacy.

DNA from Neandertals accounts for, on average, about 0.5 percent of individual Africans' genetic inheritance, or genome, far more than reported in earlier studies, Akey's team says. Most people outside of Africa today carry about three times as much Neandertal DNA as Africans do. More than 94 percent of Neandertal DNA sequences detected in today's Africans have also been observed in non-Africans, the team says.

The study also identifies comparable proportions of Neandertal DNA in the genomes of modern Europeans and East Asians, about 1.7 percent and 1.8 percent respectively. Earlier studies had estimated that East Asians possessed about 20 percent more Neandertal ancestry than Europeans.

Although the efficacy of Akey's method awaits independent confirmation, "it seems real to me," says paleogeneticist Carles Lalueza-Fox of the Institute of Evolutionary Biology in Barcelona. Along with a 2012 study of Neandertal ancestry in modern North Africans, the new report best fits a scenario in which human evolution after about 300,000 years ago featured "failed, partly successful and successful population movements out of Africa; hybridization between genetically different *Homo* populations; and back-to-Africa migrations," Lalueza-Fox says.

Paleogeneticist Cosimo Posth of the Max Planck Institute for the Science of Human History in Jena, Germany, says Akey's approach "provides an unprecedented opportunity to detect Neandertal ancestry in people around the world."

Other DNA evidence suggests that humans and Neandertals interbred in Europe and Asia perhaps 60,000 years ago. But Neandertals didn't mate with ancient people in Africa, Akey's group finds. Instead, the team's computer simulations indicate that low levels of human migration from Europe to Africa over roughly the last 20,000 years injected Neandertal DNA into African populations.

That conclusion stems from a geographic imbalance in shared Neandertal DNA among people today. Africans exclusively share 7.2 percent of their Neandertal ancestry with Europeans versus 2 percent with East Asians, the researchers find. That makes Europe a more likely launching ground for back-to-Africa migrations by humans carrying Neandertal genes. ■

BODY & BRAIN

Coronavirus may spread silently

People with no symptoms can infect others, study suggests

BY TINA HESMAN SAEY

As the coronavirus disease outbreak continues, researchers have found that people carrying the virus but not showing symptoms may be able to infect others. If infected people can spread the virus while asymptomatic, it could be harder to trace contacts and contain the epidemic.

A Shanghai woman passed the virus to colleagues in Germany before showing signs of the illness, doctors report online January 30 in the *New England Journal of Medicine*. The woman had attended a business meeting at the headquarters of the auto supplier Webasto in Stockdorf on January 20 and flew back to China on January 22. She developed a fever and chest pain about eight hours after arriving in Shanghai. She tested positive for the virus on January 26.

Meanwhile, one of her German colleagues began to feel ill on January 24 developing a fever, sore throat, chills and muscle aches. Nasal swabs and phlegm samples from the man had high levels of the coronavirus even after symptoms had passed. More testing is needed to see whether virus particles left after recovery are infectious, say infectious disease specialist Camilla Rothe of the University Hospital of Ludwig-Maximilians-Universität in Munich and colleagues.

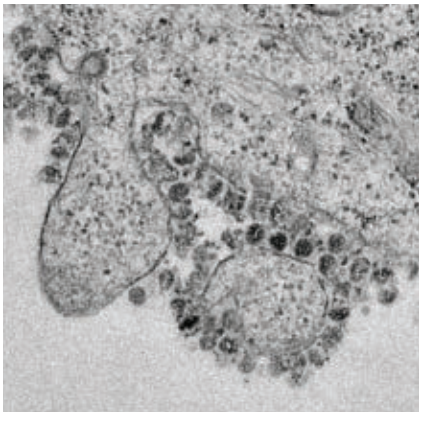
Three other Webasto employees also tested positive for the virus. Tracing their contacts, doctors concluded that the first man, known as patient one, and another person caught the virus from their Chinese colleague. Patient one apparently passed the virus to the other two coworkers, patients three and four, who both had contact with him before he developed symptoms, Rothe's team says.

Asymptomatic spread, though common for flu viruses, would be a new trick for coronaviruses. Some researchers, however, have questioned whether the virus really did spread asymptomatically in this case, though other instances of asymptomatic spread have been reported in China. "There seems to be some mounting evidence that may occur with this virus," says epidemiologist Aubree Gordon of the University of Michigan School of Public Health in Ann Arbor. "We don't know how common that is."

In a follow-up to the original report on the German cases, Bavarian health authorities and researchers at the Robert Koch Institute in Berlin interviewed the Chinese woman by phone and discovered she may have had some mild nonspecific symptoms, including a backache, while in Germany. She had also taken medication that lowers fevers, she said. The case is being investigated to determine whether she was, in fact, symptomatic, a spokesperson for the Bavarian Health & Food Safety Authority said in an e-mail to *Science News* on February 6.

But according to a detailed timeline of events published February 6 in the *New England Journal of Medicine* by Rothe and colleagues, the woman felt a little warm one evening but didn't have a fever. She took a medicine containing acetaminophen as a preventative measure to be ready for her meetings. She also reported having mild pain in the muscles and bones of her chest and being tired in the afternoon, which was her usual bedtime in China.

Whether feeling a little warm, achy and tired were symptoms of the infection or just normal consequences of jet lag may be difficult to determine. Rothe and colleagues say they stand by their description of the woman as asymptomatic, but they published the timeline to give others the chance to decide for themselves.



A cell infected with the new coronavirus can produce thousands of infectious virus particles (black dots along the cell's edges), as seen in this electron micrograph.

JOHN NICHOLLS, LEO POON AND MALIK PEIRIS/UNIV. OF HONG KONG

Concerns over the original report led Anthony Fauci, director of the U.S. National Institute of Allergy and Infectious Diseases in Bethesda, Md., to call a public health scientist in China, Fauci said February 6 during a recorded briefing with Howard Bauchner, editor in chief of the *Journal of the American Medical Association*.

Fauci's contact in China confirmed that people "absolutely" may have asymptomatic infections and could pass the virus to others. But asymptomatic transmission does not seem to be the primary way the virus spreads and probably won't affect the course of the epidemic much, Fauci said. More work is needed to understand exactly when during an illness a person can pass on the virus, he said.

Gordon has her own questions about the possibility of asymptomatic infection among the Webasto employees. Patient one supposedly had contact with one of his coworkers, patient three, only on January 20 and 21 — the same period in which patient one was exposed to the virus by his Chinese colleague. That's probably too short of an incubation period, based on what's known so far of the virus. Gordon suspects there may have been forgotten contacts between the coworkers closer to the time symptoms developed, or the virus may have spread from using "the same bathroom, the same conference room or coffeepot." It's unclear how long this coronavirus lingers on surfaces; most last only a few hours.

Although people may be able to give off infectious virus before they feel sick, Gordon says, "it may not be that easy to detect people really early in the illness even if they do have symptoms." Initial signs of the coronavrius disease, called COVID-19, resemble colds or flu. That combined with the estimates of how infectious the virus is "really leads us to worry. It's going to be very hard to control this virus, if that's even possible." ■

ATOM & COSMOS

Odd data hint at a new particle

Misbehaving kaons challenge physicists' standard model

BY EMILY CONOVER

A little-known type of particle called a kaon may be stepping into the spotlight.

This subatomic particle is attracting attention for unexpected behavior in a particle accelerator experiment. Rare kaon decays seem to be happening more often than expected. If the result holds up, the finding could hint at a never-before-seen particle that would dethrone particle physicists' reigning theory, the standard model.

There's still a good chance the researchers' result will be overturned, says physicist Yuval Grossman of Cornell University. But "there's the extremely exciting possibility that they see something totally new."

The standard model describes the particles and forces that underpin the universe. But there are still puzzles to solve, such as why there's more matter than antimatter in the universe. So physicists are leaving no stone — or kaon — unturned to test the theory. One realm subject to scrutiny is certain very rare decays of kaons. The standard model predicts precisely how rare those decays are. The KOTO experiment at the Japan Proton Accelerator Research Complex in Tokai was built to test that prediction.

KOTO should have seen only a fraction of a decay, on average, over a few years' worth of data. But in September in Perugia, Italy, at the International Conference on Kaon Physics, KOTO scientists reported four potential decays.

"It's hair-raising for sure," says physicist Yau Wah of the University of Chicago, a KOTO spokesperson. But particle physics experiments are notorious for spurious signals that can mimic real particles. More studies must be done, Wah says.

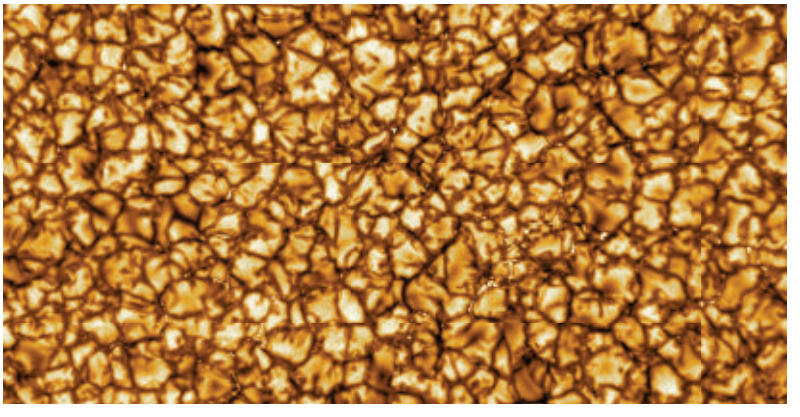
That hasn't stopped physicists from considering implications and proposing explanations for the anomaly.

KOTO searches for a particular decay of a kaon into three other particles. One of the particles, a pion, produces light that KOTO detects. The other two, a neutrino and an antineutrino, sail through the detector without a blip. So KOTO looks for one pion and nothing else. One possible explanation for the four detections is that the kaon may be decaying into a pion plus a new type of particle that, like neutrinos, leaves no trace. That scenario would reproduce the one-pion signature KOTO searches for and may happen more often, explaining the extra detections.

But there's a catch. KOTO studies kaons that have no electric charge; experiments studying charged kaons see no anomaly. If a new particle exists, it should show up for both types of kaons.

Differing sizes of kaon experiments could help explain the discrepancy between experiments, physicist Teppei Kitahara and colleagues report in a paper accepted in *Physical Review Letters*. Just a few meters long, KOTO is much smaller than other kaon experiments, says Kitahara, of Nagoya University in Japan. "Unstable new particles can easily escape the detector." In a larger detector, say, 100 meters long, the new particle could decay into other particles that could be spotted, so that the one-pion signature of decaying kaons wouldn't be reproduced. That could explain why, if a new particle exists, KOTO sees excess decays but other experiments don't.

Scientists are also considering connections to other puzzles. For example, experimental measurements disagree with predictions for the magnetic properties of electron-like particles called muons. "If you want to explain this ... you need a model beyond the standard model," says physicist Xiaoping Wang of Argonne National Laboratory in Lemont, Ill. She and colleagues have come up with a hypothetical particle that could simultaneously explain the muon conundrum and the unexpected kaon decays, the team reports January 17 at arXiv.org. ■



NSO/NSF AND AURA

ATOM & COSMOS

Snapshots illuminate new details of the sun

The world's largest solar telescope has captured the most detailed images of the sun's surface yet taken. Released January 29, the first views from the National Science Foundation's 4-meter-wide Daniel K. Inouye Solar Telescope, still under construction in Hawaii, reveal features just 30 kilometers across. The image above covers an area 36,500 kilometers across — about three times Earth's diameter — and shows plasma bubbles percolating up. In the dark lanes between bubbles, newly resolved clusters of bright points appear at the roots of magnetic fields that stretch out into space. Once completed, the telescope will, among other things, help scientists look for clues to what drives the space weather that can interfere with technology on Earth. — *Christopher Crockett*

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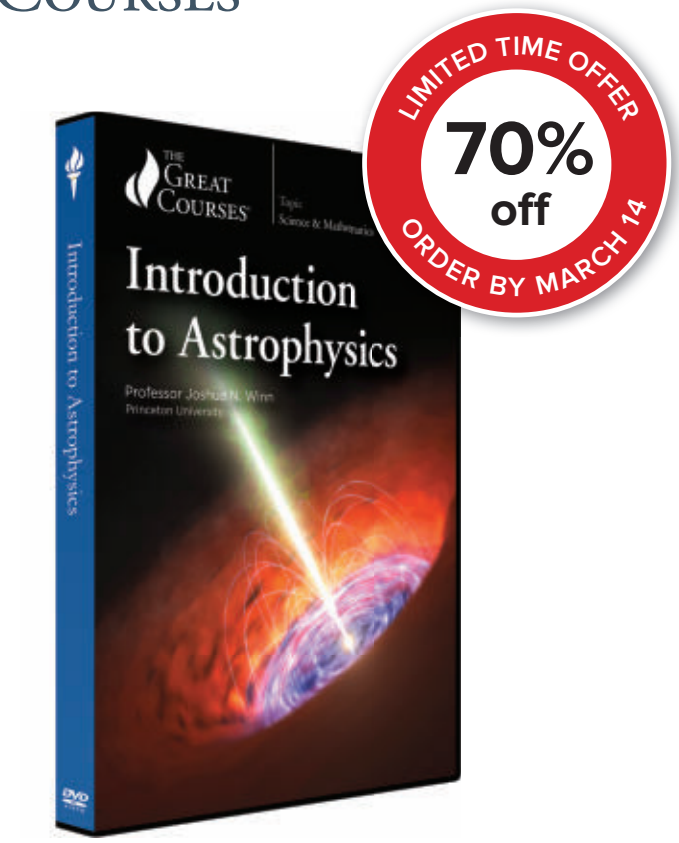

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HUMANS & SOCIETY

‘Megasites’ reshape history of cities

Archaeologists reconsider how early urban areas developed

BY BRUCE BOWER

The small Ukranian village of Nebelivka sits amid rolling hills and grassy fields. Here at the edge of Eastern Europe, empty space stretches to the horizon.

It wasn’t always so. Beneath the surface of Nebelivka’s surrounding landscape and at nearby archaeological sites, roughly 6,000-year-old remnants of what were possibly some of the world’s first cities are emerging from obscurity. These low-density, spread-out archaeological sites are known as megasites, a term that underscores their immense size and mysterious origins. Now, some scientists are arguing these settlements represent a form of urban life that has gone largely unrecognized.

Megasites were cities like no others, says archaeologist John Chapman of Durham University in England.

For decades, researchers have regarded roughly 6,000-year-old Mesopotamian sites, in what’s now Iraq, Iran and Syria, as the world’s first cities. Those cities arose after agriculture made it possible to feed large numbers of people in year-round settlements. Mesopotamian metropolises featured centralized governments, bureaucratic agencies that tracked and taxed farm production, and tens of thousands of residents packed into neighborhoods. Social inequality was central to this urban ascent, with a hierarchy of social classes that included rulers, bureaucrats, priests, farmers and slaves.

Over the last decade, however, archaeologists have increasingly questioned whether the only pathway to urban life ran through Mesopotamia. A growing number of researchers view megasites and other low-density, spread-out settlements elsewhere in the world as an alternative form of early city life.

Ukrainian megasites were built by members of the Trypillia culture between about 6,100 and 5,400 years ago. Typically covering a square kilometer or more, some sites were bigger in area than Manhattan.

Megasites may have been built to improve defense against invasions by rival villages or foreign forces. Based on that assumption, some estimates of population at these places run into the tens of thousands. But recent work at Nebelivka by Chapman and colleagues indicates megasites in general may have had only a few thousand inhabitants.

And Nebelivka appears to have lacked a class of ruling elites. Instead, excavations indicate, the site was organized to promote shared rule among groups of equal social standing. Thus, Nebelivka demonstrates that urban development doesn’t automatically split people into haves and have-nots, Chapman’s group argues.

Nebelivka novelty

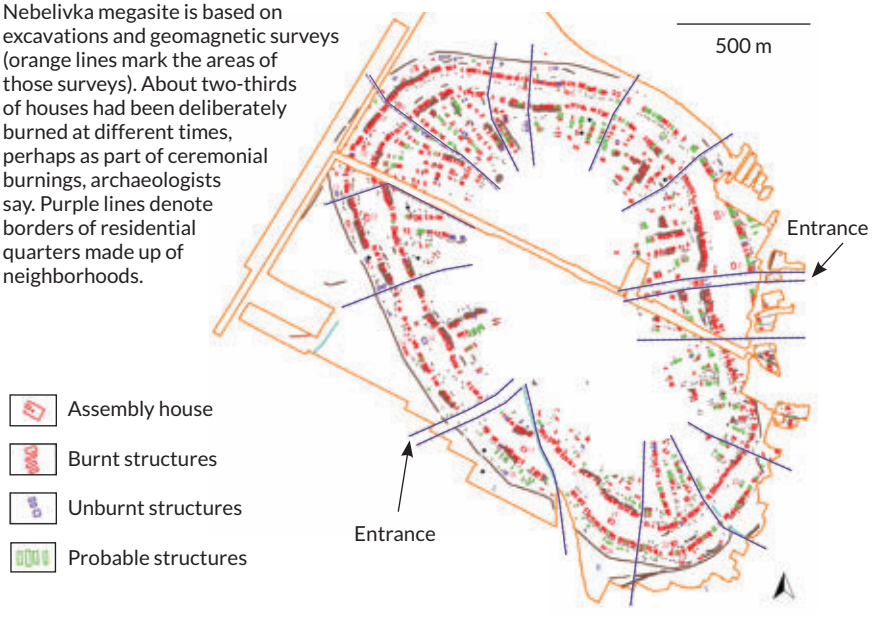
Archaeologists began excavating megasites in the 1970s. At least two dozen have been located in Ukraine.

At Nebelivka, Chapman, Durham colleague Marco Nebbia and independent, Durham-based scholar Bisserka Gaydarska have reconstructed the megasite’s entire layout. This settlement blueprint, the first of its kind for a megasite, appears in the February *Cambridge Archaeological Journal*.

Over six years of fieldwork since 2009, the team excavated and mapped structures located over more than a square kilometer. Aerial photos, satellite images and geomagnetic data, supplemented by excavations of 88 test pits, identified 1,445 residential houses and 24 communal structures dubbed assembly houses. Houses were grouped into 153 neighborhoods, a majority containing three to seven houses. Neighborhoods, in turn, formed 14 quarters, each with at least one assembly house situated in an open area.

No signs of a centralized government, a ruling dynasty, or wealth or social class disparities appear at Nebelivka, which was occupied for about 200 years, the team says. Houses were largely alike in size and design. Excavations yielded few prestige goods, such as copper items and shell ornaments. Many examples of pottery and clay figurines turned up, and more than 6,300 unearthed animal bones suggest residents ate a lot of beef and lamb. Those clues suggest daily life was much the same across Nebelivka.

Although Chapman and colleagues agree Nebelivka’s city life differed from that of Mesopotamian metropolises, the researchers disagree about the details.



City map This blueprint of Ukraine’s Nebelivka megasite is based on excavations and geomagnetic surveys (orange lines mark the areas of those surveys). About two-thirds of houses had been deliberately burned at different times, perhaps as part of ceremonial burnings, archaeologists say. Purple lines denote borders of residential quarters made up of neighborhoods.

Y. BEADNELL (BASED ON DATA FROM D. HALE), B. GAYDARSKA, M. NEBBIA AND J. CHAPMAN/*CAMBRIDGE ARCHAEOLOGICAL JOURNAL* 2020

Chapman suspects the megasite was a permanent settlement in which, at any one time, 2,000 to 3,000 people occupied up to 400 houses. Residents likely came from 10 regional groups, known from previous investigations of smaller Trypillia villages, that had traded goods and formed common cultural beliefs, he says. These groups established the neighborhoods and quarters outlined in the site plan, he speculates. Given the need to ease inevitable tensions among the groups, a council recruited from throughout Nebelivka may have made political decisions. Leadership might have even shifted annually from one group to the next, he says.

Nebbia thinks it's more likely that perhaps 3,000 to 4,000 people inhabited Nebelivka for about one month each year. During that time, people made new contacts, shared knowledge and goods, and conducted communal activities such as house building. Perhaps 100 to 150 guardians maintained Nebelivka year-round, he speculates.

A possibility favored by Gaydarska portrays Nebelivka as a center for religious pilgrims from throughout the Trypillia world. Over a roughly eight-month pilgrimage season, presumably scheduled for when weather permitted long-distance journeys, between 1,000 and 2,000 pilgrims per month inhabited Nebelivka, she suggests. Ritual leaders from various communities maintained the site and organized construction projects, she suspects, including the raising of assembly houses where religious ceremonies might have been held.

While the site plan can't unveil the exact nature of Nebelivka social life, the work reveals a large open space in the center of the megasite where researchers previously assumed many people lived. Earlier estimates that Nebelivka housed 10,000 people or more are thus way too high, the three researchers contend.

Power sharing

As at Nebelivka, an increasing number of sites in Asia, Europe and the Americas are being classified as low-density urban settlements, says archaeologist Roland Fletcher of the University of Sydney.

An artist's reconstruction shows what a Nebelivka assembly house, where communal gatherings likely occurred, might have looked like.

For instance, settlements comparable in size and population to megasites, called oppida, emerged in Europe over 2,000 years ago. Whether people inhabited oppida year-round or seasonally, these sites contained households of roughly equal status that participated in collective decision making, Fletcher says.

Aerial laser mapping has uncovered even larger examples of urban sprawl that date to about 1,000 years ago at Greater Angkor in Cambodia (*SN: 5/14/16, p. 22*) and 2,000 years ago at Maya outposts in Central America (*SN: 10/27/18, p. 11*). In those cases, kings and other power brokers ruled spread-out populations.

Though some of these sprawling sites had social inequality, egalitarian cities like Nebelivka were probably more common than has been assumed, says David Wengrow, an archaeologist at University College London. Ancient ceremonial centers in China and Peru, for instance, were cities with sophisticated infrastructures that existed before any hints of bureaucratic control, he argues.

Egalitarian rule may even have characterized Mesopotamian cities for their first few hundred years, a period that lacks archaeological evidence of royal burials, armies or big bureaucracies, Wengrow says.

Megasite mystery

Not everyone views Nebelivka as emblematic of an alternative branch of early city life. "Nebelivka may be an interesting example of a ritual, ceremonial or defensive gathering place rather than an 'all-purpose' city or a distinctive pathway to urbanism," says archaeologist Monica Smith of UCLA.

Unlike bustling Mesopotamian cities, with walls or other prominent structures along their borders, Nebelivka had a lot of open space and was encircled by only a ditch, Smith observes. From the start, cities brought together large numbers of people who had to cooperate with strangers and heed the edicts of political and religious leaders, Smith argues. Ancient cities typically had massive official structures and were densely occupied for thousands of years, unlike megasites that drew smaller crowds for several hundred years at most, she says. Smith reserves judgment on city life at Greater Angkor and the Maya sites, where further excavations might reveal higher-density occupations than currently suspected.

Smith suggests calling permanent and temporary gathering spots — a category that, in her view, includes Trypillia megasites — "collective settlements."

But Nebelivka and other megasites transcended Trypillia village life too dramatically to be classified simply as gathering places, Gaydarska argues. Trypillia people, she says, engaged in one of several early experiments in large-scale urban living, even if for only part of the year. It's time to revamp traditional ideas of what makes an ancient settlement a city, she says.

For now, the next challenge is to explain why the Trypillia megasites arose in the first place and lasted no more than around 700 years. To get a grip on that mystery, Gaydarska plans to excavate Trypillia villages dating to just before and after Nebelivka's heyday. "We have nothing to compare Nebelivka to at this point," she says. ■

C. UNWIN (BASED ON DATA FROM S. JOHNSTON); B. GAYDARSKA, M. NEBBIA AND J. CHAPMAN/*CAMBRIDGE ARCHAEOLOGICAL JOURNAL* 2020

LIFE & EVOLUTION

Modified microbes defend honeybees

Engineered gut bacteria send a self-destruct message to pests

BY SUSAN MILIUS

Deadly, fat-sucking mites and wing-wrecking viruses, take note: Specially engineered gut microbes can defend honeybees by tricking their enemies into self-destruction.

Snodgrassella bacteria were engineered to release double-stranded RNA molecules that dial down gene activity of a mite or virus. The pest then sabotages itself by shutting down some of its own vital genes. This strategy hijacks a natural gene-silencing process called RNA interference, or RNAi. The gut microbes churning out this targeted disinformation work "something like a living vaccine," says Sean Leonard, a microbiologist at the University of Texas at Austin.

The targeted approach is intriguing to scientists interested in fighting pests or other problems while minimizing the chances of hurting innocent bystanders.

In simplified tests, Leonard and colleagues targeted two big threats to North American honeybees: fat-sucking, parasitic *Varroa* mites and the deformed wing virus that those mites spread among bees (*SN: 2/16/19, p. 32*). The tests used young bees that had just shed their gut lining before taking their adult form and had not yet replenished their gut microbes. A dose of the engineered bacteria protected the bees, Leonard and colleagues report in the Jan. 31 *Science*.

For the mite test, the team tracked the fates of the pests. Mites were about 70 percent more likely to die within 10 days when feeding on bees with the booby-trapped gut microbes. Meanwhile, bees dosed with protective bacteria had a 37 percent higher survival rate 10 days after exposure to deformed wing virus.

This experiment is a proof of principle, Leonard says. Honeybees don't really live as they did in the tests — in plastic cups holding 20 equally youthful pals. The RNAi technique would need to work in the complexity of a full hive and full bee gut microbiomes, the collections of bacteria and other microbes found in the insects' innards.

"Bees have this remarkably consistent and conserved microbiome," despite the upheaval of metamorphosis, Leonard says. After transforming into an adult, a young bee replenishes its microbiome from hive mates. Normally five kinds of bacteria show up again and again, including the *Snodgrassella* bacteria engineered for this experiment.

Harnessing those bacteria to supply the double-stranded RNA is "a really novel and cool way to deliver this system," says honeybee epidemiologist Dennis vanEngelsdorp of the University of Maryland in College Park.

But he cautions that actual use is a long way off. Besides the inevitable pitfalls in trying to scale up a small lab test, he sees some big questions to consider. With RNAi, "you're turning off genes, and there has to be a very healthy debate about, 'How do we regulate this?' " he says. ■

LIFE & EVOLUTION

Pterosaur dinner included squid

A fossil of an early squid relative with a pterosaur tooth embedded in it offers rare evidence of a roughly 150-million-year-old battle at sea. While many fossils of pterosaurs with fish scales and bones in their stomachs have revealed that some of these flying reptiles ate fish, the newly described find is the first evidence that pterosaurs also hunted squid.

The squid fossil (right) was excavated in 2012 in the Solnhofen Limestone in southern Germany. The region's environment at the time of the squid's death was similar to the Bahamas, with low-lying islands dotting shallow tropical seas.

The embedded tooth (inset) fits the right size and shape for the pterosaur *Rhamphorhynchus*, paleontologists report January 27 in *Scientific Reports*. They argue the tooth was left by a pterosaur that swooped to the sea surface to snap up the roughly 30-centimeter-long squid of the extinct *Plesioteuthis* genus, but was unsuccessful, perhaps because the squid was too large or too deep for the predator to manage.

"The pterosaur was lucky that the tooth broke off," says paleontologist Michael Habib of the University of Southern California, who was not involved in the discovery. "A squid of that size could probably have pulled it under." — *John Pickrell*

RENÉ HOFFMAN

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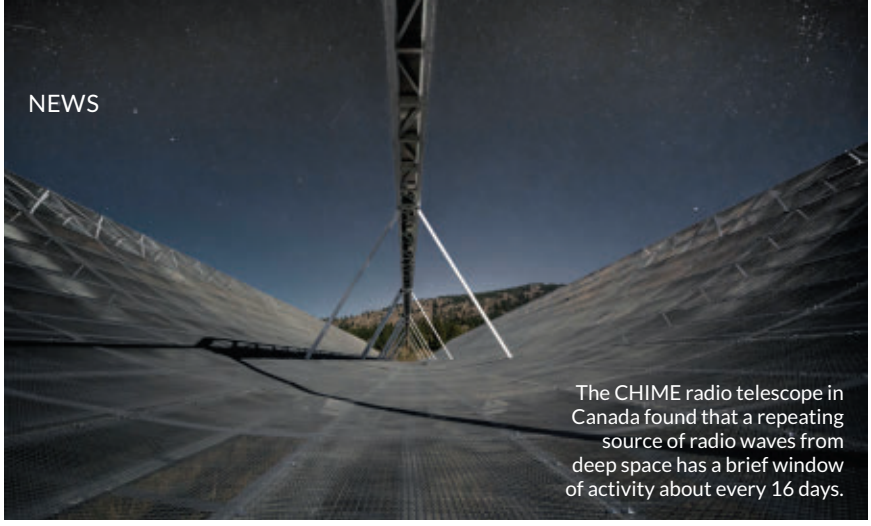


The CHIME radio telescope in Canada found that a repeating source of radio waves from deep space has a brief window of activity about every 16 days.

ATOM & COSMOS

Fast radio burst keeps a steady beat

Regular cycle of activity could point to the phenomenon's source

BY CHRISTOPHER CROCKETT

A periodic flurry of radio waves from some unknown object in deep space could help scientists figure out what's triggering similar radio bursts in other galaxies.

Since 2007, researchers have cataloged over 100 fast radio bursts, or FRBs, coming from every direction in the sky. The cause of these bursts is unknown. Only 10 have been seen to repeat (*SN: 9/14/19, p. 14*), and none had exhibited any sort of steady tempo — until now.

One of the repeaters has a brief window of activity about every 16 days, researchers report January 28 at arXiv.org. That means something about the source or the environment is reliably controlling the burst activity, a potential clue to the true nature of these enigmatic signals.

Dongzi Li, an astrophysicist at the University of Toronto, and colleagues found the pattern in data from the Canadian Hydrogen Intensity Mapping Experiment, or CHIME, radio telescope in British Columbia. The team determined that the FRB blasts out about one to two radio bursts per hour for four days and then goes silent for just over 12 days before usually repeating the cycle.

"This is very significant," says Duncan Lorimer, an astrophysicist at West Virginia University in Morgantown and codiscoverer of the first FRB (*SN: 8/9/14, p. 22*). "It's potentially going to take us in an interesting direction to get to the bottom of these repeaters."

One possible explanation for the periodicity is that the FRB source is orbiting something else, perhaps a star or black hole. In that case, the 16-day period might reveal how often the source of the radio waves is pointed toward Earth.

Alternatively, stellar winds from a companion might periodically boost or block the radio pulses. Winds might also explain why not every 16-day cycle produces bursts: If the companion occasionally belches out more material than usual, that could mask the FRB signal.

Either explanation implies that repeating FRBs — or at least, this one — might come paired with something else.

Li's team isn't ready to rule out standalone objects, with the 16-day period arising from the FRB source rotating or wobbling. But that scenario is tougher to reconcile with the data. One popular FRB candidate is a highly magnetic neutron star called a magnetar. Magnetars in our galaxy spin around once every 12 seconds or less, the team says, a far cry from the fortnight needed for this FRB.

This FRB was recently traced to a distant spiral galaxy (*SN: 2/1/20, p. 9*). Scans of its home with telescopes sensitive to other electromagnetic radiation, such as X-rays or gamma rays, might whittle down the list of suspects and move scientists closer to solving this cosmic mystery.

There's also hope of detecting more periodic FRBs, Lorimer says. "The fact that they detected periodicity on this one hints that other ones will have periodicity as well." ■

BODY & BRAIN

Concussion leaves clues in the blood

Testing levels of some proteins may one day aid in diagnosis

BY AIMEE CUNNINGHAM

A concussion diagnosis depends upon a careful assessment of symptoms. Now a large study of sports-related concussions points to a potential medical assist when evaluating an athlete for this injury.

Certain proteins in the blood are elevated after a concussion, researchers report in the January issue of *JAMA Network Open*. That discovery may one day help distinguish athletes who have suffered this brain injury from those who haven't.

Researchers took blood samples pre- and postinjury from 264 college athletes who had concussions while playing football, rugby and other contact sports from 2015 to mid-2018. Blood levels for three proteins were higher than they were before the injury occurred.

Each of the three proteins can serve as a sign that damage has occurred to a different type of brain cell, says neuropsychologist Michael McCrea of the Medical College of Wisconsin in Milwaukee. Glial fibrillary acidic protein is released in response to injury to glial cells, which provide support to nerve cells in the brain. Ubiquitin C-terminal hydrolase-L1 signals that nerve cells have been injured, and tau is a sign of damage to axons, which transmit nerve impulses. These proteins have been evaluated previously as potential markers of more severe traumatic brain injury.

McCrea's team also measured these proteins in 138 athletes who played contact sports but were not concussed and in 102 athletes who did not have the injury and played noncontact sports. Protein levels for these two groups were steady throughout the study. If there had been large variability in the protein levels in nonconcussed athletes, McCrea says, that would have undermined the association between the proteins and concussion.

CHIME COLLABORATION

Roughly 10,500 sports-related concussions are reported by NCAA college athletes in the United States each year, according to a 2015 study. A person suffering a concussion generally experiences one or more of the following symptoms: headache, nausea, dizziness, confusion and a brief loss of consciousness. But physical symptoms may not always make the diagnosis clear; a headache after a tackle might not necessarily be a sign of concussion. So scientists have been looking for chemical signals, biomarkers, that may help reveal a concussion.

It will take much more work before concussion biomarkers would be ready to use, McCrea says, including determining which combination of proteins are most reliably linked to the injury and how to quickly test for them.

"The goal of a biomarker is to provide a reproducible and accurate indicator of a medical state," says neurologist Juliana VanderPluym of the Mayo Clinic in Phoenix. "It is important to consider [biomarkers] as an aid, and not necessarily as the final determinant" of a diagnosis. For example, if an athlete gets tackled and reports symptoms that suggest a concussion but has normal levels of these proteins, she says, should that athlete be allowed to return to the game? "These are questions that we will need to address before biomarkers become part of clinical practice."

About 80 percent of the study participants were men. Future studies will need to see if the results are the same for women, VanderPluym says. Female college athletes have a higher rate of concussions than males, according to a 2016 study. Women also can experience more severe symptoms than their male counterparts and may experience worse damage to the brain. ■

BODY & BRAIN

Brain's immune cells help mice forget

Microglia appear to eliminate certain types of memories

BY LAURA SANDERS

Immune cells in the brain chew up memories, a new study in mice shows.

The finding, published in the Feb. 7 *Science*, points to a newly discovered way that the brain forgets, says neuroscientist Paul Frankland of the Hospital for Sick Children Research Institute in Toronto, who wasn't involved in the study.

That may sound like a bad thing, but forgetting is just as important as remembering. "The world constantly changes," Frankland says. Getting rid of unimportant memories — such as a breakfast menu from months ago — allows the brain to collect newer, more useful information.

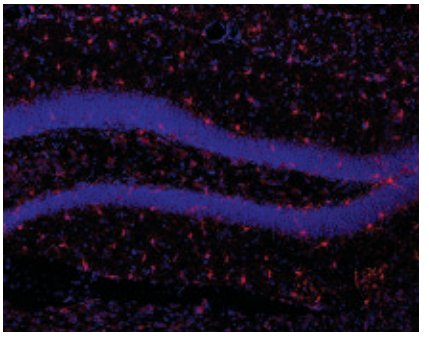
Exactly how the brain stores memories is still debated, but many scientists suspect that connections between large groups of nerve cells are important (*SN: 2/3/18, p. 22*). Forgetting likely involves destroying or changing these webs of connections, called synapses. The new result shows that microglia, immune cells that can clear debris from the brain, "do exactly that," Frankland says.

Microglia are master brain gardeners that trim extra synapses away early in life, says Yan Gu, a neuroscientist at Zhejiang University School of Medicine in Hangzhou, China. Because synapses have a big role in memory storage, "we started to wonder whether microglia may induce forgetting by eliminating synapses."

Gu's team gave mice an unpleasant memory: mild foot shocks delivered in a particular cage. Five days later, mice would still freeze in fear when placed in the cage. But 35 days later, they had begun to forget and froze less often.

Next, the researchers used a drug to get rid of microglial cells in some mice's brains. Mice with fewer microglia froze more in the cage than mice with normal numbers of microglia, suggesting that those rodents held on to the scary memory. The same was true of mice with microglia that, thanks to a different drug, were unable to gobble up synapses.

In a mouse's hippocampus, immune cells called microglia (red) can eliminate connections between nerve cells (cell bodies in blue) that are thought to store some types of memories.



CHAO WANG

The study also hints at which memories are particularly vulnerable. Scientists marked the nerve cells that stored the fearful memory with a glowing dye and gave the mice a drug that prevented those memory-holding cells from firing off signals. These unused, silent memories seemed to be more susceptible to microglia. "Less-revisited memories are easier to remove," Gu says.

The results relate to one kind of memory: a fearful one, and one that's stored in the hippocampus. That brain structure is thought to be an early, temporary stop before memories move to longer-term storage. Scientists don't know whether microglia would have a similar effect on memory-related synapses elsewhere in the brain. Microglia have been tied to the early stages of Alzheimer's disease (*SN: 4/30/16, p. 6*).

Also unclear is why some old memories, ones not recalled for years, survive. The related synapses may be extra durable, or maybe those memories are stored where microglia are less active, Gu says. Or perhaps people keep these memories strong by occasionally revisiting them subconsciously.

Other explanations for forgetting exist, such as the behavior of certain proteins and the creation of new nerve cells, as Frankland's work has suggested (*SN: 6/14/14, p. 7*). These ideas involve synapses changing with time. "All of these could conceivably be natural forgetting mechanisms," Frankland says. ■

MATTER & ENERGY

Nanoparticle is chilled to the max

Physicists have "cooled" a nanoparticle to the lowest temperature allowed by quantum mechanics. The particle's motion reached the particle's ground state, or lowest possible energy level.

For a typical material, the amount that its atoms jostle around indicates temperature. But in the case of the nanoparticle, a glass bead about 140 nanometers wide, scientists can define temperature based on the motion of the entire particle, which is made up of about 100 million atoms. That temperature reached an equivalent of twelve-millionths of a kelvin, scientists report online January 30 in *Science*.

Levitating the nanoparticle with a laser inside a specially designed cavity, the researchers reduced the particle's motion to the particle's ground state, a minimum level set by the Heisenberg uncertainty principle, which states that there's a limit to how well you can simultaneously know the position and momentum of an object.

While quantum mechanics is unmistakable in atoms and electrons, its effects are harder to observe on larger scales. To better understand the theory, physicists have previously isolated its effects in other solid objects, such as vibrating membranes or beams (*SN: 5/26/18, p. 6*). But nanoparticles have the advantage that they can be levitated and precisely controlled with lasers.

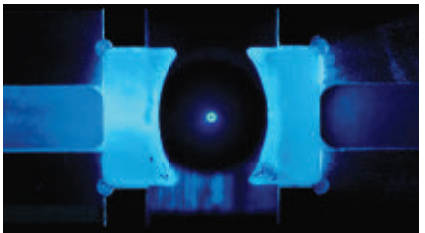
Eventually, the researchers aim to use cooled nanoparticles to study how gravity behaves for quantum objects, a poorly understood area of physics. — *Emily Conover*

BODY & BRAIN

Peanut allergy drug wins approval

A safety net may soon be available to kids with peanut allergies. On January 31, the Food and Drug Administration approved the first drug aimed at peanut allergies in the United States. The drug, Palforzia, made by Aimmune Therapeutics in Brisbane, Calif., won't allow allergic children to chomp PB&Js, but it may reduce the dangers of unintentional exposure.

A regimen of Palforzia metes out escalating doses of purified peanut powder before arriving at a daily maintenance dose. The goal is to teach the immune system that peanuts aren't a threat.



Inside this cavity, shown in false color, a particle was "cooled" to the lowest temperature allowed by quantum mechanics.

By the end of a recent clinical trial, about two-thirds of 372 allergic children and teens could tolerate the amount of peanut protein in about two peanuts (*SN: 12/22/18 & 1/5/19, p . 12*). The same was true for only 4 percent of participants who didn't get the peanut powder regimen. In tests on adults, the drug didn't seem to help much. — *Laura Sanders*

BODY & BRAIN

Decoy nanoparticles curb brain swelling in mice with head injuries

Injecting a swarm of nanoparticles into the blood of someone who has suffered a brain injury may one day help limit the damage — if results in mice can be translated to humans. In mice, nanoparticles seemed to reduce dangerous swelling by distracting immune cells away from an injured brain, researchers report online January 10 in the *Annals of Neurology*.

Two to three hours after a head injury, mice received injections of biodegradable particles made of a polymer that's already used in some dissolving sutures. Instead of rushing toward the brain, immune cells called monocytes turned their sights on these invaders. Monocytes engulfed the nanoparticles, and the cells and their cargo got packed off to the spleen for elimination, the researchers found.

Ten weeks after the injury, damaged brain spots in treated mice were about half as big as the spots in mice that didn't receive nanoparticles. Other tests showed that both brain swelling and scarring were less severe in treated mice. And behavior improved: Mice were able to walk better across a ladder if they had received nanoparticle injections.

Though there are a lot of differences between humans and mice, study coauthor John Kessler, a neurologist at Northwestern University Feinberg School of Medicine in Chicago, is optimistic about the approach. There are few ways to treat traumatic brain injuries, he says. "That's why it would be so exciting if it really works." — *Laura Sanders*

EARTH & ENVIRONMENT

Fewer worms live in mud littered with a lot of microplastics

Despite concerns over tiny bits of plastic filling the world's waterways, the long-term environmental effects of that debris are murky. Now an experiment on freshwater sediment communities exposed to microplastics for over a year helps clarify one way this pollution can be harmful.

Researchers embedded trays of sediment littered with polystyrene particles, ranging from 0 to 5 percent plastic per tray, in the bottom of an outdoor canal where bugs, snails and other critters colonized the mud. After 15 months, fewer organisms were found living in the trays with 5 percent polystyrene than in trays with less plastic, largely because fewer Naididae worms lived there.

Trays with 0 to 0.5 percent plastic averaged about 500 to 800 worms per tray; mud with 5 percent plastic averaged fewer than 300, researchers report January 31 in *Science Advances*.

That reduction in Naididae worms suggests that microplastic pollution can throw freshwater ecosystems out of whack. These worms are prey for other animals and play a key role in the carbon cycle by decomposing organic matter.

The 5 percent plastic concentration is more pollution than is typically found in freshwater sediment, says study coauthor Bart Koelmans, who studies aquatic ecology at Wageningen University & Research in the Netherlands. For instance, mud from the Rhine River in Europe has shown up to 0.1 percent plastic. But "it is likely that there are places where the concentration is … quite a bit higher," Koelmans says, and "the concentrations of today are not the concentrations of the future." — *Maria Temming*

KAHAN DARE, LORENZO MAGRINI AND YURIY COROLI/UNIV. OF VIENNA

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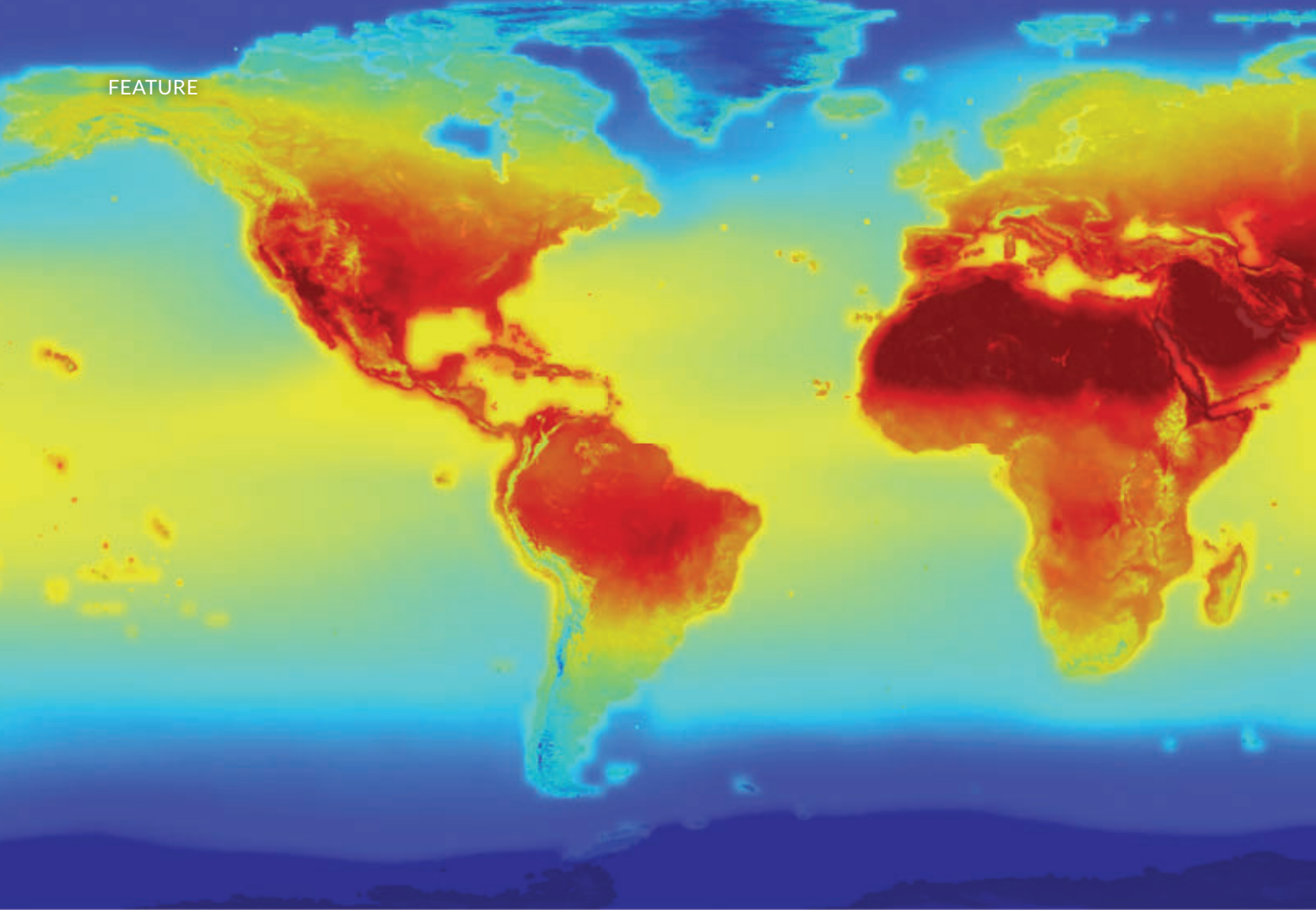


NASA

Earth's hot future

As climate models improve, worst-case scenarios are hard to pin down

By Carolyn Gramling

Earth's climatic future is uncertain, but the world needs to prepare for change.

Enter climate models, which simulate the myriad physical interactions between land, sea and sky. These simulations use supercomputers to solve the complex mathematical equations that express how these different climate components interact. Scientists can tinker with the models to predict how Earth will respond to different levels of greenhouse gases in the atmosphere, or to changing the intensity of incoming sunlight or planting forests. Researchers can reconstruct past ice ages and hothouse worlds — and envision a range of possible futures.

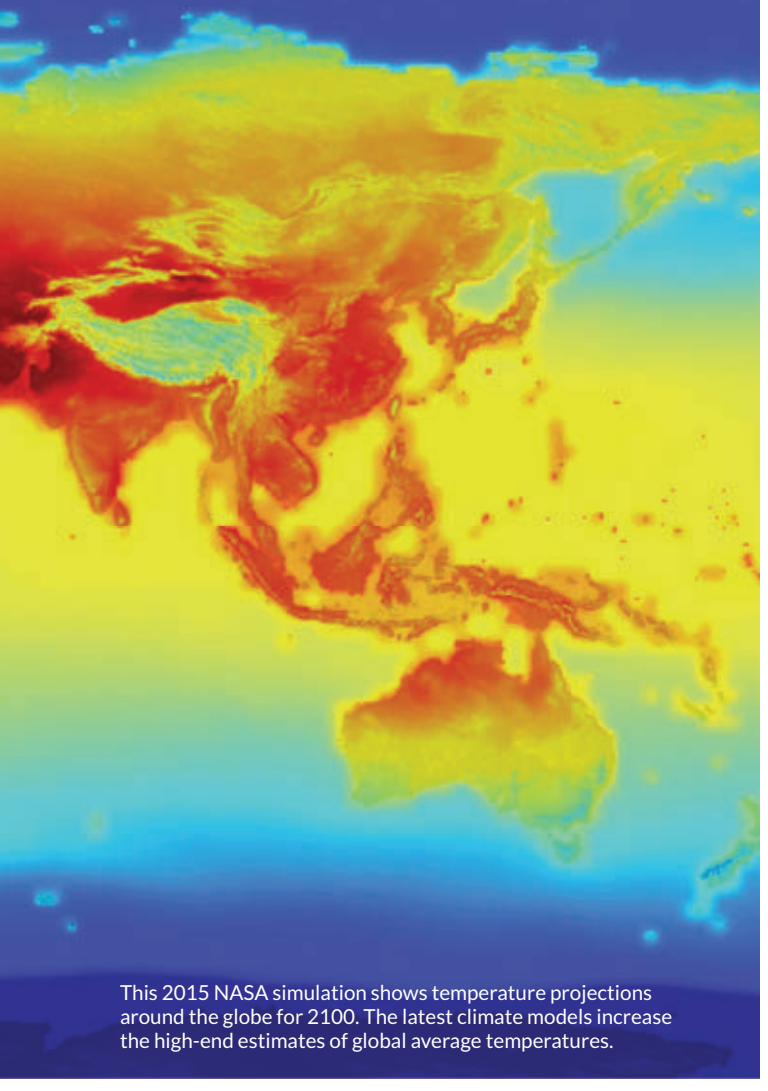
Thanks to an international effort to compare and refine such climate models, known as the Coupled Model Intercomparison Project, or CMIP, scientists now have a good idea of the best-case and the middle-of-the-road scenarios for our climate future.

But the worst-case scenarios — how hot it might get over the next century, or how high the seas might rise — are still proving hard to pin down.

Over time, climate models have gotten better and better at reproducing the more subtle aspects of climate change, such as the impact of aerosols and the ocean's capacity to absorb heat from the atmosphere. The latest models even take into account the complexity of human behavior, such as global conflicts, technological developments and other socioeconomic factors that can influence global emissions.

Uncertainties remain, of course: Scientists are still working on how best to simulate the complicated physics of clouds and the physical processes leading to ice sheet collapse.

When it comes to global warming, "we understand 80 percent



This 2015 NASA simulation shows temperature projections around the globe for 2100. The latest climate models increase the high-end estimates of global average temperatures.

of the problem," says Andrew Gettelman, a climate scientist at the National Center for Atmospheric Research in Boulder, Colo. "If you add carbon dioxide to the planet, you tend to heat things up. And once that starts, you kick off these [well-known] feedbacks," processes, such as an increase in atmospheric water vapor, that amplify global warming.

How the planet will respond to very high levels of CO_2, however, is still unclear. Now, the latest CMIP projections suggest that Earth's climate may be even more sensitive to very high levels of CO_2 than once thought. That would allow temperatures to climb even higher than previous models predicted.

What's causing that increased climate sensitivity remains hazy — although clouds, notoriously chaotic and difficult to simulate, are one likely culprit. Researchers are rushing to try to understand this conundrum, ahead of a tight timeline. The models are destined to be incorporated into the next massive assessment report of the Intergovernmental Panel on Climate Change, or IPCC, which is often used to help shape climate policy decisions. The first part of that report is scheduled for release in April 2021.

"We're having discussions of 'Do we believe these models?'" Gettelman says. "Nobody is arguing about whether [the temperature increase will be] less than 2 degrees Celsius," he points out. "We're arguing about the high end."

Turning up the heat

Six years ago, the worst-case climate scenarios were worrisome enough. Those scenarios, dubbed CMIP5, were outlined in the IPCC's 2014 assessment report. Without concerted action to reduce greenhouse gas emissions, the models suggested, by 2100 the planet could warm by as much as 4.8 degrees C, relative to the average temperature from 1986 to 2005. That's on top of an increase of 0.6 degrees C since preindustrial times. The global mean sea level could increase by up to a meter.

When that report was released, scientists were already working on the next generation of simulations, called CMIP6. By March 2019, at a progress meeting in Barcelona, it was becoming clear that something strange was going on.

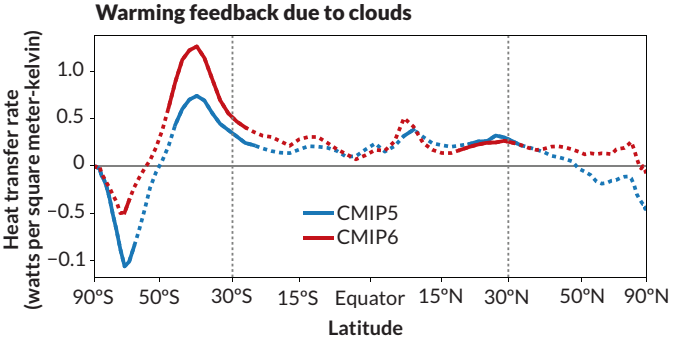
All of the simulations include estimates of equilibrium climate sensitivity, also known as ECS. ECS estimates how Earth's future climate is expected to respond to a new normal — specifically, an atmosphere that contains twice as much CO_2 as during preindustrial times. A high ECS means that the planet will respond very strongly to high levels of CO_2.

Strikingly, some of the new models project a higher ECS than previous models. Among those models are simulations developed by teams at the National Center for Atmospheric Research, the U.S. Department of Energy, the U.K. Meteorological Office and the Paris-based Institut Pierre-Simon Laplace, or IPSL. If true, greenhouse gases may exert more influence on Earth's atmosphere than thought — and temperatures could climb higher than even the highest previous projections suggested.

In September, scientists with IPSL and the French Centre National de la Recherche Scientifique, or CNRS, also in Paris, went public with their simulations. Average global warming by 2100 could be as high as 6 to 7 degrees C (or about 11 to 13 degrees Fahrenheit) above preindustrial times, according to projections from two separate climate models.

Like many next-gen climate simulations, the two French models feature finer-scale resolution and better representations of real-world physical processes than past simulations. When

Cloud cover Recent climate models, CMIP6, suggest that increasing atmospheric CO_2 levels could warm the planet more than previous models like CMIP5 predicted. As the world warms, some newer models show fewer and drier clouds, particularly in parts of the Southern Hemisphere (left on this chart), leading to enhanced absorption of sunlight by Earth.



M.D. ZELINKA ET AL/GEOPHYSICAL RESEARCH LETTERS 2020

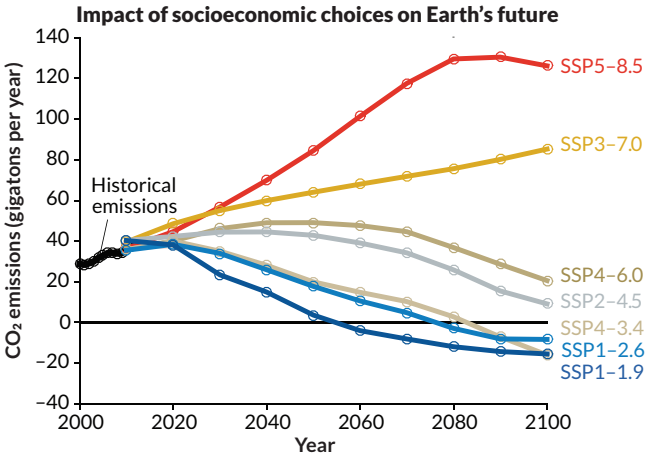
tested against present-day climate observations, the new simulations also do a better job of reproducing those observations, says CNRS climatologist Olivier Boucher.

But what causes the high ECS remains a conundrum. "Our [model] is better" in terms of the physics, Boucher says. "But it doesn't automatically translate into having more confidence for the future projections."

The trend of a higher ECS among models came up again November 21 at a meeting of the U.S. National Academies of Sciences, Engineering and Medicine's Board on Atmospheric Sciences and Climate in Washington, D.C. The most likely cause of the high ECS, Gettelman said at the meeting, was in how much the models estimate that clouds will enhance warming (*SN: 3/22/14, p. 22*). Among other factors, how high the clouds are in the atmosphere matters: Lower-altitude clouds can reflect sunlight back into space, while higher-altitude clouds can trap heat. Gettelman and colleagues also discussed the significance of clouds in ECS modeling in July in *Geophysical Research Letters*.

"Clouds at high latitudes look like they're quite important," Gettelman says. The region over the Southern Ocean is one of particular interest, and there are also studies afoot to examine the effects of high-altitude clouds in the Arctic as well as lower-altitude clouds in the tropics on future warming.

Societal shifts To improve climate predictions, scientists consider the impact of technological advances, global conflicts and population growth. These five narratives are described in the shared socioeconomic pathways, or SSPs, below. The number after each SSP, such as 8.5 or 1.9, refers to radiative forcing, a measure of how greenhouse gases lead to warming. For example, SSP5–8.5, a high-emissions scenario (red), sets radiative forcing at 8.5 watts per square meter by 2100, and makes limiting global warming to below 2 degrees Celsius nearly impossible. Other scenarios, such as SSP1, SSP2 and SSP4, may be able to achieve this goal.



SSP1	The world focuses on sustainability and inclusive development. More investments in education and health speed up the transition to sustainable development.
SSP2	Overall, resource and energy use intensity declines, but slowly. There is slow progress internationally in achieving sustainable development goals and in improving income inequality.
SSP3	A more nationalistic world focuses on achieving energy and food security goals domestically. Conflicts increase, and investment in education and technology development is low.
SSP4	High-tech economy grows, and investments increase in both fossil fuels and low-carbon energy sources. But increasing income inequality leads to conflict and uneven environmental policy.
SSP5	The world undergoes rapid technological progress and globalization, with abundant fossil fuel use and little change in climate emissions policy. But global investments in health, education and social development increase.

Choosing a path

The physical bounds for just how hot Earth could get remain unclear. But how human behaviors might lead to, or avert, such a worst-case scenario is coming into focus.

That's thanks to a new framework for climate projections that incorporates societal shifts, such as changes in demographics, urbanization, economic growth and technological development. These narratives, called shared socioeconomic pathways, or SSPs, are part of the latest CMIP models, the CMIP6. They provide a nuanced picture of real-world challenges to both climate mitigation and adaptation.

By contrast, previous climate projections focused solely on the physical effects of greenhouse gases, such as CO_2 and methane, as they linger in the atmosphere and trap radiation from the sun. These scenarios were called representative concentration pathways, or RCPs. An Earth in which greenhouse gas emissions are dramatically and swiftly curbed was represented by a scenario called RCP 2.6. A scenario in which no action was taken was RCP 8.5.

The SSP narratives add nuance by describing not only how greenhouse gas emissions can be altered by regional conflicts or technological developments, but also how these societal changes might alter opportunities for mitigation. By tracking how such changes can affect future climate change, scientists hope that SSPs can also help nations better assess how to meet their own emissions targets, as pledged under the Paris Agreement (*SN: 1/9/16, p. 6*).

Uncertainty in the ice

Human behavior isn't the only source of uncertainty when it comes to envisioning worst-case scenarios. Scientists also are wrestling with simulating the complicated physical interactions of ice and ocean and atmosphere, particularly as temperatures continue to rise.

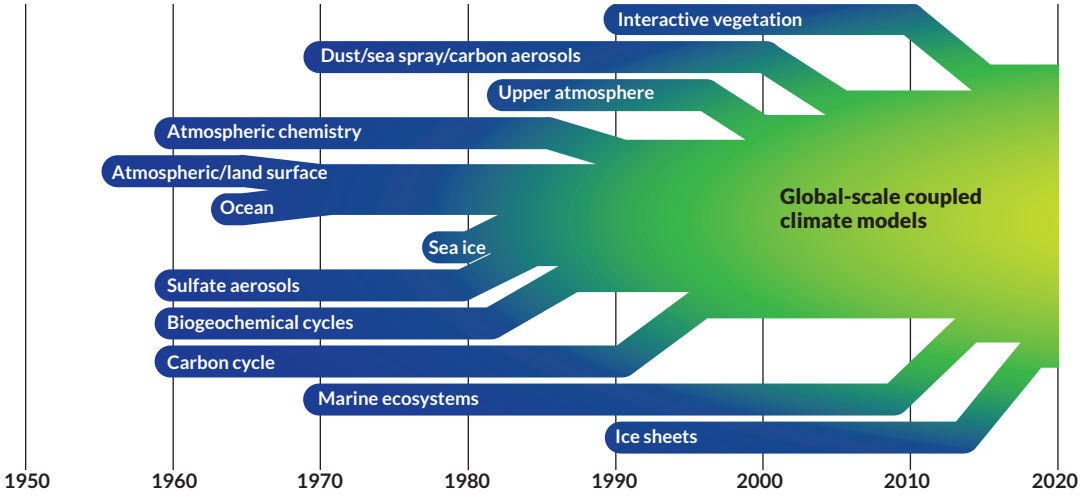
"Most oceans have air on top of them, and [some] oceans have ice on top of them. And the ice is moving, the ice is interacting. It's a very difficult thing," says Richard Alley, a glaciologist at Penn State.

Climate models are just now getting to the point where they can reproduce many of these interactions by coupling them into one simulation, Alley says. Doing so is key to accurately projecting possible futures: Such coupled simulations reveal how these interactions feed into one another and can raise the

J. ROGELJ *ET AL/NATURE CLIMATE CHANGE* 2018

Merging the models

Today's climate simulations stand on the shoulders of many giants. In the late 1950s came general circulation models, each describing the physics of the atmosphere, land surface or oceans. Over time, these and other factors, from ice sheets to aerosols, were bundled into "coupled" models. As more processes have been added, as shown here by the U.K.-based Carbon Brief, the simulations are drawing even closer to an approximation of the real world.



potential for even higher temperatures or even higher seas.

But there are numerous sources of uncertainty when it comes to anticipating the worst-case scenario. For example, how fast the seas will rise is linked to how quickly the great ice sheets blanketing Greenland and Antarctica will lose ice to the ocean, through melting or collapse.

Climate simulations are still not reproducing that melting well, even those in the IPCC's special report on climate change's impacts on ice and oceans released in September (*SN Online: 9/25/19*). That's partly because scientists don't fully understand how the ice responds to climate change, says Eric Rignot, a glaciologist at the University of California, Irvine. "We're making progress," he says, "but we are not there."

One of the largest uncertainties is how warming oceans can erode the vast underbellies of glaciers fringing the ice sheets, Rignot says. To identify how such erosion might occur requires detailed bathymetry maps, depth charts of the seafloor that can reveal channels that allow warmer ocean water to sneak into fjords and eat away at the glaciers (*SN Online: 4/3/18*). Rignot and colleagues have been creating some of those maps for Greenland.

Scientists also are trying to get boots-on-the-ground data to tackle other uncertainties, such as how warming can change the behavior of the ice sheets themselves as they stretch, bend and slide across the ground. In 2018, an international collaboration of scientists began a five-year project to study the ongoing breakup of the Florida-sized Thwaites Glacier, part of the West Antarctic Ice Sheet, in real time.

Warm ocean waters are thinning the glacier, which supports the ice sheet like a buttress, slowing the flow of ice toward the ocean. Thwaites is melting fast and may rapidly and irreversibly collapse within several hundred years. Some scientists fear that the glacier's retreat is already unstoppable.

And there are other processes not yet included in the CMIP models that could send ice tumbling rapidly into the sea: Meltwater may seep through cracks and crevasses to the base of an ice sheet, lubricating its slide from land to ocean. Meltwater can also refreeze into solid, impermeable slabs that can speed up the flow of newer meltwater into the ocean (*SN: 10/12/19 & 10/26/19 , p. 16*). Perhaps most frighteningly, some researchers have suggested that future warming could cause Antarctica's giant, steep ice cliffs to suddenly lose large chunks of ice to the ocean, rapidly raising sea levels (*SN: 3/2/19, p. 6*).

There's a good reason why current climate models don't include the ice cliff hypothesis, Alley says. "The best models, the ones that you can have the most faith that they're reconstructing what's happened recently, generally do not spend a lot of effort on breaking things off."

The problem isn't in simulating the physics of ice breaking off; it's in simulating exactly which ice shelves will break off — and when. That makes the potential error of simulating those processes very large.

"That's a lot of the tension in the community right now," Alley adds. "How to deal with this is still proving very difficult."

The IPCC's September report noted the ice cliff hypothesis, but considered it deeply uncertain. But that doesn't mean it's impossible, Alley says, or that it hasn't happened in the past.

Evidence from ocean sediments reveals that giant icebergs have broken away from continent-based cliffs and melted out at sea in the past. If Thwaites Glacier retreats all the way to Antarctica's interior, ongoing calving could create massive cliffs twice as high and 10 times as wide as any observed in Greenland, Alley noted at the American Geophysical Union's annual meeting in San Francisco in December.

The IPCC is "assuming we'll get lucky and it won't happen," Alley said. But the ocean sediment data raise "really serious questions about that assumption."

Gettelman, meanwhile, cautions that the lingering uncertainty in future projections does not mean the world should wait to see what happens or wait for scientists to figure it out. "It really means we need to do something soon," he says. Whether the highest temperature or sea level rise projections turn out to be accurate or not, "it's still pretty bad." ■

Explore more

- Mark D. Zelinka *et al*. "Causes of higher climate sensitivity in CMIP6 models." *Geophysical Research Letters*. Published online January 3, 2020.

FEATURE

When grief comes with the job

Scientists grapple with the emotional toll of studying nature as it rapidly changes

By Jonathan Lambert

Marine biologist Tim Gordon sets up an underwater speaker on a degraded reef in Indonesia's Spermonde Archipelago to test whether playing the sounds of a healthy coral reef can attract young fish back to the reef.

T. GORDON

Arriving at Australia's Great Barrier Reef in October 2016, Tim Gordon thought he was living a dream. As a boy growing up in the southeast African country of Malawi, he'd covered his bedroom walls with Technicolor reef posters and vowed one day to explore those underwater worlds.

The marine biologist was unprepared for what he found: a silent and colorless field of submerged rubble.

At Lizard Island, off the northeastern coast of Queensland, Gordon hoped to study the sounds of the reef's creatures. "A reef should be noisy," with crunching parrot fish, scraping sea urchins and myriad squeaks, rumbles and whoops of other marine animals, says Gordon, of the University of Exeter in England. But many of these creatures had vanished as climate change warmed the ocean, triggering widespread coral bleaching in 2016 and 2017.

"Instead of documenting nature's wonders," he says, "I was documenting its degradation."

Scientists like Gordon are grieving over the ecological losses they're witnessing firsthand. They are worried about the probability of more losses to come and are frustrated that warnings about the dangers of unchecked carbon emissions have gone largely unheeded.

Already, climate change is altering the environment at a quickening pace. Glaciers are losing billions of tons of ice each year (*SN Online: 9/25/19*). Wildfires and storms are growing more intense and destructive (*SN Online: 12/10/19*). Permafrost, which locks carbon in the earth, is thawing, disrupting Arctic communities, releasing carbon and accelerating warming.

And thanks in part to other human-caused threats, including pollution and habitat destruction, 1 million species are at risk of extinction (*SN: 12/16/19, p. 5*).

"There's this idea that scientists have to be completely emotionally detached from what they study," Gordon says. But the magnitude of the damage he and others are seeing is taking an emotional toll. "Especially," he says, "because it doesn't look like this is going to get sorted out anytime soon."

Early observers

Grief is a natural response when a loved one is lost and their absence is strongly felt. But humans also become attached to, and love, their natural

surroundings, whether a forest held sacred by a certain community or a beloved oak seen from a bedroom window. Plants and animals, winding rivers and rugged mountains can all stir deep emotions.

When those places are lost or degraded, people mourn. The rapid decline of the American chestnut, an iconic tree that once dominated the eastern forests but largely disappeared during a fungal blight in the early 20th century, stirred widespread grief, says Susan Freinkel, a journalist who wrote a book about the tree.

"The chestnut was intimately bound up with a way of life in the Appalachian Mountains, the heart of the tree's range," Freinkel says. Chestnut wood walled homes and its bark covered roofs. Mattresses were stuffed with leaves, and people roasted the ubiquitous and creamy nuts. "That intimate connection made people feel like they were losing a beloved friend when the trees began dying," she says.

The grief was profound for some. Joe Tribble from eastern Kentucky recalled, "Man, I had the awfullest feeling about that as a child, to look back yonder and see those trees dying. I thought the whole world was going to die," according to a collection of oral histories compiled by Nyoka Hawkins in 1993.

The first people affected by environmental change are often the farmers, fishers, indigenous communities and others who live off and work the land. Also affected are scientists who are focused on monitoring and studying — and increasingly on saving — our natural world.

Scientists are "at the very tip of the spear ... watching Armageddon in slow motion, cataloging loss every day," says Lise Van Susteren, a psychiatrist in Washington, D.C. In particular, she says, those who've spent their career studying a species or ecosystem that's rapidly disappearing suffer the most. "They can't turn away from it and focus on something else," she says.

To raise awareness about the possible mental health effects of climate disruption, Van Susteren cofounded the Climate Psychiatry Alliance, a national network of psychiatrists committed to addressing what she calls the defining threat of our time. Eventually, climate disruption will affect everyone, she acknowledges. But climate scientists already are acutely aware of what's happening.

"Some scientists are more open about it than others," Van Susteren says. "But I don't know of a single one who isn't distressed about what they're seeing."

To get a handle on the scale of the problem, a group of social scientists working on a project called the Adaptive Mind began a survey in spring 2019. They asked scientists and other professionals working to help society adapt to climate change how they were coping.

The Central Arctic Ocean is usually locked in ice. But recent warming allowed an August 2017 expedition to sail into the area without assistance from an icebreaker ship. Tim Gordon (shown) and colleagues sampled the water.

T. GORDON

According to preliminary results, 80 percent of 122 respondents said they were feeling burned-out, although their reasons could go beyond climate grief. Many of them also said that, while they remain committed to their work, they often feel they aren't doing enough or working fast enough, says social scientist Susanne Moser, project leader of the Adaptive Mind.

"That's the best recipe to burnout," which can force some to leave a scientific field altogether, says Moser, of Antioch University in Keene, N.H. "These people look existential dread in the eyes on a daily basis," she says. "When you let climate science and all that it means really sink in, and connect it to your local reality, it quickly becomes not just a cognitive experience, but an emotional experience."

> "These people look existential dread in the eyes on a daily basis."
>
> SUSANNE MOSER

"A parental sense of responsibility"

Kayaking across an Alaskan bay lined by towering rock cliffs in August 2019, glaciologist Ethan Welty felt a profound sense of despair. A decade earlier, the bay was covered in ice, part of the gigantic Columbia Glacier that Welty began studying in 2009. Now, he paddled among drifting icebergs, kilometers away from the glacier's edge.

With the cliffs exposed, "it was arguably more beautiful than it was before, but I was just overcome with grief," says Welty, of the University of Colorado Boulder. He wasn't upset just by the glacier's rapid retreat, by some 20 kilometers over just four decades. After all, the Columbia Glacier's retreat isn't due solely to human-caused climate change, but also because of natural processes

Social scientist Ashlee Cunsolo (left) interviews Nunatsiavut resident Susan Saksagiak about her experiences and her work as a mental health professional supporting Inuit neighbors experiencing climate grief in Nain, Canada.

associated with the Little Ice Age that ended in the 1800s.

But Welty sees the glacier's demise as a sign of what's to come with global climate change. As atmospheric temperatures continue to climb, many of the world's glaciers will melt (*SN: 1/21/17, p. 14*), causing ecosystems to be lost, sea levels to rise and, eventually, coastlines to become swamped *(SN Online: 10/29/19*).

"Before I went to Columbia Glacier, I didn't grasp how quickly these landscapes can change and how nature is not just a stable thing that we can rely on indefinitely," Welty says. "When you repeatedly return to a place, you develop a sort of attachment. It's almost a parental sense of responsibility."

For fellow glaciologist Andy Aschwanden of the University of Alaska Fairbanks, the sense of loss over the world's shrinking ice is compounded by feelings of frustration and helplessness. He and colleagues have spent decades warning about climate change consequences, yet climate-warming carbon emissions continue to rise. Researchers project that 2019 will be another record-setting year of global carbon dioxide emissions (*SN Online: 12/3/19*).

"I struggle to grasp how it can be that the science has been relatively clear since the 1970s," Aschwanden says, "yet people still aren't taking meaningful action." He hopes that will change as more people see climate change affecting their daily lives (*SN: 12/21/19 & 1/4/20, p. 25*).

"Whether it's indigenous communities noticing changes in migratory patterns [of hunted animals], or coastal residents seeing more erosion, more people are talking about climate change," he says. "It gives me hope, even though the window for action is closing."

Opening up

Dealing with ecological grief can be difficult and lonely. There rarely are customs or protocols among scientists for processing it.

"When a loved one dies, society wraps around you ... you get leave from work or school. There's a funeral, people bring food," says social scientist Ashlee Cunsolo of the Labrador Institute of Memorial University in Happy Valley–Goose Bay, Canada. "But there are no rituals for ecologically based grief. Many people don't talk about it at all, because they find it embarrassing, or they don't know what to say."

While studying how Inuit communities in northeast Canada are coping with climate change, Cunsolo became so stressed that she developed a pinched nerve in her shoulder and had to take six weeks off work. The Inuit's stories were heart-wrenching, she says. One elder told her: "Inuit are people of the sea ice. If there's no more sea ice, how can we be people of the sea ice?"

Inuit lands are part of a region that has experienced warming at a rate three times the global average since 1948, according to a 2019 Canadian government report. For years during her research, Cunsolo kept her grief to herself. "I didn't talk about it, because I didn't want to take ownership of their pain as a nonindigenous settler," she says. But eventually Cunsolo shared her feelings with Inuit community members, which she says was helpful. "That was a turning point; we all opened

Glaciologist Andy Aschwanden drills an ablation stake, to monitor ice levels over time, into the Black Rapids Glacier in eastern Alaska in April 2016.

FROM TOP: INEZ SHIWAK; GABE WOLKEN

up and started talking." She says Inuit community members are coping too, in part by creating programs, such as classes on traditional weaving practices, to keep people connected to their culture when they can't go out on the ice as much.

Other scientists are also talking about their fears and frustrations as the stakes of climate change become stark. Spurred on by more open discussion, Cunsolo says she and other researchers are developing a survey on climate change, mental health and ecological grief to assess the impact on those working in ecology, conservation and environmental fields globally.

Gordon, the coral researcher, and two other reef scientists penned a letter in the Oct. 11 *Science* titled "Grieving environmental scientists need support." The three argued that scientists should be more open about the emotional toll of their work, and urged universities and institutions to adopt protocols for helping researchers cope. Dozens of scientists sent Gordon personal notes of thanks. "Scientists really welcomed the emotional honesty," he says.

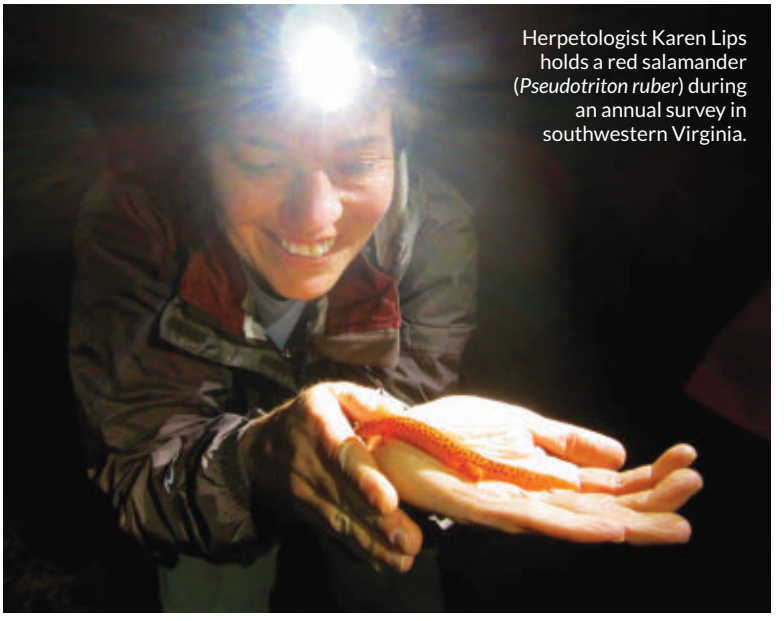
After acknowledging the stress of studying degraded coral reefs, Gordon shifted his work toward trying to restore this ecosystem. "I wanted to channel my grief into something more positive," he says. He's using underwater speakers that mimic the sounds of a healthy reef to help baby fish naturally swept out to sea find their way home, a journey made difficult without the beacon of reef noise. The method shows early signs of working, Gordon and colleagues wrote November 29 in *Nature Communications*. The approach might complement other tools scientists are using to restore degraded reefs (*SN: 10/29/16, p. 18*)

But not everyone can shift their work's focus. Moser, of the Adaptive Mind project, suggests that scientists can be realistic while still maintaining hope. "It's not a Pollyanna-ish hope that everything will be just fine," she says. Instead, she points to the sort of hope often found among people who are terminally ill, who must decide how to move forward despite a bleak prognosis. She advises that scientists similarly could try to envision a worthwhile and reachable future and then figure out how to work toward it.

Time for advocacy

Herpetologist Karen Lips had already been dealing for decades with dread when she decided she could help by doing more in science policy and diplomacy.

CARLY MULETZ WOLZ



Herpetologist Karen Lips holds a red salamander (*Pseudotriton ruber*) during an annual survey in southwestern Virginia.

Amphibians have been in sharp decline due to pollution, habitat destruction and the spread of the deadly chytrid fungus *Batrachochytrium dendrobatidis*, or *Bd* (*SN: 4/27/19, p. 5*). Climate change is also bringing higher temperatures that alter ecosystems, for example, drying up streams.

Lips, of the University of Maryland in College Park, was among the first scientists to raise the alarm about *Bd*, after she had witnessed waves of death in frog populations in the 1990s in the Talamanca Mountains in southeastern Costa Rica. Some scientists suggest climate change could make the threat from *Bd* for certain species even worse. Warming also threatens to squeeze many amphibian species out of the narrow temperature ranges for which they're adapted.

It can be "depressing work," Lips says. But it's also "exciting because you're helping fill in the gaps of a story, outline the scope of the problem, ultimately hoping to help solve the problem." At the same time, she can get discouraged by the limited impact one scientist can have.

Even when she has successes — she helped persuade the U.S. Fish and Wildlife Service to temporarily ban imports of certain amphibians to the United States in 2009 to reduce the chytrid threat — the effort might address only one tiny part of the problem.

"But that's all we've got," Lips says. "I'd hate to sit here and say we saw this happening, but didn't do anything. That's unacceptable." ■

"More people are talking about climate change. It gives me hope, even though the window for action is closing."

ANDY ASCHWANDEN

Explore more

■ Climate Psychiatry Alliance: climatepsychiatry.org

What Stars Are Made Of
Donovan Moore
HARVARD UNIV., $29.95

BOOKSHELF

A persistent astronomer's journey

It was 1924, and Cecilia Payne-Gaposchkin was on the verge of a breakthrough. Faint rainbows of starlight, recorded on photographic glass, held secrets to how the universe was put together. If only she could read the starlight's story.

As with every other challenge in her life, Payne-Gaposchkin would not stop. She once went without sleep for 72 hours, struggling to understand what the stars were telling her.

"It was an impatience with the ordinary — with sleep, meals, even friendships and family — that had driven her as far back as she could remember," journalist Donovan Moore writes in his book celebrating the life of Payne-Gaposchkin (who added "Gaposchkin" to her name upon marriage in 1934). After her death in 1979, other scientists would go on to remember her as "the most eminent woman astronomer of all time." During a time when science was largely a men's club, she had figured out the chemical makeup of the stars.

In *What Stars Are Made Of,* Moore takes readers on a meticulously researched tour of Payne-Gaposchkin's remarkable life, drawn from family interviews, contemporary accounts and Payne-Gaposchkin's own writings. It's a riveting tale of a woman who knocked down every wall put before her to get the answers she desired about the cosmos.

Growing up in England, her love of science started before she could read. But English society in the early 1900s didn't know what to do with such a determined girl. Days before her 17th birthday, she was told to leave school after administrators found they couldn't meet her insatiable need to learn math and science. During physics lectures at the University of Cambridge, she, like all women, had to sit at the front, forced to parade past male students stomping in time with her steps.

And yet, she persisted, becoming a woman of firsts. In 1925, Payne-Gaposchkin became the first person to receive a Ph.D. in astronomy from Radcliffe College in Cambridge, Mass. In 1956, she was the first woman to be promoted to full professor at Harvard and several months later was the first to chair a department at the university.

Her big breakthrough came not long after finding work at Harvard College Observatory in 1923. She had taken it upon herself to analyze the institution's library of stellar spectra: starlight broken into its component colors, revealing elements in the stars based on which wavelengths of light were missing.

The trouble was, no one had yet combed through the spectra to take a census of the atoms. Doing so required using the new field of quantum physics to identify dozens of element signatures in thousands of spectra — a task to which Payne-Gaposchkin was uniquely suited. The work was grueling and tedious, demanding she harness her keen observational skills, sharp mathematical mind and rigorous physics training.

After roughly two years of nearly unbroken focus, she overturned one of the prevailing thoughts of the day: that stars were chemically similar to Earth. Instead, hydrogen appeared to be a million times as abundant as expected, and helium a thousand times so. Earth, it seemed, was not the template for the universe.

At the time, Payne-Gaposchkin's findings were largely dismissed as spurious. It wasn't until the American astronomer Henry Norris Russell came to the same conclusion years later that minds started to change.

While opinions about her work were slow to change, progress in opinions toward women was glacial. Payne-Gaposchkin taught at Harvard for nearly two decades before being listed in the course catalog. Yet, her hunger for knowledge never stopped. A student once marveled at "her views on Italian art, or paleolithic axes, or mosaic woodworking, or the earliest printed edition of *Reynard the Fox*," Moore writes.

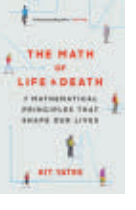
Payne-Gaposchkin is the lead character of Moore's book. But the book is also a tale of early 20th century science and the barriers that all women at the time faced. Anyone interested in any of these topics will revel in this book's detail.

As for Payne-Gaposchkin, while she was aware of these barriers, she didn't see herself as a feminist pioneer. She was drawn to the stars, and the stars were blind to gender. "She did not consider herself a woman astronomer," Moore writes. "She was an astronomer." — *Christopher Crockett*

BOOKSHELF

The Dance of Life
Magdalena Zernicka-Goetz and Roger Highfield
A biologist shares insights from her career to explain how a single fertilized egg develops into the trillions of cells that make up a human being. *Basic Books, $30*

Einstein in Bohemia
Michael D. Gordin
The 16 months Albert Einstein spent living in Prague had a profound effect on his personal and professional life, a historian argues. *Princeton Univ., $29.95*



The Math of Life and Death
Kit Yates
A mathematician mines headlines and history to help readers understand how a variety of mathematical principles apply to everyday life. *Scribner, $26*

Top right: Students learned about basic chemical reactions, chemical bonds and states of matter through slime-making activities during STEAM Night.

Left and bottom right: Participants created collages with different color circles of varying radii that followed the Fibonacci sequence, a mathematical series where each number is equal to the sum of the two preceding numbers.

Society's STEM Action Grant program supports Marie's Kids

Encouraging students to see themselves as scientists

Exposing children to science and engineering can make them more likely to pursue those subjects later in life. This tenet is central to the mission of Marie's Kids, one of the Society for Science & the Public's 2019 STEM Action Grantees. The STEM Action Grant program aims to bolster and support community-driven nonprofit organizations that are working to enhance the public's understanding of science and to increase participation of underrepresented populations in STEM fields. With the $2,500 grant Marie's Kids received, the organization has been able to expand its outreach to underserved areas of Charleston, Dorchester and Berkeley counties in South Carolina.

This past October, Marie's Kids hosted its first "STEAM Night," an interactive experience designed to introduce elementary school students and their parents to science, technology, engineering, arts and math through hands-on activities at North Charleston Elementary School.

"We believe that if we can get underrepresented students interested in STEM early, especially through the integration of art, we will help them to recognize science and engineering principles in their daily lives and encourage them to see themselves as engineers and scientists," said Marie's Kids executive director, Myrtede Alfred. "By presenting knowledgeable and diverse STEAM role models, we directly challenge the notion that science and engineering are restricted to certain kinds of people. We aim to broaden participation in STEM by starting the pipeline at the earliest possible stages of formal education."

REGENERON SCIENCE TALENT SEARCH

A program of SOCIETY FOR SCIENCE & THE PUBLIC
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Amogh Bhatnagar
Mequon, WI


Andrew Brinton
Merrick, NY


Cynthia Chen
Cupertino, CA


Lauren Chen
Irmo, SC

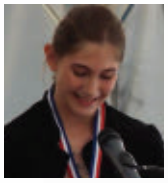

Holly Cheng
Mount Kisco, NY


Brendan Crotty
Muskogee, OK


Ankush Dhawan
Newburgh, IN

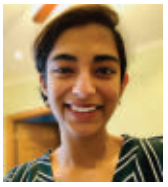

Maria Fields
Detroit, MI


Ari Firester
New York, NY


Makayla Gates
Peralta, NM


Victoria Graf
Arlington, VA


Zander Hill
Scottsdale, AZ


Raina Jain
Riverside, CT

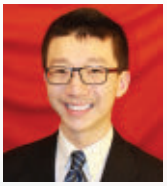

Anushka Jetly
Friendswood, TX


Helena Jiang
Gainesville, FL


Nithin Kavi
Acton, MA


Olivia Krivitsky
Englewood Cliffs, NJ

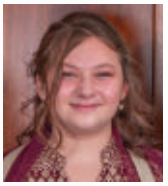

Caitlin Kunchur
Irmo, SC


Rupert Li
Portland, OR

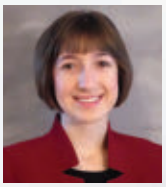

Jason Liu
Reno, NV


Kyra McCreery
Sea Cliff, NY


Nadine Meister
Ellicott City, MD

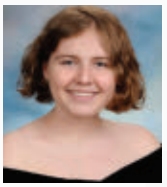

Sonja Michaluk
Titusville, NJ

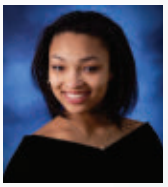

Arjun Neervannan
Irvine, CA


Annie Ostojic
Munster, IN


Lillian Petersen
Los Alamos, NM


Alina Pollner
San Diego, CA


Katherine St George
Merrick, NY


Anaiah Thomas
Teaneck, NJ

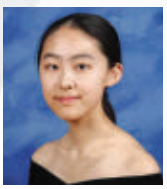

Adriane Thompson
Westerville, OH


Rohan Wagh
Portland, OR


Ella Wesson
Manhasset, NY

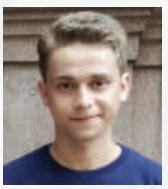

Alek Westover
Belmont, MA


Brian Wu
Scarsdale, NY


Eva Xie
Flushing, NY


Ellie Yang
Chesterfield, MO


Kevin Yang
Boulder, CO


Jake Yasonik
Mequon, WI


Faye Yu
Andover, MA

About the Regeneron Science Talent Search

The Regeneron Science Talent Search is the nation's oldest and most prestigious science and math competition for high school seniors. The competition is designed to engage and inspire the next generation of scientific leaders.

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Much of the Milky Way galaxy is hidden behind thick lanes of interstellar dust. But that dust was no match for Spitzer's infrared vision. Here, hundreds of thousands of stars gather around dust clouds in the galaxy's center.

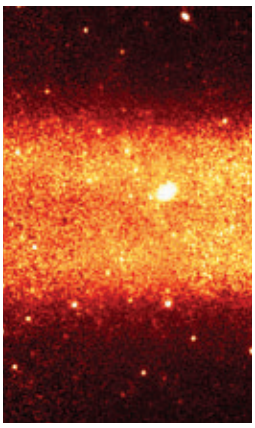
Memoirs of a space telescope, written in infrared

After 16 years and five months in space, the Spitzer Space Telescope has signed off.

On January 30, engineers instructed the telescope to power down, bringing an end to one of NASA's premier orbiting observatories. The telescope spied on planets and comets in the solar system, found worlds orbiting other stars, witnessed the births and deaths of stars, charted the Milky Way and sought out galaxies in the farthest reaches of the cosmos. The images on these pages highlight some of Spitzer's most awe-inspiring discoveries. These include a giant, nearly invisible ring encircling Saturn (right) and a medley of Earth-sized planets (below) around the not-too-distant star TRAPPIST-1 — one of the telescope's most famous achievements.

Some of the universe hides behind dust that blocks visible starlight from reaching our eyes. But Spitzer's detectors were sensitive to infrared light that can penetrate clouds of dust, revealing what lurks beyond. The telescope launched on August 25, 2003, into an orbit that trails Earth around the sun (*SN: 12/20/03 & 12/27/03, p. 387*). Named for the late astronomer Lyman Spitzer Jr., who in 1946 first proposed putting telescopes in space, the mission originally was planned to operate for just 2½ years. Spitzer soldiered on, but every day the telescope gets farther from Earth, a result of its orbit, which made it more difficult to communicate with. — *Christopher Crockett*

Spitzer discovered Saturn's largest and otherwise invisible ring (a slice of the ring is shown in infrared below).



Spitzer found most of the seven Earth-sized worlds (illustrated) around TRAPPIST-1, nearly 40 light-years away.

FROM TOP: JPL-CALTECH/NASA, S. STOLOVY, SSC; JPL-CALTECH/NASA, UNIV. OF VIRGINIA; R. HURT/JPL-CALTECH/NASA, T. PYLE/IPAC

When viewed in visible light, the Sombrero galaxy, about 28 million light-years from Earth, is a dark ring of dust. But details in dust lanes (red and green) glow in infrared light, revealing that the galaxy is slightly warped.

Stars are born in dusty cocoons that hide many details of formation. But Spitzer peered through the dust and into stellar birthing grounds throughout the Milky Way. About 400 light-years from Earth, the nebula Rho Ophiuchi (one section shown) is one of the closest of these nurseries. With Spitzer, scientists spied on several hundred stars being born there.

Like a boat moving through water, winds from the speeding star Zeta Ophiuchi (at center), about 370 light-years from Earth, make waves in dust (red) half of a light-year ahead of the star.

CLOCKWISE FROM TOP: INFRARED: JPL-CALTECH/NASA, R. KENNICUTT/UNIV. OF ARIZONA, THE SINGS TEAM. OPTICAL: HUBBLE SPACE TELESCOPE, HUBBLE HERITAGE TEAM; JPL-CALTECH/NASA; JPL-CALTECH/NASA, HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS

JANUARY 18, 2020

Resurrecting sound

Following the April 2019 fire that badly damaged Paris' Notre Dame cathedral, acoustics researcher Brian Katz and colleagues hope to help restore the cathedral's iconic sound, ***Emily Conover*** *reported in "Saving Notre Dame's sound"* (SN: 1/18/20, p. 18).

Reader **Pamela Dellal** found the story moving and comforting. "I am a professional singer who had the irreplaceable privilege of performing in Notre Dame as a soloist, singing music of Hildegard von Bingen dating from the 12th century," she wrote. "When I heard about the catastrophe, my heart constricted; I felt as if I was losing a friend."

Dellal has performed in more than 50 buildings in Europe, Australia and the United States, she wrote. Notre Dame cathedral "was the only space that didn't simply spread out my sound, but actually picked out individual notes which hung in the space, creating harmony with my subsequent notes. I was not alone; I was singing a duet with the magnificent structure," she wrote.

"At that moment, I understood the power of its architecture and how it inspired a revolution in music," **Dellal** wrote. "No other space possesses that clarity. If the expertise of Brian Katz is able to restore the unique sound and response of Notre Dame, the entire world will once more be able to experience this phenomenon."

Traffic jam

When they pile up in brain cells, misfolded proteins called prions can derail energy-producing mitochondria and potentially contribute to cell death, ***Tina Hesman Saey*** *reported in "Prions clog nerve cell traffic"* (SN: 1/18/20, p. 11).

Reader **Brian Mahood** was surprised to learn that prions could diminish or block communication between brain cells. "This might be an irreversible event and thus leave one with 'holes' in one's memory," **Mahood** wrote. "I would be grateful if you could clarify this for me."

Cell death isn't great for anything the brain does, including memory, says *Science News* neuroscience writer **Laura Sanders**.

"But one cell dying on its own, or losing its connections to other cells via prion traffic jams, wouldn't make a memory 'hole.' If that were the case, we'd forget something every time a brain cell died," **Sanders** says. Memories are thought to be stored across networks of brain cells, though exactly how is a mystery. "One idea, ironically enough, is a prionlike protein," she says.

Brain freeze

A long-term stay at an Antarctic research station may have shrunk a part of crew members' brains, ***Aimee Cunningham*** *reported in "Isolated in Antarctica, people's brains shrank"* (SN: 1/18/20, p. 5).

Reader **Dale Cyphert** wondered if other areas of the brain became larger when the one part shrank. "Presumably the whole brain didn't just shrink, but there's some redistribution of neurological work going on?" he asked.

Other parts of the crew members' brains did not become larger to compensate for volume loss, **Cunningham** says. The area of the brain that shrank is especially vulnerable to environmental deprivation. "Although the study is small, the work suggests that the isolation and static environment that the crew members experienced meant this part of their brains wasn't getting enough stimulation," she says.

The context in which such brain changes happen matters. *Science News* neuroscience writer **Laura Sanders** notes that brain shrinkage doesn't always imply damage. "Shrinking isn't necessarily bad," **Sanders** says. "And size doesn't have to track with function."

For example, after a woman has a child, her brain shrinks in a way that scientists think specializes the organ and makes it more efficient. "Same goes for teenage brain development," **Sanders** says. "Brain connections get refined, and some areas get smaller as the brain matures."

Join the conversation

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GEOLOGIC ROAD TRIP OF THE MONTH

The wide-open spaces of Joshua Tree National Park are ideal for the teddy bear cholla cactus, a beautiful plant that you will regret getting too close to. (33°55.50N, 115°55.77W) —Ivar Midtkandalen

JOSHUA TREE NATIONAL PARK

Joshua Tree National Park is located in the Little San Bernardino Mountains, part of the eastern Transverse Ranges between the Salton Trough of the Colorado Desert and the Mojave Desert. Geologically, the park's rocks and structures belong to the Mojave Desert. You can drive into the park from either the south entrance from I-10 (exit 168) or from the west or north entrances from CA 62 in Yucca Valley.

The Cottonwood Springs/Pinto Basin Road cuts across the center of the park from the CA 62 entrances to the I-10 entrance. Unpaved side roads and hiking trails give access to various scenic locations. Keys View Road, which is paved but narrow and slow, leads to windy Keys View at an elevation of 5,185 feet. You can also see a lot of fascinating geology from the Geology Tour Road, but it requires four-wheel drive.

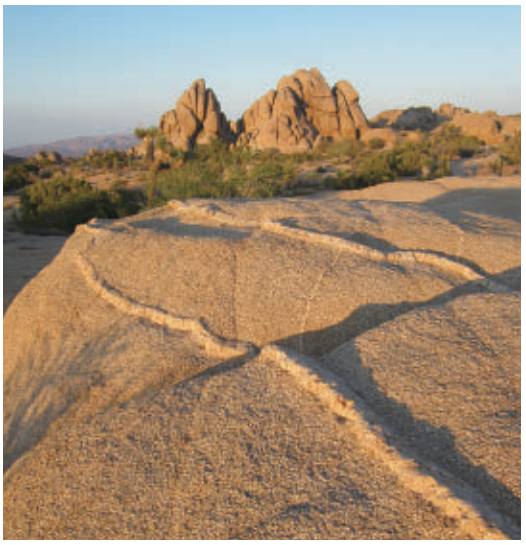
Much of the north half of the park consists of granite, part of the huge intrusion of magma that formed the batholiths of the Sierra Nevada and Peninsular Ranges when the Farallon Plate subducted beneath the North American Plate in Mesozoic time. Proterozoic granite and metamorphic rocks, intruded by the granite, are also exposed in the park. Metasedimentary rocks, metamorphosed before Cretaceous time, crop out in some less accessible areas. The best place to see Proterozoic rocks is in a few roadcuts between I-10 and the Cottonwood Springs entrance station, where Pinto Gneiss is exposed.

Granite is exposed and accessible in the Wonderland of Rocks, especially in the Jumbo Rocks and White Tank areas. Look for Arch Rock in White Tank Campground, the Old Woman and Cyclops Rock in Hidden Valley Campground, the Trojan and the Ox along the Hidden Valley Nature Trail, Bread Loaf Rock near Belle Campground, and Skull Rock near Jumbo Rocks Campground.

If you climb some gentle outcrops of granite, you'll notice large, blocky crystals of white or gray potassium feldspar set among minerals grains that are all about the same size. Based on the kind and abundance of minerals, geologists give separate and daunting names. Some of them take the name of the place where they are exposed, such as Twentynine Palms quartz monzonite and White Tank monzodiorite. The distinctions among them may be subtle and difficult without careful analysis, especially when cruising at the park's designated speed limits.

If you walk on and around the granitic rocks and through some of the ravines, you'll notice white veins slicing across the granite here and there. These light-colored, fine-grained veins of quartz and feldspar are called aplite dikes, whereas those with large crystals of quartz, feldspar, and mica are pegmatite dikes. They intruded along cracks and joints in the granite when it was cool enough to fracture but still contained some melted rock that could fill and crystallize in those fractures.

Several major faults bound Joshua Tree National Park and are considered active. Strands of the San Andreas fault lie along the southwest edge of the park in Coachella Valley. The Blue Cut fault slices east-west through the center of the park, and the Pinto Mountain fault comes out of Morongo Valley along the north edge of the park. You won't see much of these two faults, because they lie beneath valley fill, but some faults are nicely exposed along the Geology Tour Road and in canyons along the northeast edge of Coachella Valley.



Fine-grained aplite dikes of quartz and feldspar intruded this granite and are more resistant to erosion than the granite. (33°59.12N, 116°00.94W) —Tyson McKinney

Sacred Stone of the Southwest is on the Brink of Extinction

Centuries ago, Persians, Tibetans and Mayans considered turquoise a gemstone of the heavens, believing the striking blue stones were sacred pieces of sky. Today, the rarest and most valuable turquoise is found in the American Southwest—but the future of the blue beauty is unclear.

On a recent trip to Tucson, we spoke with fourth generation turquoise traders who explained that less than five percent of turquoise mined worldwide can be set into jewelry and only about twenty mines in the Southwest supply gem-quality turquoise. Once a thriving industry, many Southwest mines have run dry and are now closed.

We found a limited supply of turquoise from Arizona and snatched it up for our ***Sedona Turquoise Collection***. Inspired by the work of those ancient craftsmen and designed to showcase the exceptional blue stone, each stabilized vibrant cabochon features a unique, one-of-a-kind matrix surrounded in Bali metalwork. You could drop over $1,200 on a turquoise pendant, or you could secure 26 carats of genuine Arizona turquoise for **just $99**.

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