Lost and Found Matter | Lessons From Past Pandemics

Science News

MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC ■ JUNE 20, 2020

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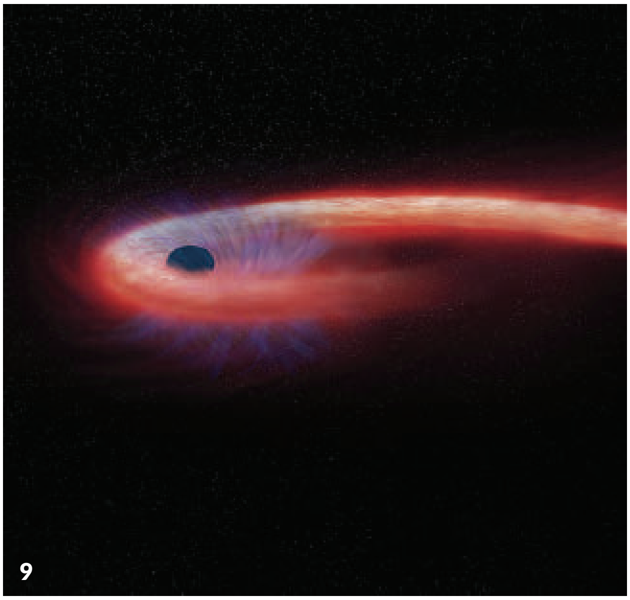

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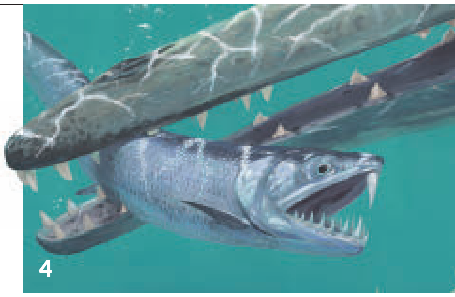

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Departments

COVER Physicists try to construct ways to find and correct errors in quantum computers without wrecking the data. *Nicolle Rager Fuller*

FROM TOP: INCAMERASTOCK/ALAMY STOCK PHOTO; JOSCHUA KNÜPPE; M. WEISS, CSC/NASA

History reveals how societies survive plagues

This isn't the first time in history that societies have been racked by social unrest while in the grip of a pandemic.

That may be scant comfort, but as Bruce Bower explains in this issue (Page 24), impacts of a pandemic often reach beyond the toll of illness and death. In the mid-200s, the Plague of Cyprian may have helped to irreversibly weaken the Roman Empire. In the 19th century, soldiers sent to Haiti by Napoleon Bonaparte to quash rebellion succumbed to yellow fever, leading to Haitian independence and Napoleon's sale of the territory of Louisiana to the United States.

Yellow fever's grip on Louisiana perpetuated racial inequity, Bower reports. White people who survived gained special privileges once they were immune to the mosquito-borne disease. Enslaved people, however, did not; surviving yellow fever just made them more valuable as workers.

The coronavirus pandemic has tracked long-standing racial fault lines in the United States, with African Americans more apt to become seriously ill or die from COVID-19 (*SN Online: 4/10/20*). Black people often work in jobs where they are more likely to be exposed, more often have other health conditions that put them at greater risk, and have less access to care.

As protests over the death of George Floyd at the hands of Minneapolis police swept the nation, physicians' groups including the American Medical Association and the American Academy of Pediatrics called for the country to address the violence and inequities of racism as a public health crisis. "Racism is detrimental to health in all its forms," the AMA statement read.

Scientists warned for decades of the risk of a pandemic, but societies world-wide failed to prepare. The economic, social and human costs of racism have been clear for even longer, yet remain a heavy burden.

But those failures don't have to be our future. History offers many examples of societies adapting and evolving in response to the assaults of pandemics, Bower writes. In these awful times, we also have opportunities to change history for the good. *—Nancy Shute, Editor in Chief*

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SSP

Excerpt from the June 27, 1970 issue of *Science News*

50 YEARS AGO

Panel to study animal feeds

Most animal feeds contain antibiotics ... to promote fast weight-gain in species raised for human food. However, these animals may harbor microorganisms that have developed a resistance to antibiotics, and some scientists fear that these resistant organisms may be passed on to human beings.... [The U.S. Food and Drug Administration has appointed a panel to review whether] antibiotic resistance in man is enhanced by long-term, low-level exposure from foods.

UPDATE: The first hint that antibiotic-resistant bacteria in livestock can jump to humans came in 1976, when scientists found higher levels of such bacteria in the guts of farmers who fed antibiotics to chickens than in those farmers' neighbors. In terms of the food supply, the FDA has detected varying levels of antibiotic-resistant bacteria in meat since monitoring began in 1996. Cooking should kill these bacteria, though some have been linked to illness in humans. Since 2013, the FDA has phased out the use of antibiotics for promoting growth in livestock.

A saber-toothed fish (illustrated) is caught in the jaws of an early whale.

INTRODUCING

Extinct anchovy kin were armed to the teeth

Less pizza topping and more toothy hunter, ancient anchovy relatives had quite the bite.

Fossils show that these fish had a mouthful of fearsome teeth. Two newly analyzed specimens sport spiky teeth along the lower jaw and one giant dagger jutting down from the top jaw, scientists report in the May *Royal Society Open Science*.

Such chompers suggest that the now-extinct fish possibly fed on other fish. Today's anchovies feast mostly on plankton. "They have super tiny teeth. They look nothing like these things," says paleontologist Alessio Capobianco of the University of Michigan in Ann Arbor.

The ancient fish were large compared with their modern relatives, which top out at around 37 centimeters long. One of the fossil fish, a newly identified species named *Monosmilus chureloides*, may have stretched nearly a meter long.

Physical features tie the fish, which lived roughly 50 million years ago, to their modern kin. Today's anchovies open wide to gulp food. The fossil fish also had gaping maws — probably to help catch fish given those big teeth, Capobianco says.

Such predatory fish may have filled voids left by the extinction of many marine species about 66 million years ago. *— Carolyn Wilke*

TEASER

Astronauts could use their urine to make cement

Future astronauts could make lunar buildings out of moon dust and pee.

That's the suggestion of chemist Anna-Lena Kjøniksen and her colleagues, who made a cement from urea — a major component of urine — and faux lunar soil.

Humans taking up long-term residence on other planets or the moon will need to pack light and tap into local resources to keep costs down. Researchers have previously suggested using lunar soil for cement to 3-D print dwellings. But most recipes require a lot of water, which is scarce on the moon.

Scientists 3-D printed these miniature walls with a cement containing urea — an abundant compound in human urine — and lab-made lunar soil.

Kjøniksen, of Østfold University College in Halden, Norway, thought human waste could come in handy. Urea cuts down on the water needed for cement by keeping mixes from getting too crumbly. Her team mixed powder containing silica and aluminum oxide, a stand-in for lunar soil, with a urinelike solution mostly made of urea and some water. The cement held its shape under light weight and withstood temperature changes. Stacking several layers using a 3-D printer made a tiny wall, the team reported in the Feb. 20 *Journal of Cleaner Production*.

Kjøniksen plans to investigate whether astronauts would have to purify urine, or if they could use pee in cement directly. *— Lisa Grossman*

FROM TOP: JOSCHUA KNÜPPE; © S. PILEHVAR, ESA

SCIENCE STATS

COVID-19 pandemic has led to a drop in global carbon emissions

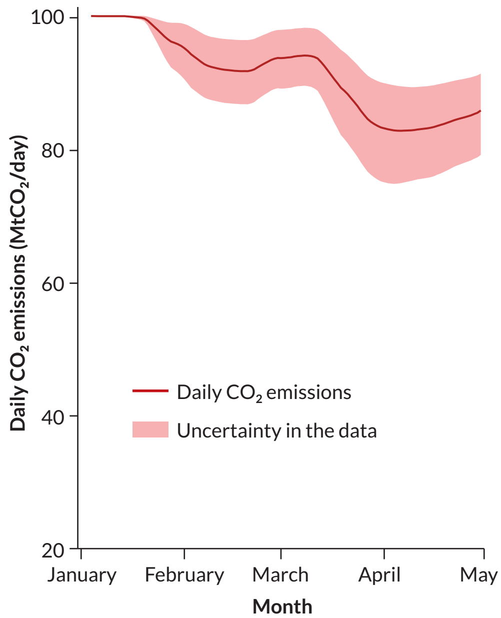
Stay-at-home orders haven't just curbed the spread of COVID-19. They've briefly cleared the air.

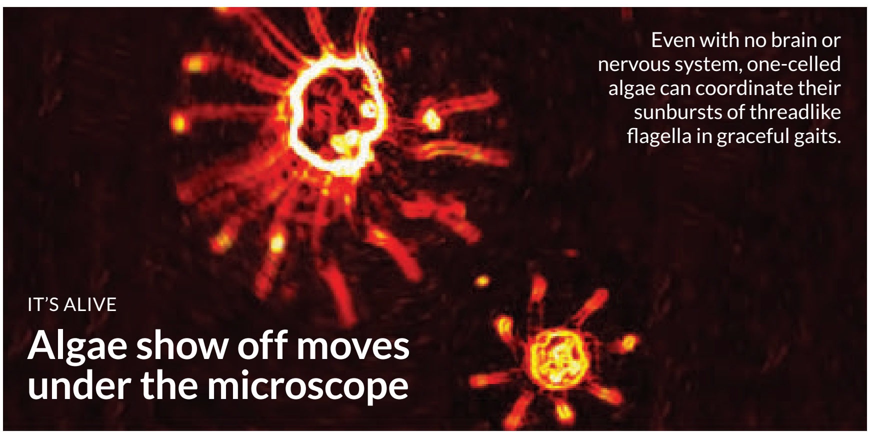
Daily global carbon dioxide emissions dropped 17 percent, from about 100 million metric tons to about 83 million metric tons, by early April compared with average daily emissions in 2019, researchers report May 19 in *Nature Climate Change*. Among other changes, the lockdowns grounded planes, reduced traffic and changed people's patterns of energy use.

If the world returns to a pre-pandemic level of activity by mid-June, researchers say, 2020's total emissions will be about 4 percent lower than in 2019. If some restrictions remain through the end of the year, 2020 emissions could be as much as 7 percent lower.

This COVID-19–related decline in emissions isn't sustainable and comes at a high cost, says Rob Jackson, an environmental scientist at Stanford University. But it underscores the deep cuts needed to limit warming to 1.5 degrees Celsius by 2100. Nations would need to cut emissions by 7.6 percent each year over the next decade, scientists say. *— Carolyn Gramling*

Global carbon dioxide emissions, January–April 2020





Even with no brain or nervous system, one-celled algae can coordinate their sunbursts of threadlike flagella in graceful gaits.

IT'S ALIVE

Algae show off moves under the microscope

Microscopic specks of algae can trot like a horse. Or gallop.

Moving diagonally opposite limbs, or flagella in this case, in unison — that's a trot, says Kirsty Wan, a biophysicist at the University of Exeter in England. She compares the gaits of creatures large and small. Wan's lab is working on the conundrum of how single-celled creatures, with no nervous system or brain, coordinate "limbs" to create various gaits. Some of those movements get far trickier than trots and gallops.

Her work echoes that of 19th century photographer Eadweard Muybridge, who used a then-novel imaging technique to reveal hoof positions obscured in the blur of a horse galloping. Wan now creates Muybridge moments for microalgae. Using a range of microscopy analytics on what she calls "my private collection of weird algae," Wan and colleagues have documented microalgae that coordinate from four to 16 flagella.

In some four-limbed cells, flagella can move in neighborly pairs, pulling back in a sort of double vision breaststroke. To these microscopic critters, water feels thicker than the splashy stuff that giant humans easily swish aside. So the algal breaststroke has little glide. It's more like a slog through molasses.

Wan looked hard for microalgae with eight flagella and found three species. One, *Pyramimonas octopus*, has a gait unlike any Muybridge ever saw. Wan calls it the rotary breaststroke. Flagella across from each other in the array of eight will curl in for the stroke as their neighbors are uncurling a few beats behind.

P. octopus is a twitchy microbe that goes through "shocks," Wan says. An alga swims along, then "like a knee-jerk reaction," it changes direction, though she can't see what spooks the microbe. In comparison, when she watches a two-flagella *Chlamydomonas* species, "sometimes it twirls; sometimes it spins," but there's nothing so dramatic as the abrupt pullback.

The most elaborate gait she's seen may have been lost to science. Wan once grew the Arctic's *P. cyrtoptera*, the only microalgal species she knows of with an array of 16 flagella. Sometimes opposite pairs of flagella stroke in unison as the motion ripples around and around the array in a gait she calls a "wave." Her colony died, however, and so did her supplier's. "I hope it still exists somewhere in the world," she says. "Otherwise, I might have ... taken the last footage." *— Susan Milius*

FROM TOP: C. LE QUÉRÉ *ET AL*/*NATURE CLIMATE CHANGE* 2020; K.Y. WAN, RAYMOND E. GOLDSTEIN

Watch algae gallop at **bit.ly/SN_AlgaeMoves**

News

ATOM & COSMOS

'Missing matter' may be found

Baryons appear to hide in the space between galaxies

BY MARIA TEMMING

At long last, all of the universe's ordinary matter seems to be present and accounted for.

Astronomers have taken a new census of matter in the universe by examining how bright flashes of radio waves from other galaxies, called fast radio bursts, are distorted by particles on the way to Earth. This analysis suggests that about half of the universe's ordinary matter, which has eluded detection for decades, is lurking in intergalactic space, researchers report in the May 28 *Nature*.

The mystery of the missing matter has vexed cosmologists for at least 20 years. This elusive material isn't the invisible, unidentified dark matter that makes up most of the mass in the universe. It's ordinary matter, composed of garden-variety particles called baryons, including protons and neutrons.

Observations of light emitted when the universe was young indicate that baryons should make up about 5 percent of all the mass and energy in the cosmos. But in the modern universe, all the matter that astronomers can easily see, like the stars and gas in galaxies, adds up to only about half of what's expected.

Scientists have long suspected the missing matter is hiding between galaxies, along filaments of gas strung between galaxy clusters in a vast cosmic web (*SN: 3/8/14, p. 8*). "But we haven't been able to detect it very well, because it's really, really diffuse, and it's not shining brightly," says astrophysicist Jason Hessels of the University of Amsterdam, who was not involved in the new work.

Some intergalactic matter is detectable by how it absorbs the light of distant, bright objects called quasars (*SN: 5/13/00, p. 310*). But the only way to take inventory of all the baryons hanging out in intergalactic space relies on mysterious blasts of radio waves from other galaxies, possibly generated by energetic activity around neutron stars or black holes (*SN: 2/29/20, p. 14*).

No one knows what causes these fast radio bursts, or FRBs, but they can make useful baryon detectors. A burst's high-frequency, high-energy radio waves zip through intergalactic matter faster than the low-frequency waves. The more intergalactic matter that a radio burst's waves pass through, the farther its lower-frequency waves fall behind — creating a detectable smear in the radio signal by the time it reaches Earth.

Flashes of radio waves from other galaxies, detected by the Australian Square Kilometre Array Pathfinder (shown), may have helped solve the mystery of the universe's "missing matter."

Astrophysicist J. Xavier Prochaska of the University of California, Santa Cruz and colleagues examined five fast radio bursts from five galaxies, all detected by the Australian Square Kilometre Array Pathfinder. For each FRB, the researchers compared the arrival times of radio waves of different frequencies to tally up the number of baryons that the burst encountered on its journey through intergalactic space. Then, using the distance between the FRB's host galaxy and the Milky Way, Prochaska's team calculated the baryon density along that path.

The average density of matter between the Milky Way and each of the five FRB host galaxies came out to about one baryon per cubic meter. The material in the Milky Way is about 1 million times as dense as that, Prochaska says, making the intergalactic stuff "a very wispy medium." But all that wispy material, taken together, is enough to account for all the universe's missing matter — bringing ordinary matter up to about 5 percent of the modern universe's overall mass and energy, the researchers say.

Astrophysicist J. Michael Shull of the University of Colorado Boulder cautions that "five is an awfully small number" of FRB observations from which to draw conclusions about the number of baryons throughout the modern universe. But "once they get their error bars beaten down with many, many more bursts ... I think that will really be the nail in the coffin on this baryon problem," he says.

Using more fast radio bursts as cosmic weigh stations will also be useful for pinpointing exactly where all the matter in the universe is located, says Shami Chatterjee, a radio astronomer at Cornell University who wasn't involved in the work.

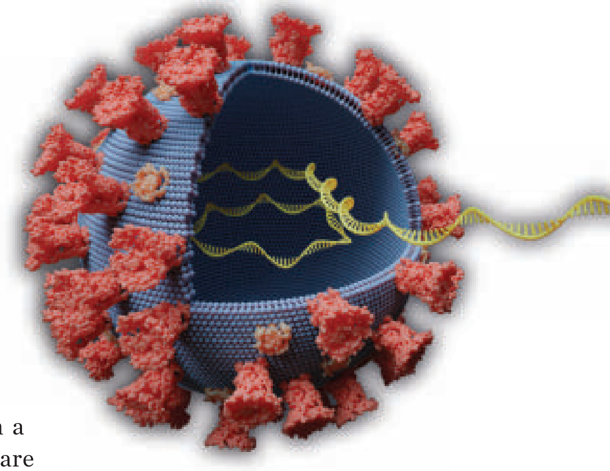
Right now, all the researchers can say about the lost-and-found matter is that it's between galaxies. But with thousands of FRB observations, astronomers could tease out the slight variations in baryon density along the sight lines between the Milky Way and other galaxies to map out the cosmic web, Chatterjee says. ■

CSIRO, ALEX CHERNEY

GENES & CELLS

The new coronavirus is mutating

Whether those changes are bad is up in the air



A coronavirus's genetic material consists of a single strand of RNA (yellow in this illustration). Some mutations in the RNA's nucleotides (yellow ladder rungs) have no effect at all.

VCHAL/ISTOCK/GETTY IMAGES PLUS

BY ERIN GARCIA DE JESUS

In movies, infectious pathogens mutate and inevitably become more dangerous. In the blockbuster *Contagion*, a deadly virus acquires a mutation that causes the death toll to spike in mere days.

Reality is far less theatrical.

Over the last few months, several research groups have claimed to identify new strains of the coronavirus called SARS-CoV-2. But determining whether a change in a virus amounts to a "new strain" is hard, and none of the reported changes have been shown to make the virus more dangerous.

These reports have confused the public. Each time such studies surface, fear rises, and experts rush to explain that viruses mutate all the time. The coronavirus is no exception.

"In fact, it really just means that it's normal," says Kari Debbink, a virologist at Bowie State University in Maryland. "Not all of those mutations are meaningful."

Viruses are protein shells that contain either DNA or RNA as their genetic material. For SARS-CoV-2, it's RNA. RNA is composed of nucleotides arranged in triplets called codons. Those trios provide the instructions for which amino acids to use to build a virus's proteins. A mutation is a change to one of these nucleotides.

Mutations can arise when a virus infects cells and makes copies of its genetic instructions. This process is error-prone because most RNA viruses don't have the tools to proofread their genetic material for mistakes. Coronaviruses including SARS-CoV-2, however, have a proofreading enzyme, so changes accumulate more slowly than in viruses such as influenza.

"Strains," "variants" or "lineages" are terms scientists may use to describe viruses that have identical or closely related strings of RNA. But "strain" is often interpreted to mean a whole new scourge. "The use of the term 'strain' does little more than cause panic," says virologist Jeremy Luban of the University of Massachusetts Medical School in Worcester. "It doesn't really get at what the important issues are."

A mutation can affect a virus in a number of ways. Some mutations are "silent" — an altered nucleotide results in a codon that still codes for the same amino acid. But even if an amino acid changes, the virus might not act in an obviously different way. And sometimes a mutation results in a dysfunctional virus.

Only certain kinds of mutations make a virus more dangerous. Such changes may shield the virus from the immune system or make it resist treatments. Mutations could speed up the virus' spread among people or increase disease severity.

Such worrisome mutations are rare but can be hard to identify. A preliminary study posted online May 5 at bioRxiv.org, for instance, identified a mutation in the SARS-CoV-2 spike, the protein that allows the virus to break into cells. This new virus variant is now found more often in Europe and the United States than is the original form of the virus. That may mean the change makes the virus more transmissible, the authors say. But the study lacked lab experiments to support the claim.

Or the new variant may have ended up in certain regions due to random chance — a person infected with a virus that had the mutation just happened to hop on a plane. The study didn't provide enough evidence to distinguish between the possibilities.

"What I think has been potentially confusing to people is that we're watching this very normal process of [viral] transmission and mutation happen in real time," says Louise Moncla, an evolutionary epidemiologist at the Fred Hutchinson Cancer Research Center in Seattle. "And there's this real desire to understand whether these mutations have any functional difference."

To grasp a mutation's importance requires more than one experiment, Debbink says. In addition to examining viral genetic sequences from coronavirus patients globally, scientists will need studies in lab-grown cells or in animals to pinpoint whether viruses with particular mutations behave differently. Competition experiments — in which two different versions of a virus are mixed with cells in a dish or used to infect an animal — can help show which variant is more successful at making copies of itself, that is, which one "wins."

Other tests could reveal if mutations in the spike protein alter how strongly it attaches to the protein on human cells that allows the virus to gain entry or whether changes modify how easily the virus gets into a cell after binding.

But lab results may not provide the full picture either. "Just because something's different in a cell doesn't necessarily mean that it's different when you scale that up to the whole human body," says Emma Hodcroft, a molecular epidemiologist at the University of Basel in Switzerland. "You're going to need some animal studies or some really good human data."

That takes time. Meanwhile, more mutations will pop up — and experts will track them. "The data will tell us whether we need to worry, and in what way we need to worry," Moncla says. "Everyone should take a deep breath and realize that [the virus mutating] is exactly what we've always expected to happen, and we don't necessarily need to be concerned." ■

GENES & CELLS

Malaria parasites may keep time

Plasmodium appears to have its own circadian clock

BY JAKE BUEHLER

The parasites that cause malaria may march to the beat of their own drum.

New genetic analyses suggest that *Plasmodium* parasites possess their own circadian rhythms and don't depend on a host for an internal clock, researchers report in the May 15 *Science*. Figuring out how *Plasmodium*'s clock ticks may lead to ways to disrupt it, potentially adding to the arsenal of treatments for malaria.

A malarial infection is a series of cyclical symptoms. Depending on the *Plasmodium* species involved, fever and chills return roughly every 24, 48 or 72 hours because of the parasites' synchronized reproduction and destruction of a host's red blood cells.

Researchers had thought that rhythm was likely driven by a host's circadian rhythm, says molecular parasitologist Filipa Rijo-Ferreira of the University of Texas Southwestern Medical Center in Dallas. Circadian clocks help organisms anticipate cyclic changes in the environment, like day and night cycles. These clocks are made up of genes and proteins that drive daily rhythms, such as the release of hormones. In animals, the clock typically operates on a 24-hour cycle.

Rijo-Ferreira and colleagues recently showed that the *Trypanosoma* parasite that causes sleeping sickness has its own internal clock. So the team decided to look for one in *Plasmodium*.

The scientists tracked the rhythms of genes turning on and off in malaria parasites in infected mice. Some mice lived in constant darkness, throwing off the mice's circadian rhythms. But the timing of gene activity in these mice's parasites was similar to that of parasites in mice exposed to regular day-night cycles.

To see if the parasites used a host's feeding schedule to orient their clock, the team provided mice with food spread evenly throughout the day. The mice's *Plasmodium* kept the same rhythms as those in mice fed once daily.

And when the parasites were in hosts genetically engineered to lack a clock entirely, the parasites' timekeeping ability ticked right along unhindered. Taken together, these results suggest that *Plasmodium* has its own clock.

In mice engineered to have a circadian clock slightly longer than 24 hours, the parasites appeared to attempt to synchronize their clocks to that of their host's, slowing their pace. While malaria parasites can parallel their host's schedule, they don't depend on it for a clock, the team concludes, suggesting that the parasites use their clocks to align with a host's during an infection.

Syncing up all the clocks in a population of malaria parasites inside of a host does require input from the host's rhythms, the researchers say. In mice lacking an internal clock, the synchrony within an entire parasite population slowly decayed, falling apart after eight or nine days. This asynchrony is similar to what happens to internal clocks in groups of mammalian cells without any external cues, such as sunlight or chemicals.

LIFE & EVOLUTION

Neon colors aid stressed-out corals

After a bleaching event, bright pigments help bring back algae

BY CAROLYN WILKE

For some corals, going bright may be part of their fight against bleaching.

Higher-than-normal temperatures can cause some corals to bleach and lose the algae that dwell within their cells. Those algae help feed the corals and give them color, so bleached corals can become bone white and struggle to survive. But after some corals bleach, they turn neon hues: red, blue, green or purple.

Some researchers had suspected that with the algae gone, the bleached corals' natural colors shine through. But a new study suggests a different dynamic. Certain wavelengths of light appear to trigger an uptick in the corals' production of pigments, which act as a sunscreen to create a more hospitable home for returning algae, researchers report online May 21 in *Current Biology*.

"Some of these corals are trying to protect themselves with really spectacular side effects," says Daniel Wangpraseurt, a coral reef scientist at the University of Cambridge who was not involved with the study.

A survey of bleaching events globally from 2010 to 2019 revealed that some corals' neon colors corresponded with mild heat stress, caused by a long spell of warmer waters or a brief temperature spike. In most cases, the new colors appeared two to three weeks after the heat stress, says study coauthor and marine biologist Elena Bollati of the National University of Singapore. She did the study while at the University of Southampton in England.

In the lab, Bollati and colleagues simulated mild bleaching by exposing corals to a slow ramp up in temperature. As the heat rose, the amount of algae in cells, detected by the red light algae emit under a certain wavelength of light, plummeted. A few weeks after the heat stress, corals bumped up their levels of a fluorescent compound that gives them color. An

RICHARD VEVERS/THE OCEAN AGENCY, XL CATLIN SEAVIEW SURVEY

After a warm spell, some corals, such as these *Acropora* corals in the Pacific Ocean, turn bright hues after bleaching white.

Rijo-Ferreira says she isn't surprised that *Plasmodium* has a circadian rhythm, given how many times internal clocks have independently evolved in organisms ranging from bacteria to fungi to animals. "It's almost unbelievable that an organism wouldn't have a clock," she says.

Further support for an internal clock comes from a separate study, also in the May 15 *Science*, led by molecular biologist Steven Haase of Duke University. Haase's team isolated *Plasmodium* from a host, growing four different strains of the parasite in the lab and tracking patterns of gene activity. As many as 92.6 percent of the known genes for *Plasmodium* appear to be clock-controlled, keeping time in the absence of a host.

Uncovering the molecular components of the timekeeping mechanism could help confirm that the parasite has an independent clock that consistently ticks, says Sarah Reece, an evolutionary parasitologist at the University of Edinburgh. "It's still possible [that the parasites] keep time in a simpler way," she says, for instance, by reacting to some external stimuli. ■

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imbalance of nutrient levels also could cause colorful bleaching, the team found.

After losing algae, an increased exposure to blue light in sunlight may play a role in this rise in pigment production, the team found. Healthy, unbleached corals rely on algae's pigments to absorb some sunlight. Without algae, more light, including blue wavelengths, can bounce around inside the corals' skeleton structure, boosting the exposure of the corals' living tissue to light.

Blue light prompted bleached corals to pump out more of their own protective pigments. Vividly colored areas of the corals more quickly regained symbiotic algae than areas with less pigment.

Corals "have this capacity to fight back" after bleaching, says coauthor and marine biologist Jörg Wiedenmann of the University of Southampton. But, he says, their long-term survival depends on curbing climate change so that corals don't experience too much stress. ■

ATOM & COSMOS

Shredded stars may rev up neutrinos

Physicists claim to trace a high-energy particle to its source

A black hole shredding a star (illustrated) may have birthed a high-energy neutrino. Gas (red) from the star spirals toward the black hole. Some stellar material gets flung outward (blue).

M. WEISS, CXC/NASA

BY EMILY CONOVER

A neutrino that plowed into Antarctic ice offers a cautionary message: Don't stray too close to the edge of an abyss.

The subatomic particle may have been blasted outward when a star was ripped to pieces during an encounter with a black hole, physicists report May 11 at arXiv.org. If it holds up, the result would be the first direct evidence that such star-shredding events can accelerate subatomic particles to extreme energies. It would mark only the second time that a high-energy neutrino has been traced back to its origins.

With no electric charge and very little mass, neutrinos are known to blast across the cosmos at high energies. But scientists have yet to fully track down how the particles get so juiced up.

One potential source is what's called a tidal disruption event. When a star gets too close to a supermassive black hole, gravitational forces pull the star apart. Some of the star's guts spiral toward the black hole and get gobbled up. Other bits of the star are spewed outward.

The neutrino, spotted on October 1, 2019, had an energy of 200 trillion electron volts. That's about 30 times the energy of each of the protons in the most powerful human-made particle accelerator. The neutrino's signature was picked up by IceCube, a detector deep in the Antarctic ice that senses light produced when neutrinos interact with the ice.

When IceCube finds a high-energy neutrino, astronomers scour the sky for anything unusual in the direction from which the particle came, such as a short-lived flash of light. Astronomers with the Zwicky Transient Facility in California came up with a possible match: a tidal disruption event called AT2019dsg.

The probability that a neutrino and a similar tidal disruption event would overlap by chance is only 0.2 percent, Marek Kowalski of the Deutsches Elektronen-Synchrotron in Zeuthen, Germany, and colleagues report. But that doesn't meet physicists' stringent burden of proof. "Just one event is difficult to convince [us] this source is really a neutrino emitter," says astrophysicist Kohta Murase of Penn State.

Kowalski declined to comment for this article, as the study has not yet been accepted for publication in a journal.

To have birthed such an energetic neutrino, the event must have accelerated protons to high energies. Those protons must then have crashed into other protons or photons (particles of light). That process produces particles called pions, which decay and emit neutrinos.

Now, scientists are aiming to pin down exactly how that acceleration might have happened. The protons might have been launched within a wind of debris that flowed outward in all directions. Or they could have been accelerated in a powerful, geyserlike jet of matter and radiation.

Previously, astronomers matched an energetic neutrino to a flaring blazar, a bright source of light powered by a supermassive black hole (*SN: 8/4/18, p. 6*). Both a blazar flare and a tidal disruption event release a lot of energy in a small amount of time, says astrophysicist Ke Fang of Stanford University.

Making more observations of high-energy neutrinos is crucial, Fang says. "This is the only way we can clearly understand how the universe is operating at this extreme energy." ■

A bumblebee sinks its mouthparts into a leaf to nick a small hole. Little cuts like this seem to jolt plants into starting to flower early.

LIFE & EVOLUTION

Bumblebee-bitten plants bloom early

Leaf nipping becomes more common when pollen is scarce

BY SUSAN MILIUS

Here's a tip for bumblebees interested in getting a slowpoke plant to bloom early: Just bite it.

At least three bumblebee species use their mouthparts to snip little confetti bits out of plant foliage, researchers report in the May 22 *Science*. This foliage biting gets more common when there's a pollen shortage, says Consuelo De Moraes, a chemical ecologist and entomologist at ETH Zurich.

In experiments, mustard and tomato plants nibbled by *Bombus terrestris* bees bloomed earlier than unbitten plants by days, or even weeks, say De Moraes and colleagues. For the bumblebees, accelerating bloom times could be a lifesaver. When trying to found colonies in early spring, the bees rely on flower pollen as a protein source for raising their young.

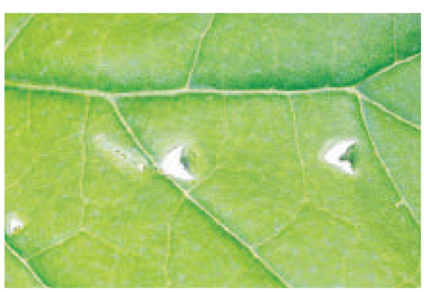
Ecologist Foteini Paschalidou, now at France's National Institute for Agricultural Research in Versailles-Grignon, was the first team member to call attention to the behavior. She noticed it during a project with *B. terrestris* bees kept indoors. At first, De Moraes worried: "Is it something wrong with them?"

The bees' supplier and some farmers who used bees to pollinate crops assured the researchers that nipping happens elsewhere, though the team hasn't found any accounts in the scientific literature.

To test a link between leaf biting and pollen shortages, the researchers did a caged-bee test. After three days without pollen, bumblebees trapped with nonblooming plants were more likely to poke holes in foliage than a bee group buzzing among plentiful flowers. When researchers swapped the bees' situations, the insects now trapped without blooms started nibbling leaves.

Tests done on building roofs with bees free to seek flowers in rooftop planters and elsewhere also found a link between pollen shortage and increased leaf biting, the researchers report.

The notion that bee damage to a leaf could jump-start flowering originally struck coauthor Mark Mescher of ETH Zurich as a long shot. Yet in lab tests, tomato plants punctured five to 10 times by pollen-deprived bees bloomed 30 days earlier on average than undamaged plants. The speedup time varied by plant species. For instance, bee-nipped black mustard (*Brassica nigra*) bloomed only about 16 days early.



During a pollen shortage, a bumblebee cruising a leaf becomes more likely to make punctures and cuts that leave small holes (shown).

The bee-pestered plants' acceleration is not entirely unprecedented. Some other forms of stress, including drought, skimpy nutrients and assault by leaf-eating insect pests, also have triggered early blooming, Mescher points out. But just what's going on with the bee bites and how they might tap into the internal clock that triggers a plant to switch from leafing to flowering remain big questions.

So far, the best efforts of human scientists waiting with forceps and a razor on rooftops to mimic bee activity in real time, bite by bite, on comparison plants have produced only modest acceleration in the black mustard and no meaningful change in the tomatoes. So there might be something special in a bee bite.

In a happy accident, the outdoor trials attracted visits from two other *Bombus* species that checked out the plants on offer and also nicked holes in leaves. That confirms that leaf nibbling is not just some quirk of a commercial lineage of bees, though two longtime bumblebee watchers — Lynn Adler of the University of Massachusetts Amherst and Dave Goulson of the University of Sussex in England — say they've never noticed it.

Goulson says he's fascinated by the idea. *B. terrestris* commonly cuts holes in plant parts, but in a slightly different context. Instead of groping for nectar through the natural openings of flowers, these and other bumblebees often bite little holes through the outer wall of a flower for a sip. "I can imagine that hungry bees unable to find flowers might try biting leaves in desperation," Goulson says. Flower biting might thus have evolved into leaf biting, though, as Mescher points out, it could have happened the opposite way, too.

With hole-punching to check for, clearly now is a great time to go watch bees. ■

FROM TOP: HANNIER PULIDO, C. DE MORAES, MESCHER LABORATORIES; F. PASHALIDOU *ET AL/SCIENCE* 2020

CYNTHIA LIUTKUS-PIERCE

HUMANS & SOCIETY

Trove of human footprints found

Ancient impressions give peek at hunter-gatherer life in Africa

BY BRUCE BOWER

In Tanzania, hundreds of human footprints (some shown) are preserved in an ancient mudflow.

Over 400 human footprints preserved in volcanic sediment provide a peek at social life among ancient hunter-gatherers.

The impressions, found in Tanzania, add up to Africa's largest collection of ancient human footprints, say evolutionary biologist Kevin Hatala of Chatham University in Pittsburgh and colleagues.

People walked across a muddy layer of volcanic debris dating to between 19,100 and 5,760 years ago, the researchers report May 14 in *Scientific Reports*. Dating of a thin rock layer that partly overlaps the sediment narrows the footprints' age to about 12,000 to 10,000 years ago.

Hatala's team analyzed footprint sizes, distances between prints and which way prints pointed. One collection of tracks was made by 17 people walking southwest. Comparisons with modern prints suggest that this group consisted of 14 women, two men and one young boy.

The women may have been foraging while a few males visited or accompanied them, the researchers speculate. Some present-day hunter-gatherers form largely female food-gathering groups.

The study is "a nice piece of work," though it's hard to specify what people were doing, says geologist Matthew Bennett of Bournemouth University in Poole, England.

Many more sets of footprint tracks would be needed to argue convincingly that hunter-gatherers at that time had female foraging groups, Bennett says. And it would still be unknown if the women were gathering plants or hunting prey.

Other sites present especially promising opportunities for studying ancient behavior, he says. He is involved in work in New Mexico that has uncovered tens of thousands of footprints of humans, mammoths and other creatures from more than 10,000 years ago. Early results suggest that humans there hunted giant sloths (*SN: 5/26/18, p. 14*). Bennett expects those prints will yield many more insights into Stone Age hunting. ■

MATH & TECHNOLOGY

Artificial eye mimics the real thing

Device's capabilities could equal or exceed those of humans

BY MARIA TEMMING

Scientists don't yet have the technology to rebuild someone with bionic body parts. But a new artificial eye brings cyborgs one step closer to reality.

The device, which mimics the human eye's structure, is about as sensitive to light and has a faster reaction time than a real eyeball. It may not come with the telescopic or night vision capabilities that Steve Austin had in *The Six Million Dollar Man* television show, but the electronic eye does have the potential for sharper vision than human eyes, researchers report in the May 21 *Nature*.

"In the future, we can use this for better vision prostheses and humanoid robotics," says engineer and materials scientist Zhiyong Fan of the Hong Kong University of Science and Technology.

The human eye owes its wide field of view and high-resolution eyesight to the concave retina — an area at the back of the eyeball covered in light-detecting cells. For the synthetic eyeball, Fan and colleagues used a curved aluminum oxide membrane, studded with nano-sized sensors made of a light-sensitive material called perovskite, to mimic that architecture. Wires attached to the artificial retina send readouts from those sensors to external circuitry for processing, just as nerve fibers relay signals from a real eyeball to the brain.

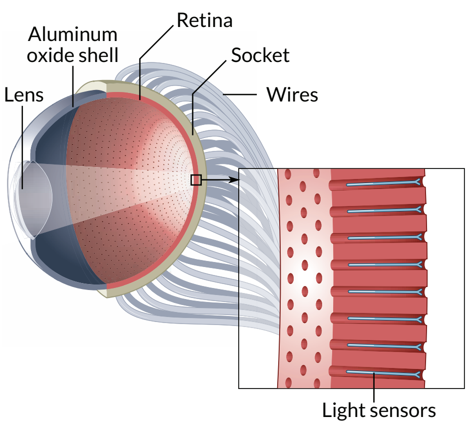
The artificial eyeball registers changes in lighting faster than human eyes can — within about 30 to 40 milliseconds, rather than 40 to 150 milliseconds. The device can also see dim light about as well as the human eye. Although its 100-degree field of view isn't as broad as the 150 degrees a human eye can take in, it's better than the 70 degrees visible to ordinary flat arrays of imaging sensors.

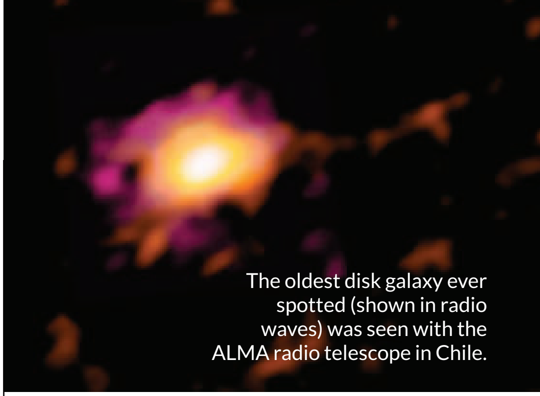
In theory, this synthetic eye could perceive a much higher resolution than the human eye, because the artificial retina has about 460 million light sensors per square centimeter. A real retina has about 10 million light-detecting cells per square centimeter. But higher resolution would require separate readings from each sensor. In the current setup, each wire plugged into the synthetic retina is about a millimeter thick, so big that the wire touches many sensors at once. Only 100 such wires fit across the back of the retina, creating images that have 100 pixels.

To show that thinner wires could be connected to the artificial eyeball for higher resolution, Fan's team used a magnetic field to attach a small array of metal needles, each 20 to 100 micrometers thick, to nanosensors on the synthetic retina one by one.

That method of creating individual ultrasmall pixels is impractical, says Hongrui Jiang, an electrical engineer at the University of Wisconsin–Madison whose commentary on the study appears in the same issue of *Nature*. "For a few hundred nanowires, OK, fine, but how about millions?" Engineers will need a much more efficient way to manufacture vast arrays of tiny wires on the back of the artificial eyeball to give it superhuman sight, he says. ■

Eye see A new artificial eye is based on the structure of the human eye. Nanoscale sensors embedded in the artificial retina measure light that passes through the lens at the front of the eye. Wires attached to the back of the retina ferry signals from the sensors to external circuitry for processing, similar to how nerve fibers connect the eye to the brain.





The oldest disk galaxy ever spotted (shown in radio waves) was seen with the ALMA radio telescope in Chile.

ATOM & COSMOS

Surprisingly old disk galaxy is seen

Spiral galaxies can grow up faster than scientists thought

BY LISA GROSSMAN

The oldest disk-shaped galaxy ever spotted formed just 1.5 billion years after the Big Bang, a study finds.

That's much earlier than astronomers thought that this type of galaxy could form. Previous observations show that disk-shaped galaxies — including sprawling, spiral systems like the Milky Way — didn't show up in large numbers until between 3 billion and 4 billion years after the Big Bang, which occurred about 13.8 billion years ago.

This precocious galaxy's existence suggests that massive spiral galaxies are able to grow up relatively quickly, astronomers report in the May 21 *Nature*.

The new research "challenges the accepted paradigm for how disk galaxies form and evolve in the universe," says Rachel Somerville, an astrophysicist at the Flatiron Institute in New York City who was not involved in the study.

The earliest galaxies probably arose when clumps of invisible dark matter pulled in surrounding gas and dust, forming stars and eventually creating round, blobby galaxies, observations and computer simulations suggest. Theorists reason that early galaxy assembly was a violent process that scrambled and heated gas. Since hot gas expands, the idea goes, the first galaxies were spherical blobs because they were too hot for the gas to settle into a disk. Only when gas has had lots and lots of time to cool can it collapse into

FROM TOP: M. NEELEMAN, ESO, NAOJ, ALMA, S. DAGNELLO/NRAO, AUI, NSF; H. JIANG/NATURE 2020 bright starry disk galaxies, researchers thought.

In the last 15 years or so, however, simulations have showed that cold streams of gas could sneak into ancient, blobby galaxies, potentially making it easier for disk galaxies to arise more quickly.

To see if that process, called the cold accretion method, actually occurs, astronomer Marcel Neeleman and colleagues sought the earliest disk galaxies they could find. Most early galaxies are too far away and thus too faint for Earth-based telescopes to catch light from their stars. But sensitive radio telescopes can detect light from more distant quasars — blazing, white-hot disks surrounding supermassive black holes — filtering through the galaxies' gas. A quasar behind the early disk galaxy, called DLA0817g, let the galaxy show up in silhouette, revealing its contents and structure.

Neeleman, of the Max Planck Institute for Astronomy in Heidelberg, Germany, and colleagues first saw hints of DLA0817g's shape using the Atacama Large Millimeter/submillimeter Array in Chile, the team reported in 2017. Follow-up observations in 2019 showed that the galaxy is rotating like a record: Half of the galaxy's gas is moving away from Earth, and half is moving toward us. That motion is a sure sign that the galaxy is a cold, flat rotating disk, and likely has a spiral shape, the scientists say.

The galaxy is also massive, at least 72 billion times the mass of the sun. Growing a massive galaxy of any shape so quickly "is challenging enough," says study coauthor J. Xavier Prochaska, an astrophysicist at the University of California, Santa Cruz. "But the shocker is to see one in a nice spiral disk."

The team unofficially named the galaxy the Wolfe Disk after astrophysicist Arthur Wolfe of the University of California, San Diego, who died in 2014. Wolfe was one of the first to suggest that disk galaxies existed in the universe's infancy, to widespread skepticism, says Prochaska, who was one of Wolfe's Ph.D. students.

"He was right, at least partially," Prochaska says. "He deserves credit for having planted that flag against all conventional wisdom." ■

MATTER & ENERGY

Physicists make a new kind of crystal

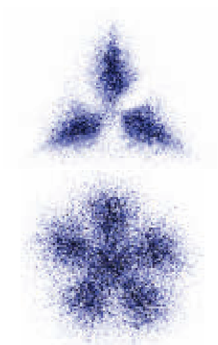
Quantum repulsion rule forces atoms into regular arrangements

BY EMILY CONOVER

Physicists have harnessed the aloofness of quantum particles to create a new type of crystal.

Some particles shun one another because they are forbidden to take on the same quantum state as their neighbors. Atoms can be so reluctant to overlap that they form a crystal-like arrangement even when they aren't exerting any forces on one another, physicists report May 8 at arXiv.org. Called a Pauli crystal, the configuration results from a quantum mechanical rule called the Pauli exclusion principle.

Scientists had predicted the existence of Pauli crystals, but no one had observed them until now. "It just teaches us how beautiful physics is," says quantum physicist Tilman Esslinger of ETH Zurich. The experiment reveals there are still new phenomena to be observed from a foundational principle taught in introductory physics classes. "If I wrote a textbook," Esslinger says, "I would put that [experiment] in."



Flower-shaped patterns appear in the map of atoms' momenta due to the Pauli exclusion principle. The patterns are evidence that groups of atoms (three atoms, top; six, bottom) had formed a Pauli crystal.

S. JOCHIM GROUP/HEIDELBERG UNIV.

Although the Pauli crystals themselves are based on known physics, the technique used to observe them could help scientists better understand certain mysterious states of matter, such as superconductors, materials that conduct electricity without resistance, or superfluids, which flow without friction.

Discovered by Austrian physicist Wolfgang Pauli in 1925, the Pauli exclusion principle forbids electrons within an atom from acquiring matching sets of quantum properties, such as energy and angular momentum. Physicists soon realized that the rule governs not only electrons but an entire class of particles called fermions, which also includes protons, neutrons and many types of atoms. As a result, fermions can repel one another without directly interacting. Whereas typical crystals form their regular arrangements thanks to electromagnetic interactions, a Pauli crystal forms only due to this repulsion.

"It's the most simple state of matter that you can imagine," says Selim Jochim of Heidelberg University in Germany.

Jochim and colleagues created a Pauli crystal out of lithium atoms, corralled by lasers into a two-dimensional region about a micrometer in radius. The team put groups of three or six atoms in that trap at a time. The atoms were too close together to directly image their positions to reveal any crystal-like structure. Instead, the team measured the atoms' momenta by watching where the particles traveled when released. After the experiment was repeated many times, the researchers found correlations, or patterns, in the atoms' momenta.

Because position and momentum are closely related properties for these trapped particles, the relationship between the momenta also means that the atoms formed a regular spatial configuration akin to a crystal. Different flower-shaped configurations of the particles' momenta arose depending on the number of particles in the trap. ■

EARTH & ENVIRONMENT

Dormant Mauna Kea rumbles regularly

But the earthquakes aren't harbingers of an imminent eruption

BY CAROLYN GRAMLING

Hawaii's long-dormant Mauna Kea volcano has been quietly and regularly rumbling for decades — but there's no need for alarm.

The tiny earthquakes aren't signs of the volcano's unrest and are likely linked to gases bubbling from a pool of slowly cooling magma deep underground, researchers report in the May 15 *Science*.

Since at least 1999, the team reports, the ground deep beneath Mauna Kea has been shaking periodically, about every seven to 12 minutes. The source of the quakes, each no more than about magnitude 1.5, is about 25 kilometers deep at the base of Earth's crust.

It's "one of the strangest seismic signals we've ever seen," says Aaron Wech, a volcanologist at the U.S. Geological Survey's Alaska Volcano Observatory in Anchorage.

Small, deep, slow quakes are a familiar type of seismicity associated with volcanoes, says John Vidale, a seismologist at the University of Southern California in Los Angeles who was not involved in the study. "Many volcanoes have this kind of signal," known as deep long-period earthquakes, or DLPs. But the long-lasting, highly periodic rhythm of Mauna Kea's quakes is unusual.

What causes DLPs is a mystery. Scientists have generally thought that DLPs are related to the movement of magma within a volcano's complicated plumbing. Sometimes DLPs portend an eruption: There were hundreds of pulses of DLPs in the weeks preceding the devastating 1991 eruption of the Philippines' Mount Pinatubo.

But more often, DLPs don't appear to presage an eruption at all. In those cases, scientists have suggested, the quakes may be related to stress and strain caused by hot magma pushing its way into rock fractures and then cooling and contracting. If true, DLPs might be the groans of rocks cracking from the strain.

Wech and colleagues suggest something else is going on at Mauna Kea: The quakes may be related to gases emitted by a pool of cooling magma deep underground. As the gases leave in a process called "second boiling," they seep up into fractures in the surrounding rock, pressurizing it. As the gases accumulate, the pressure builds until the rock gives a grumbling heave and then is quiescent until the pressure builds again.

The discovery of Mauna Kea's DLPs was "an accident," Wech says. In 2013, he used an algorithm to pore through reams of seismic signals coming from beneath the most active volcano on Hawaii's Big Island, Kilauea, which has been erupting on and off since 1983.

From 1999 to 2018, over a million tiny earthquakes trembled beneath Hawaii's Mauna Kea volcano (shown).

"We decided to apply this technique across the whole island, because why not? And then we started seeing these [signals] beneath Mauna Kea, which in itself was odd," Wech says. Mauna Kea, one of the five volcanoes on the Big Island, hasn't erupted in about 4,500 years.

Wech initially thought those signals were short-term. But in 2016, he checked again, and the rumblings were still going on and were still periodic. His team traced the signals back to the earliest data available, from 1999, and identified more than a million DLPs from 1999 to 2018.

After pinpointing the origin of the signals to the spot deep beneath Mauna Kea, the team then examined seismic waves that had passed through the region. Those waves tended to slow down in the region, often a sign of fluids. That suggested that some process related to the pool of magma, not moving faults, was the origin of the quakes.

Because the signals have been so consistent for so long, Wech says, he and colleagues suspected that moving magma wasn't the trigger. An alternative is the exodus of gases from that pool of stalled, slowly cooling magma repeatedly pressurizing rock fractures — again and again, every seven to 12 minutes or so.

Vidale says he finds the results intriguing and plausible. "I don't think it's proof, but it's good evidence," he says. "They identify something that's clearly an ongoing process that's been happening for years at regular intervals." Other DLPs, he notes, tend to be irregular or come in clusters.

It's hard to say whether second boiling is at play at other volcanoes reverberating with DLPs. "There are probably several mechanisms involved," Vidale says.

Creating a one-size-fits-all assessment for volcanoes has proved tricky; each volcano has its own personality, its own inner workings. "There's a movement to quantify data from volcanoes around the world" to try to come up with overarching categories and classifications, the better to understand and anticipate eruptions, Vidale adds. "But it's still a bit of a black art." ■

JUSTINREZNICK/ISTOCK/GETTY IMAGES PLUS

ATOM & COSMOS

SpaceX launch marks a milestone for commercial spaceflight

For the first time, humans hurtled into orbit on a commercial rocket. SpaceX's Crew Dragon spacecraft launched from Cape Canaveral, Fla., on May 30, taking two U.S. astronauts to the International Space Station.

Called Demo-2, the flight was the ultimate test of the spacecraft's ability to ferry a crew into orbit. The Falcon 9 rocket that carried the Crew Dragon to space returned to Earth and landed safely on a floating platform.

Astronauts had not launched into orbit from the United States since 2011, when NASA's space shuttle program ended (*SN: 6/18/11, p. 20*). Since then, the Russian Soyuz spacecraft have been the only way for astronauts of any nationality to reach the space station.

The launch marked a transition in crewed space travel for NASA, shifting the agency from having complete control over U.S. launches to the space station to being a customer of a private spaceflight company. That shift should free NASA to focus on more complicated missions, such as sending humans to the moon and Mars.

After one to three months, the astronauts will return to Earth in the Crew Dragon capsule. — *Lisa Grossman*

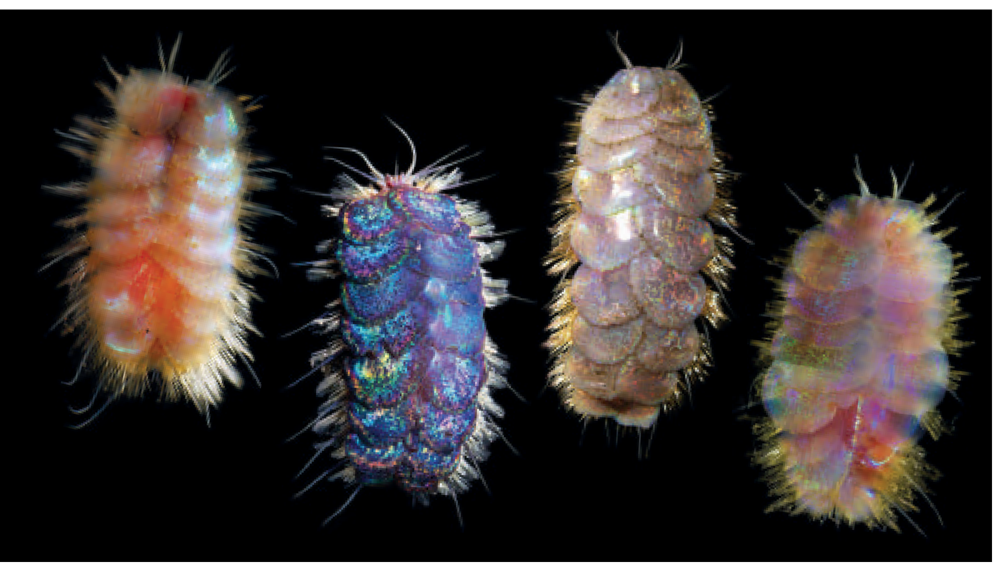
LIFE & EVOLUTION

Elvis worms come in four varieties

A new look at "Elvis worms" has the scale worm family all shook up. What was considered one type is actually four.

These deep-sea dwellers of the eastern Pacific Ocean flaunt iridescent scales reminiscent of the sequins on Elvis' iconic jumpsuits. Researchers compared the genetic material across different Elvis worms with DNA from other scale worm species. This analysis, reported May 12 in *ZooKeys*, splits Elvis worms into four species and puts them in the *Peinaleopolynoe* genus.

Scientists don't know why the worms have such eye-catching scales, given the animals live in the deep, dark sea. It could be a side effect of evolving thicker scales, which happen to refract more light, says Greg Rouse, a marine biologist at the Scripps Institution of Oceanography in La Jolla, Calif. Thicker scales could come in handy in a fight, since some Elvis worms are apparently biters, a behavior Rouse and colleagues discovered while watching a worm skirmish. — *Maria Temming*



The four species of Elvis worms, just millimeters to centimeters long, each have their unique showiness (from left: *Peinaleopolynoe mineoi*, *P. orphanae*, *P. goffrediae* and *P. elvisi*).

A.S. HATCH ET AL/*ZOOKEYS* 2020

MATH & TECHNOLOGY

Moisture threatens 'The Scream'

Insight into paint preservation could help "The Scream" show its face in public again.

Edvard Munch's 1910 version of this iconic artwork is almost always kept in storage under carefully controlled lighting and about 50 percent humidity to prevent decay of the painting's fragile cadmium sulfide pigments.

A new analysis, reported May 15 in *Science Advances*, shows that moisture is the main reason for deterioration.

Researchers analyzed microscopic flakes of paint from "The Scream" along with chemically similar paint that was artificially aged in the lab. X-ray probes of the samples revealed cadmium sulfate, a breakdown product of cadmium sulfide, in paint flecks from "The Scream." Cadmium sulfate also showed up in artificially aged paints exposed to at least 95 percent humidity in both light and darkness. Similar samples exposed to light in 45 percent humidity didn't show signs of decay.

The painting may be fine under normal lighting but should be kept at 45 percent humidity or below, the researchers suggest. — *Maria Temming*

GENES & CELLS

Why Peruvians are among the world's shortest people

Nearly 4,000 common variations in DNA are known to affect height, with each one nudging stature up or down a millimeter or so. But a gene variant found in almost 5 percent of Peruvians reduces height by 2.2 centimeters on average.

That's the biggest effect on stature recorded to date for a common version of a gene. People who carry two copies of the variant — one from each parent — are, on average, about 4.4 centimeters shorter than the average height of people who don't carry the variant, researchers report online May 13 in *Nature*.

The finding helps explain why the Peruvian people are among the shortest in the world. Men average about 5 feet, 5 inches tall and women are about 5 feet.

The affected gene is *fibrillin 1*, or *FBN1*, which produces a protein involved in forming bone, skin, connective and other tissues. The researchers found evidence that natural selection has favored the gene variant, though exactly what evolutionary advantage it gives is not clear. — *Tina Hesman Saey*

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Wind Speed
+ Current/Top Speed
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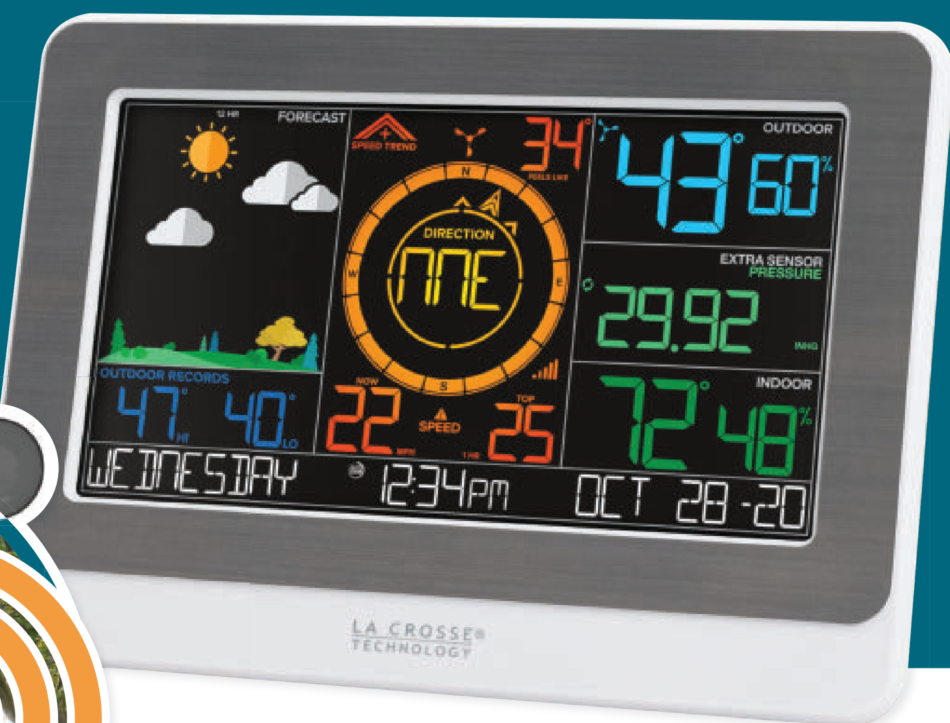

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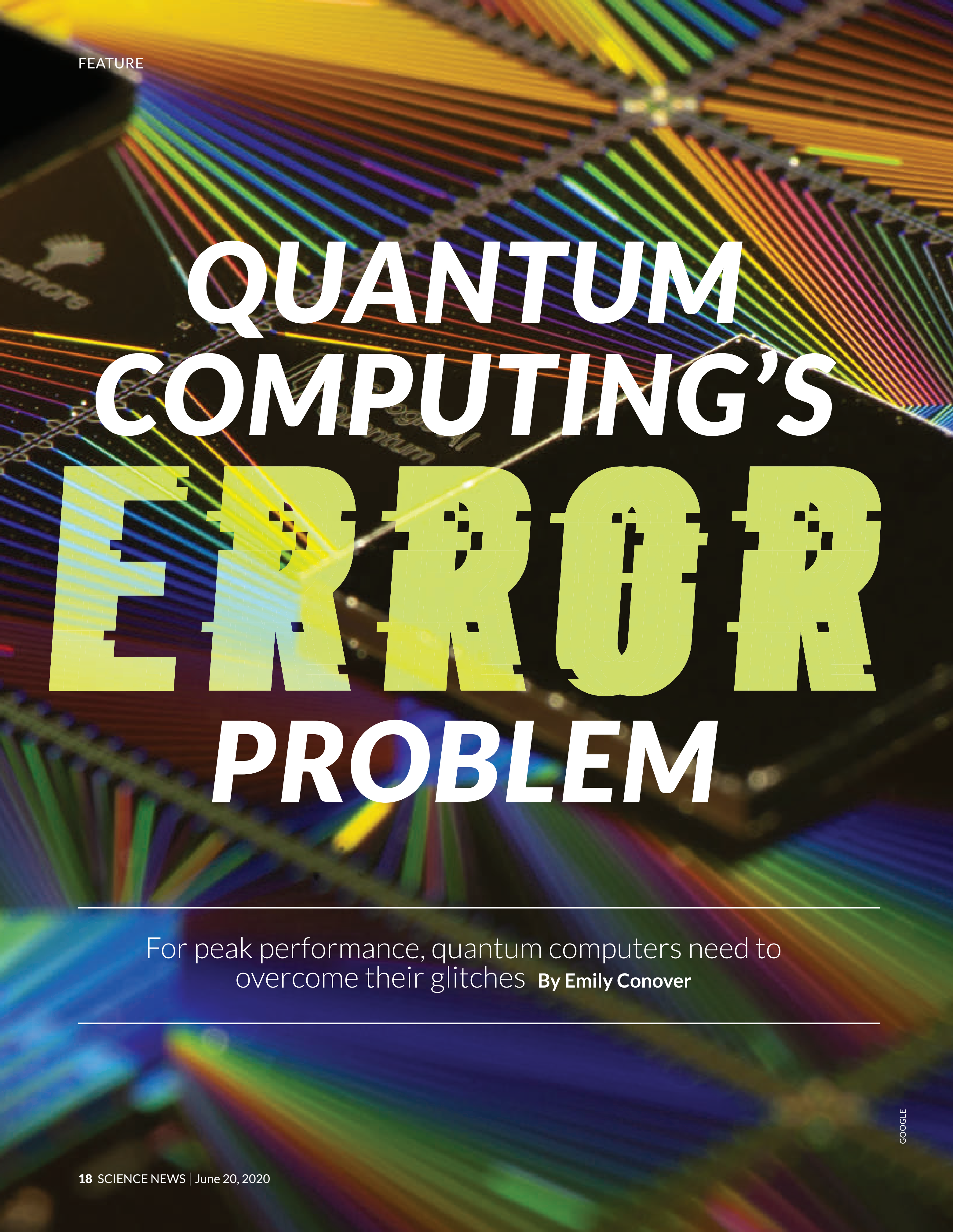


QUANTUM COMPUTING'S ERROR PROBLEM

For peak performance, quantum computers need to overcome their glitches **By Emily Conover**

GOOGLE

Astronaut John Glenn was wary about trusting a computer.

It was 1962, early in the computer age, and a room-sized machine had calculated the flight path for his upcoming orbit of Earth — the first for an American. But Glenn wasn't willing to entrust his life to a newfangled machine that might make a mistake.

The astronaut requested that mathematician Katherine Johnson double-check the computer's numbers, as recounted in the book *Hidden Figures*. "If she says they're good," Glenn reportedly said, "then I'm ready to go." Johnson determined that the computer, an IBM 7090, was correct, and Glenn's voyage became a celebrated milestone of spaceflight (*SN: 3/3/62, p. 131*).

A computer that is even slightly error-prone can doom a calculation. Imagine a computer with 99 percent accuracy. Most of the time the computer tells you 1+1=2. But once every 100 calculations, it flubs: 1+1=3. Now, multiply that error rate by the billions or trillions of calculations per second possible in a typical modern computer. For complex computations, a small probability for error can quickly generate a nonsense answer. If NASA had been relying on a computer that glitchy, Glenn would have been right to be anxious.

Luckily, modern computers are very reliable. But the era of a new breed of powerful calculator is dawning. Scientists expect quantum computers to one day solve problems vastly too complex for standard computers (*SN: 7/8/17, p. 28*).

Current versions are relatively wimpy, but with improvements, quantum computers have the potential to search enormous databases at lightning speed, or quickly factor huge numbers that would take a normal computer longer than the age of the universe. The machines could calculate the properties of intricate molecules or unlock the secrets of complicated chemical reactions. That kind of power could speed up the discovery of life-saving drugs or help slash energy requirements for intensive industrial processes such as fertilizer production.

But there's a catch: Unlike today's reliable conventional computers, quantum computers must grapple with major error woes. And the quantum calculations scientists envision are complex enough to be impossible to redo by hand, as Johnson did for Glenn's ambitious flight.

If errors aren't brought under control, scientists' high hopes for quantum computers could come crashing down to Earth.

IBM researchers Hanhee Paik (left) and Sarah Sheldon (right) work on a quantum computer that is cooled by a hanging dilution refrigerator. IBM has made 18 quantum computers available for use online, and all grapple with errors.

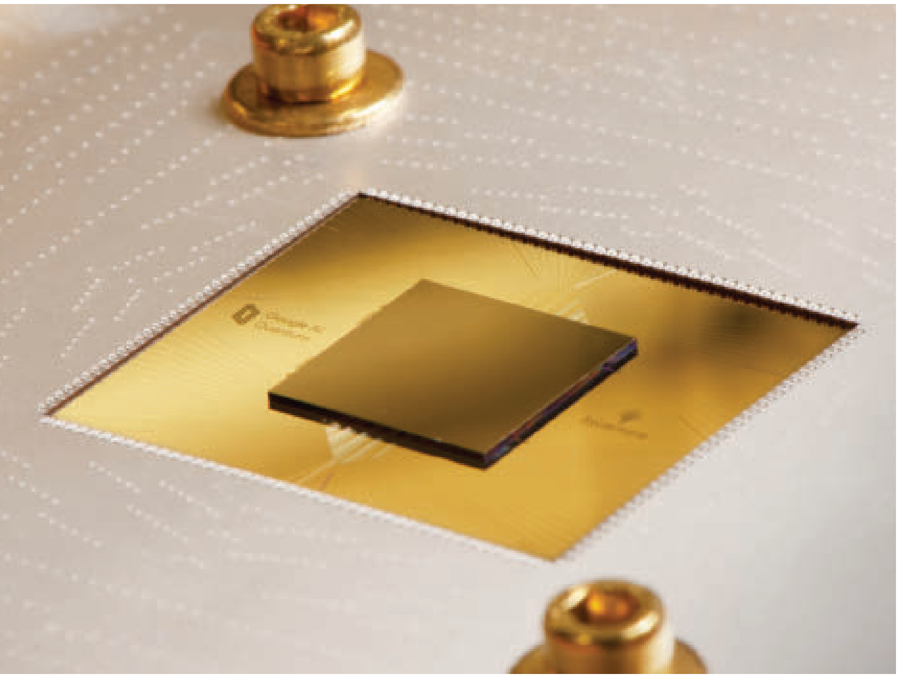
IBM RESEARCH

Fragile qubits

Conventional computers — which physicists call classical computers to distinguish them from the quantum variety — are resistant to errors. In a classical hard drive, for example, the data are stored in bits, 0s or 1s that are represented by magnetized regions consisting of many atoms. That large group of atoms offers a built-in redundancy that makes classical bits resilient. Jostling one of the bit's atoms won't change the overall magnetization of the bit and its corresponding value of 0 or 1.

But quantum bits — or qubits — are inherently fragile. They are made from sensitive substances such as individual atoms, electrons trapped within tiny chunks of silicon called quantum dots, or small bits of superconducting material, which conducts electricity without resistance. Errors can creep in as qubits interact with their environment, potentially including electromagnetic fields, heat or stray atoms or molecules. If a single atom that represents a qubit gets jostled, the information the qubit was storing is lost.

Additionally, each step of a calculation has a significant chance of introducing error. As a result, for complex calculations, "the output will be garbage,"



Google's 54-qubit chip, called Sycamore, was used to demonstrate quantum supremacy. Now researchers want to use upgraded versions of the chip to perform error correction.

says quantum physicist Barbara Terhal of the research center QuTech in Delft, Netherlands.

Before quantum computers can reach their much-hyped potential, scientists will need to master new tactics for fixing errors, an area of research called quantum error correction. The idea behind many of these schemes is to combine multiple error-prone qubits to form one more reliable qubit. The technique battles what seems to be a natural tendency of the universe — quantum things eventually lose their quantumness through interactions with their surroundings, a relentless process known as decoherence.

"It's like fighting erosion," says Ken Brown, a quantum engineer at Duke University. But quantum error correction provides a way to control the seemingly uncontrollable.

Make no mistake

Quantum computers gain their power from the special rules that govern qubits. Unlike classical bits, which have a value of either 0 or 1, qubits can take on an intermediate state called a superposition, meaning they hold a value of 0 and 1 at the same time. Additionally, two qubits can be entangled, with their values linked as if they are one entity, despite sitting on opposite ends of a computer chip.

These unusual properties give quantum computers their game-changing method of calculation. Different possible solutions to a problem can be considered simultaneously, with the wrong answers canceling one another out and the right one being amplified. That allows the computer to quickly converge on the correct solution without needing to check each possibility individually.

The concept of quantum computers began gaining steam in the 1990s, when MIT mathematician Peter Shor, then at AT&T Bell Laboratories in Murray Hill, N.J., discovered that quantum computers could quickly factor large numbers (*SN Online: 4/10/14*). That was a scary prospect for computer security experts, because the fact that such a task is difficult is essential to the way computers encrypt sensitive information. Suddenly, scientists urgently needed to know if quantum computers could become reality.

Shor's idea was theoretical; no one had demonstrated that it could be done in practice. Qubits might be too temperamental for quantum computers to ever gain the upper hand. "It may be that the whole difference in the computational power depends on this extreme accuracy, and if you don't have this extreme accuracy, then this computational power disappears," says theoretical computer scientist Dorit Aharonov of Hebrew University of Jerusalem.

But soon, scientists began coming up with error-correction schemes that theoretically could fix the mistakes that slip into quantum calculations and put quantum computers on more solid footing.

For classical computers, correcting errors, if they do occur, is straightforward. One simple scheme goes like this: If your bit is a 1, just copy that three times for 111. Likewise, 0 becomes 000. If one of those bits is accidentally flipped — say, 111 turns into 110, the three bits will no longer match, indicating an error. By taking the majority, you can determine which bit is wrong and fix it.

But for quantum computers, the picture is more complex, for several reasons. First, a principle of quantum mechanics called the no-cloning theorem says that it's impossible to copy an arbitrary quantum state, so qubits can't be duplicated.

Secondly, making measurements to check the values of qubits wipes their quantum properties. If a qubit is in a superposition of 0 and 1, measuring its value will destroy that superposition. It's like opening the box that contains Schrödinger's cat. This imaginary feline of quantum physics is famously both dead and alive when the box is closed, but opening it results in a cat that's entirely dead or entirely alive, no longer in both states at once (*SN: 6/25/16, p. 9*).

GOOGLE

So schemes for quantum error correction apply some work-arounds. Rather than making outright measurements of qubits to check for errors — opening the box on Schrödinger's cat — scientists perform indirect measurements, which "measure what error occurred, but leave the actual information [that] you want to maintain untouched and unmeasured," Aharonov says. For example, scientists can check if the values of two qubits agree with one another without measuring their values. It's like checking whether two cats in boxes are in the same state of existence without determining whether they're both alive or both dead.

And rather than directly copying qubits, error-correction schemes store data in a redundant way, with information spread over multiple entangled qubits, collectively known as a logical qubit. When individual qubits are combined in this way, the collective becomes more powerful than the sum of its parts. It's a bit like a colony of ants. Each individual ant is relatively weak, but together, they create a vibrant superorganism.

Those logical qubits become the error-resistant qubits of the final computer. If your program requires 10 qubits to run, that means it needs 10 logical qubits — which could require a quantum computer with hundreds or even hundreds of thousands of the original, error-prone physical qubits. To run a really complex quantum computation, millions of physical qubits may be necessary — more plentiful than the ants that discovered a slice of last night's pizza on the kitchen counter.

Creating that more powerful, superorganism-like qubit is the next big step in quantum error correction. Physicists have begun putting together some of the pieces needed, and hope for success in the next few years.

Scratching the surface

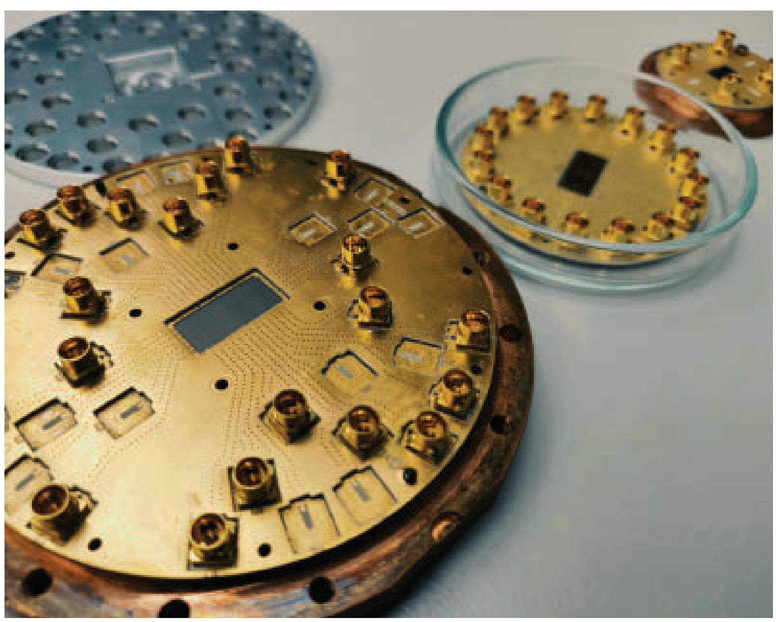
Massive excitement accompanied last year's biggest quantum computing milestone: quantum supremacy. Achieved by Google researchers in October 2019, it marked the first time a quantum computer was able to solve a problem that is impossible for any classical computer (*SN Online: 10/23/19*). But the need for error correction means there's still a long way to go before quantum computers hit their stride.

Sure, Google's computer was able to solve a problem in 200 seconds that the company claimed would have taken the best classical computer 10,000 years. But the task, related to the generation of random numbers, wasn't useful enough to revolutionize computing. And it was still based on relatively imprecise qubits. That won't cut it for the most tantalizing and complex tasks, like faster database searches. "We need a very small error rate ... to run these long algorithms, and you only get those with error correction in place," says physicist and computer scientist Hartmut Neven, leader of Google's quantum efforts.

So Neven and colleagues have set their sights on an error-correction technique called the surface code. The most buzzed-about scheme for error correction, the surface code is ideal for superconducting quantum computers, like the ones being built by companies including Google and IBM (the same company whose pioneering classical computer helped put John Glenn into space). The code is designed for qubits that are arranged in a 2-D grid in which each qubit is directly connected to neighboring qubits. That, conveniently, is the way superconducting quantum computers are typically laid out.

As in an ant colony with workers and soldiers, the surface code requires that different qubits have different jobs. Some are data qubits, which store information, and others are helper qubits, called ancillas. Measurements of the ancillas allow for checking and correcting of errors without destroying the information stored in the data qubits. The data and ancilla qubits together make up one logical qubit with, hopefully, a lower error rate. The more data and ancilla qubits that make up each logical qubit, the more errors that can be detected and corrected.

Researchers from ETH Zurich recently used a seven-qubit chip (like the one in the foreground below) to demonstrate a simple error-detection scheme.



QUANTUM DEVICE LAB/ETH ZURICH

In 2015, Google researchers and colleagues performed a simplified version of the surface code, using nine qubits arranged in a line. That setup, reported in *Nature*, could correct a type of error called a bit-flip error, akin to a 0 going to a 1. A second type of error, a phase flip, is unique to quantum computers, and effectively inserts a negative sign into the mathematical expression describing the qubit's state.

Now, researchers are tackling both types of errors simultaneously. Andreas Wallraff, a physicist at ETH Zurich, and colleagues showed that they could detect bit- and phase-flip errors using a seven-qubit computer. They could not yet correct those errors, but they could pinpoint cases where errors occurred and would have ruined a calculation, the team reported in a paper published June 8 in *Nature Physics*. That's an intermediate step toward fixing such errors.

But to move forward, researchers need to scale up. The minimum number of qubits needed to do the real-deal surface code is 17. With that, a small improvement in the error rate could be achieved, theoretically. But in practice, it will probably require 49 qubits before there's any clear boost to the logical qubit's performance. That level of error correction should noticeably extend the time before errors overtake the qubit. With the largest quantum computers now reaching 50 or more physical qubits, quantum error correction is almost within reach.

IBM is also working to build a better qubit. In addition to the errors that accrue while calculating, mistakes can occur when preparing the qubits, or reading out the results, says physicist Antonio Córcoles of IBM's Thomas J. Watson Research Center in Yorktown Heights, N.Y. He and colleagues demonstrated that they could detect errors made when preparing the qubits, the process of setting their initial values, the team reported in 2017 in *Physical Review Letters*. Córcoles looks forward to a qubit that can recover from all these sorts of errors. "Even if it's only a single logical qubit — that will be a major breakthrough," Córcoles says.

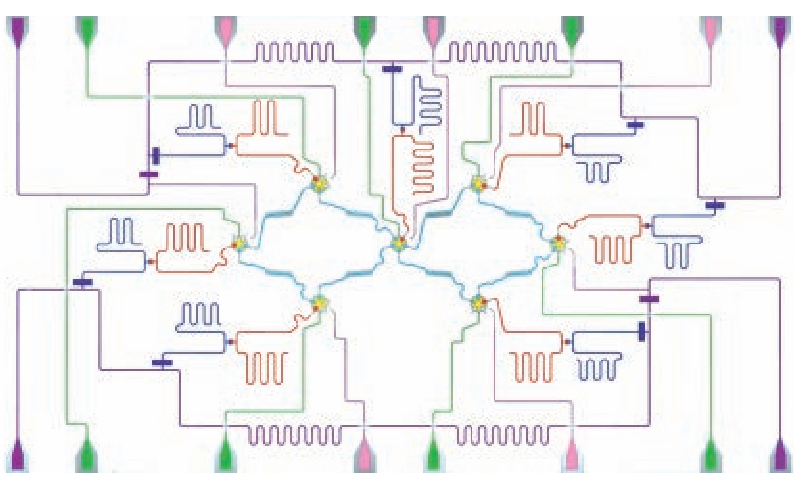
In the meantime, IBM, Google and other companies still aim to make their computers useful for specific applications where errors aren't deal breakers: simulating certain chemical reactions, for example, or enhancing artificial intelligence. But the teams continue to chase the error-corrected future of quantum computing.

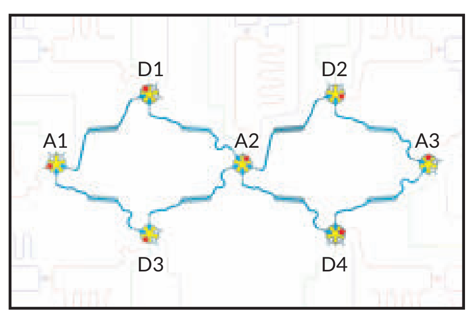
It's been a long slog to get to the point where doing error correction is even conceivable. Scientists have been slowly building up the computers, qubit by qubit, since the 1990s. One thing is for sure: "Error correction seems to be really hard for anybody who gives it a serious try," Wallraff says. "Lots of work is being put into it and creating the right amount of progress seems to take some time."

On the threshold

For error correction to work, the original, physical qubits must stay below a certain level of flakiness, called a threshold. Above this critical number, "error correction is just going to make life worse," Terhal says. Different error-correction schemes have different thresholds. One reason the surface code is so popular is that it has a high threshold for error. It can tolerate relatively fallible qubits.

Imagine you're really bad at arithmetic. To sum up a sequence of numbers, you might try adding them up several times, and picking the result that came up most often.





Fixer upper A logical qubit made up of seven physical qubits (yellow in both false-colored microscope images of a quantum chip) can detect errors. Four data qubits (D1–D4, above) store information, and three ancilla qubits (A1–A3) check for two different types of errors.

BOTH: QUANTUM DEVICE LAB/ETH ZURICH

Let's say you do the calculation three times, and two out of three of your calculations agree. You'd assume the correct solution was the one that came up twice. But what if you were so error-prone that you accidentally picked the one that didn't agree? Trying to correct your errors could then do more harm than good, Terhal says.

The error-correction method scientists choose must not introduce more errors than it corrects, and it must correct errors faster than they pop up. But according to a concept known as the threshold theorem, discovered in the 1990s, below a certain error rate, error correction can be helpful. It won't introduce more errors than it corrects. That discovery bolstered the prospects for quantum computers.

"The fact that one can actually hope to get below this threshold is one of the main reasons why people started to think that these computers could be realistic," says Aharonov, one of several researchers who developed the threshold theorem.

The surface code's threshold demands qubits that err a bit less than 1 percent of the time. Scientists recently reached that milestone with some types of qubits, raising hopes that the surface code can be made to work in real computers.

Getting clever

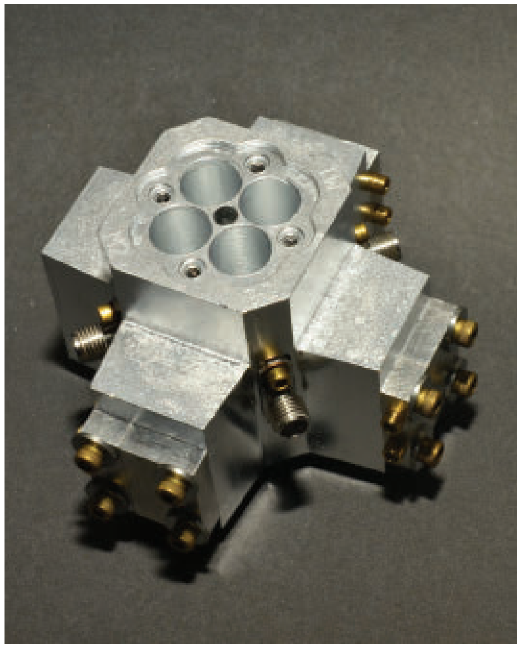
But the surface code has a problem: To improve the ability to correct errors, each logical qubit needs to be made of many individual physical qubits, like a populous ant colony. And scientists will need many of these superorganism-style logical qubits, meaning millions of physical qubits, to do many interesting computations.

Since quantum computers currently top out at fewer than 100 qubits (*SN: 3/31/18, p. 13*), the days of million-qubit computers are far in the future. So some researchers are looking at a method of error correction that wouldn't require oodles of qubits.

"Everybody's very excited, but there's these questions about, 'How long is it going to take to scale up to the stage where we'll have really robust computations?' " says physicist Robert Schoelkopf of Yale University. "Our point of view is that actually you can make this task much easier, but you have to be a little bit more clever and a little bit more flexible about the way you're building these systems."

Schoelkopf and colleagues use small, superconducting microwave cavities that allow particles of light, or photons, to bounce back and forth within. The numbers of photons within the cavities serve as qubits that encode the data. For example, two photons bouncing around in the

KEVIN CHOU



A block of aluminum with four cylindrical cavities has four qubits. A qubit's value is encoded in the number of photons bouncing back and forth within a cavity. The device, built by researchers at Yale University, allows for error correction without the huge numbers of qubits other schemes require.

cavity might represent a qubit with a value of 0, and four qubits might indicate a value of 1. In these systems, the main type of error that can occur is the loss of a photon. Superconducting chips interface with those cavities and are used to perform operations on the qubits and scout for errors. Checking whether the number of photons is even or odd can detect that type of error without destroying the data.

Using this method, Schoelkopf and colleagues reported in 2016 in *Nature* that they can perform error correction that reaches the break-even point. The qubit is just beginning to show signs that it performs better with error correction.

"To me," Aharonov says, "whether you actually can correct errors is part of a bigger issue." The physics that occurs on small scales is vastly different from what we experience in our daily lives. Quantum mechanics seems to allow for a totally new kind of computation. Error correction is key to understanding whether that dramatically more powerful type of calculation is truly possible.

Scientists believe that quantum computers will prove themselves to be fundamentally different than the computer that helped Glenn make it into orbit during the space race. This time, the moon shot is to show that hunch is right. ■

Explore more

- Julian Kelly, Rami Barends and Austin Fowler. "A step closer to quantum computation with quantum error correction." Google AI Blog. March 4, 2015. bit.ly/Google-quantum-error

Past plagues offer lessons for society

Starting with the Roman Empire, societies have often been resilient through deadly outbreaks **By Bruce Bower**

Inspired by plagues and religious wars in Europe, Pieter Bruegel the Elder's circa 1562 painting "The Triumph of Death" depicts a terrifying scene of destruction in which an army of skeletons attacks the living.

INCAMERASTOCK/ALAMY STOCK PHOTO

It was an optimistic time. A healthy economy showered wealth on elites and allowed many ordinary citizens to live comfortably. Local goods and exotic imports filled shops and markets. Political leaders ruled a vast network of cities and trade routes.

Then the enemy attacked. An infectious disease leapfrogged from one population center to another. People died in droves. Political leaders scrambled to recover from a dizzying sucker punch to public and economic health.

This is not a tale about the United States or any other nation besieged by the new coronavirus. It's a story about the ancient Roman Empire, where a contagion known as the Antonine Plague felled victims throughout the realm, from Egypt to continental Europe and the British Isles, in the late 160s.

Accurate mortality data for the Antonine Plague don't exist. But written accounts from that time point to mass deaths. Physician and philosopher Galen described victims suffering from open sores in the windpipe, rashes of dark blisters, vomiting, diarrhea, fever and other symptoms of what may have been smallpox. Perhaps 7 million to 8 million people perished in what some consider to be history's first pandemic, says Kyle Harper of the University of Oklahoma in Norman. Harper is a historian of the Roman Empire and ancient epidemics.

The Antonine Plague and other epidemics and pandemics that struck before 20th century vaccines and medical knowledge hold lessons, but no easy answers, for governments and people today grappling with COVID-19.

One lesson looms large: Societies can't indefinitely avoid outbreaks, but they can withstand even severe pandemics. Past political systems have found ways to bounce back from mass illness and unthinkable numbers of deaths.

The extent to which deadly outbreaks have altered the course of civilizations is controversial, though. Some scholars, such as Harper, contend that pandemics often changed political systems in big ways. Others argue that pandemics, though deadly, caused relatively little political and economic havoc.

Whatever the political and economic fallout, pandemics and epidemics have typically had social consequences, for better or worse. For instance, devastating yellow fever outbreaks in the 19th century bolstered the institution of slavery in New Orleans. Yet in Haiti, the disease actually helped enslaved people seeking freedom from French colonists.

"Sometimes [infectious diseases] accelerate history or reveal where a society was already going, while sometimes they fundamentally change the trajectory of societies," Harper says.

Possible first pandemic This map shows the extent of the Roman Empire (dark gray) at the time of Marcus Aurelius' reign. Red dots mark sites where written sources possibly refer to the Antonine Plague, which began in 165 and may have been the first pandemic. SOURCE: K. HARPER/*THE FATE OF ROME* 2017

Diseased empire

Sometimes pandemics do both within the same society. Widespread infectious disease influenced both the expansion and decline of the Roman Empire, Harper argues. In his 2017 book *The Fate of Rome: Climate, Disease and the End of an Empire*, he writes that pandemics interacted with climate fluctuations to induce resilience at first, and then later cause irreversible weaknesses in the Roman Empire.

Pandemics and epidemics have typically had social consequences, for better or worse.

Humans, though, suffered from infectious diseases well before Roman times. In particular, the origin of cities, starting about 6,000 years ago, brought people into closer quarters, where bacteria and viruses could more easily spread, especially through contaminated food and water supplies in a time before proper sanitation (*SN: 2/29/20, p. 10*).

But it wasn't until the rise of Rome that the elements needed to bring about pandemics appear to have come together for the first time. Population growth and long-distance trade in the Roman Empire proved a boon to diseases that jumped from animals to people, such as smallpox and measles.

The Antonine Plague struck during the reign of Marcus Aurelius in the late 160s. Though millions died, the empire was big enough to absorb those losses; roughly 90 percent of the empire's population remained intact, Harper says. Political reorganization and power sharing were required to counteract food shortages and an economic decline in the wake of the pandemic. Marcus Aurelius invited civic leaders from throughout the empire to join his imperial government. Their wealth and knowledge helped Roman elites improve conditions in the empire's provinces, and provincial governments were given greater power to resolve local issues.

Roman society rebounded, at least for a while.

Then, in the mid-200s, a poorly understood pestilence known as the Plague of Cyprian swept through the Roman Empire. Eyewitness accounts, including that of Cyprian the Bishop of Carthage, whom the disease was named after, described painful deaths preceded by days of fatigue, bloody stool, fever, bleeding from the eyes, blindness and hearing loss. An influenza virus or a viral hemorrhagic fever similar to yellow fever or Ebola may have caused this deadly outbreak, Harper suspects.

Combined with drought, foreign invasions, infighting among generals and a rapid loss of coin values, the Plague of Cyprian brought the Roman Empire to its knees. For over a decade, the disease spread and probably killed a larger percentage of the population than the Antonine Plague had, Harper says, though precise numbers are hard to establish. As the central government reeled, a series of emperors were chosen — and sometimes quickly deposed — by the military based on an aspiring ruler's popularity with generals. But the empire never regained its former prominence.

By the early 400s, the western half of the Roman Empire gave way to invading armies. In the east, the empire held on for a bit. But in the mid-500s, an outbreak of bubonic plague known as the Justinianic Plague, caused by the bacterium *Yersinia pestis* (*SN: 1/19/19, p. 12*), spread through Roman territory just as volcanic eruptions caused substantial global cooling, likely leading to lower Mediterranean crop yields, Harper contends. He suspects death rates reached 50 percent

C. CHANG

or more of the population. Soon after, the Roman Empire suffered military losses to Islamic armies and was reduced to a minor state. Rather than swiftly destroying the Roman realm, plague and climate change "sapped the vitality of the empire," Harper says.

Political resilience

Harper's reconstruction of Roman history rings hollow to environmental historian Merle Eisenberg. Even given large mortality rates, the plagues that hit the Roman Empire had limited social and political fallout, contends Eisenberg, of the University of Maryland's National Socio-Environmental Synthesis Center in Annapolis.

Written accounts and archaeological data recently analyzed by Eisenberg and colleagues (*SN: 1/18/20, p. 15*) indicate that life during the Justinianic Plague, for instance, proceeded much as it had before the outbreak in some places. Roman legislation continued to be issued, the monetary system remained stable and farmland continued to be cultivated, as indicated by ancient pollen collected from lake beds. "Plague certainly struck the Mediterranean, but it did not seem to impact the lives of most people," Eisenberg says.

Mass deaths should have made it difficult for survivors to bury plague victims with inscribed tombstones and to erect new buildings with inscriptions detailing who built them and why. But the number of such inscriptions in Syria, a region hit hard by the plague, stayed stable during the pandemic, Eisenberg's group reported in December in the *Proceedings of the National Academy of Sciences*. Eisenberg concludes that substantially less than half of the Roman Empire's population succumbed to the Justinianic Plague.

That estimate is based on limited evidence that doesn't tap into that plague's broad political and social effects across the Roman Empire, Harper argues. But given considerable gaps in what's known about how the outbreak played out from one region to another, this debate will be difficult to resolve.

For his part, Eisenberg says true devastation from a pandemic didn't arrive until the medieval Black Death, which killed perhaps 75 million to 200 million people — half of Europe's population — from 1346 to 1351. Recurrences of the Black Death, caused by the same bacterium as the Justinianic Plague, lasted until the 18th century in Europe and the 19th century in the Middle East. But even the Black Death fell far short of causing civilization to collapse, Eisenberg says.

Harper and other historians have suggested that the Black Death spared so few farmers and other laborers that survivors successfully demanded better working conditions from the ruling class. John Haldon, a Princeton University historian of ancient Europe and the Mediterranean, agrees that mass deaths spurred economic shifts, such as a gradual loosening of the feudal system in which peasants received parcels of land in return for serving a lord or king. "Yet there were no political collapses at all," says Haldon, who supervised Eisenberg's graduate research but did not participate in his Justinianic Plague study. Western European states and kingdoms stayed largely intact during medieval times.

In modern times, better medical care and vaccines have generally kept pandemic mortality rates below those suffered centuries ago. But a modern, globalized world in which many nations are economically intertwined and communications flash instantly across continents is especially vulnerable to financial disruptions when pandemics hit, Eisenberg suspects.

"Premodern plagues generally caused more deaths than infectious diseases today do," he says. "But pandemics today, such as COVID-19, have larger political and economic impacts than those in the past."

From his perspective, history's lesson for people now is to stay vigilant: Once the coronavirus has been medically contained, the hard work of dealing with the pandemic's shocks to our way of life must accelerate.

Certifiably immune

Shocks from some past outbreaks have run deep. Unrelenting outbreaks of infectious disease can modify an existing social order or even help to bring it down, historians have found.

Consider yellow fever. The mosquito-borne viral disease aided a successful rebellion of black enslaved people in Haiti against French colonial rule. Yale University historian of science and medicine Frank Snowden describes that event in his 2019 book *Epidemics and Society: From the Black Death to the Present*.

Haiti's uprising of enslaved people lasted from 1791 to 1804. When Napoleon Bonaparte sent more than 60,000 soldiers to put down the rebellion, many of the European newcomers quickly succumbed to yellow fever because they lacked immunity that black Haitians had already acquired. Yellow fever

Previous exposure to yellow fever helped enslaved Haitians launch a successful rebellion against French soldiers who lacked immunity to the infection. An 1802 battle in that struggle is illustrated here.

AUGUSTE RAFFET/WIKIMEDIA COMMONS

ended up helping the enslaved Haitians defeat French forces in battle and win their freedom.

The disease also thwarted Napoleon's ambitions to expand his empire into the Americas, Snowden says. In 1803, as a humiliating military defeat fast approached in Haiti and plans of using the island as a launching pad for North American conquests faded, the cash-strapped French ruler sold the territory of Louisiana to the United States. That transaction set the stage for yellow fever to instigate entirely different social changes related to slavery in 19th century New Orleans.

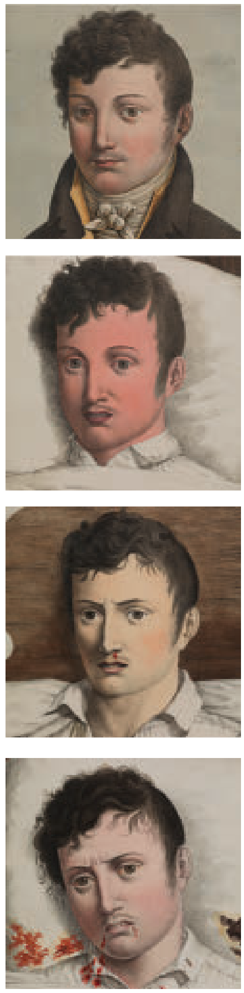
Yellow fever killed more than 150,000 people there between 1803 and 1860, just before the Civil War. No cure or vaccination existed for a disease that killed about half of those it infected. Yellow fever deaths were painful and horrifying. Many victims vomited thick, black blood before succumbing after several days. Those who survived the infection became immune, or what people at the time called "acclimated."

In a city with stark divisions between rich and poor, between men and women and within racial groups — whites, "free people of color" and enslaved people — acclimated citizens held special status, says historian Kathryn Olivarius of Stanford University. White people who survived yellow fever often sought a medical certificate of acclimation, ensuring them access to good jobs, bank loans and houses in the best neighborhoods. Many immigrants arriving in New Orleans in the 1840s, especially Irish and Germans, saw infection as a path to success and were willing to risk death to become acclimated.

That immunity-based social system produced New Orleans' most powerful and wealthy families, many of which are still prominent, Olivarius concluded in the April 2019 *American Historical Review*. Her analysis included written accounts, official documents and medical articles from the pre–Civil War era.

Black people received no such benefits. Not only did the slave economy withstand repeated epidemics, but immunity to yellow fever boosted the likelihood of a long working life and increased an enslaved person's monetary value to an owner by 25 to 50 percent, Olivarius estimates.

For COVID-19, though, it's not yet clear if someone who recovers gains immunity (*SN: 6/6/20, p. 22*). Even so, the prospect of immunity as a social and economic benefit is real. Countries such as Chile, Germany and the United Kingdom are considering issuing "immunity passports." The documents would certify that a person has recovered from COVID-19, which would let these individuals move about more freely and go back to work early. Immunity passports might become an increasingly attractive strategy if it takes a year or more to develop a coronavirus vaccine, as expected. "If so, we should heed lessons from the past and beware of potential social perils," Olivarius says.



Getting yellow fever, as depicted as a progression of symptoms in these 1819 paintings, could result in bleeding and vomiting of blood. Because yellow fever was often fatal, some people who survived the disease achieved special status in New Orleans during the 19th century.

Forgetting pandemics

A final lesson to glean from the past is perhaps the hardest to follow: Don't forget what happened. Don't let the next generation forget, either, because another outbreak could surely arrive when it is least expected.

The influenza pandemic of 1918 and 1919, which killed an estimated 50 million people or more worldwide, was forgotten by many people soon after it burned out.

"It's curious how such a major event could be so quickly forgotten," Snowden said on April 2 during an online interview hosted by *JAMA*. A book by historian Alfred Crosby, *America's Forgotten Pandemic,* highlighted how that major event was put out of mind by many who survived, Snowden added.

Scientists have warned for the last 20 years — as a series of infectious diseases including SARS and MERS emerged — that new pandemics are on the horizon, Snowden said in the *JAMA* interview. Yet the world was woefully unprepared for COVID-19.

Perhaps pandemic forgetfulness is itself contagious. In his 1722 book *A Journal of the Plague Year*, Daniel Defoe, also the author of *Robinson Crusoe,* used historical accounts to construct a fictional man's experiences during an actual 1665 bubonic plague outbreak in London.

Defoe presents harrowing accounts of plague deaths and forced isolation of the infected in their homes. Yet as infections waned, people flocked into the streets and "cast off all apprehensions" when encountering individuals limping from plague-caused groin sores and exhibiting other symptoms that "were frightful to the last degree, but the week before."

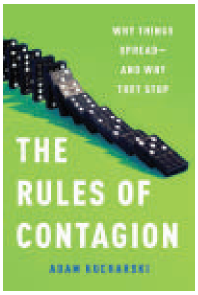
In any age, a return to the soothing certainty of daily routines can help erase memories of an epidemic's hideous toll. Time will tell if this viral amnesia repeats itself when COVID-19 finally retreats. ■

Explore more

- Frank Snowden. *Epidemics and Society: From the Black Death to the Present.* Yale University Press, 2019.
- Kathryn Olivarius. "Immunity, capital and power in antebellum New Orleans." *American Historical Review.* April 2019.

INTERVIEW

From COVID-19 to violence, outbreaks share the same principles



The Rules of Contagion
Adam Kucharski
BASIC BOOKS, $30

Epidemiologists like to say, "If you've seen one pandemic, you've seen ... one pandemic." But behind each outbreak lie core principles that help explain why the outbreak began, why it grew, why it peaked when it did and why it ended. In *The Rules of Contagion*, mathematician and epidemiologist Adam Kucharski of the London School of Hygiene & Tropical Medicine outlines those principles and shows how they apply beyond infectious disease, to the spread of ideas, financial crises, violence and more.

Kucharski hardly mentions the novel coronavirus sweeping the globe. He was just wrapping up final edits when the first cases of COVID-19 appeared in Wuhan, China. But the book still feels extraordinarily prescient. Kucharski provides context for readers to understand the current pandemic, as well as a framework for thinking about other types of contagious spread. *Science News* spoke with Kucharski about the principles of contagion, disease modeling and misinformation. The following conversation has been edited for length and clarity. — *Cassandra Willyard*

Your book looks at the principles of contagion and how they apply beyond infectious diseases. Why is it useful to transport those ideas to other fields?

I've noticed that the same mistakes get made repeatedly across fields. For example, after the 2008 financial crisis, a lot of people realized that the network structure between banks and loans and exposure to risk was very similar to a lot of the network features that caused problems with sexually transmitted infections in the 1970s and '80s. If there are a lot of "loops" in the network, with people connected to each other in multiple ways, it makes it harder to stop the spread. If the network is structured so that highly connected individuals are disproportionately linked to less-connected individuals, it can result in an outbreak that spreads slower at first, but eventually reaches more of the network. Pre-2008, the financial network had both of these features.

It's also important to understand the underlying network. When looking at violence, it might be tempting to think the events are random, but there is often a series of connections that link them, and targeting these links with interventions can help prevent future incidents.

You write that we need to separate the features that are specific to a particular outbreak from the underlying principles that drive contagion. What are those principles?

There are four factors that are worth bearing in mind. The first one is duration — how long people are infectious for. The second is what people do while they're infectious: the opportunities for contagion. Another feature is what I call the transmission probability — the chance something actually gets across during an interaction. Then the final important one is susceptibility. If you have the virus or if you try to spread an idea, what is the chance that someone is susceptible?


The basic rules of a disease outbreak can help explain how other things spread among people, including ideas and violence.

ORBON ALIJA/E+/GETTY IMAGES

Modeling, which is the focus of your book, has played an important role in the coronavirus response. But models aren't perfect. How do we prevent inaccurate predictions from eroding people's confidence in modeling?

It helps to get away from the idea that all models are trying to make an exact forecast of what will happen in a month's time or two months' time. I see models as a way of clarifying our thinking about how the process works. Every time you see someone in the media claiming they have a solution to COVID, they are implicitly relying on a model. They might not outline what that model is, but they are making assumptions about how transmission functions, and they're making assumptions about how their proposed measure will influence transmission. The advantage of a model is it lays out those steps very clearly, and it means that people can criticize them.

After the 2016 U.S. presidential election, the spread of misinformation gained a lot of attention. How have social media platforms tried to combat this in response to COVID-19?

We've seen some quite dramatic changes in terms of what's being limited. A few years ago, the focus was on attempting to remove all the harmful content. The problem with trying to reactively remove all harmful content is that online outbreaks spread so quickly — it's difficult to keep up with transmission. A more effective approach may be to reduce susceptibility. We're seeing a lot more focus on preemptive messaging. If you type COVID into a search bar on most tech platforms, you will have a huge amount of credible information before you find anything that might lead you down some sort of rabbit warren into unreliable information. This is one of the first times that we've really seen that level of blanket preempting across multiple platforms — Google, Instagram, Twitter, Facebook. ■

Science News for Students

Science News for Students is an award-winning, free online magazine that reports daily on research and new developments across scientific disciplines for inquiring minds of every age — from middle school on up.

How to find the next pandemic virus before it finds us

When viruses pass from wildlife to people, it's called a spillover. Few spillovers affect more than a handful of people. But as COVID-19 shows, spillovers can sometimes trigger global pandemics. To head off a big new outbreak, researchers around the world are scouting viruses in wild animals, such as bats, that could trigger new human diseases. One group isolated some 400 new coronaviruses from Chinese bats and found signs that some of these have spilled over into local villagers. But spillovers also can go in the other direction, as when human measles moved to wild gorillas. — *Lindsey Konkel*

Read more: www.sciencenewsforstudents.org/finding-next-pandemic

Sleep helps teens cope with discrimination

Sleep aids learning and moods. It also can help teens cope with discrimination, a study now shows. Each day for two weeks, black, Asian and Latinx ninth-graders from five high schools in New York City answered questions about their moods and any discrimination they had experienced. Each night, a watchlike device recorded their sleep. When teens slept better, they were less likely to fixate on negative events the next day, this study found. The teens also had less trouble addressing difficult issues. How much extra sleep, on average, made a difference? Just six minutes a night. — *Alison Pearce Stevens*

Read more: www.sciencenewsforstudents.org/sleep-helps-copes-with-discrimination

Here's one way to harvest water right out of the air

Researchers have developed new materials to help slake the thirst of people living in remote or dry areas. These metal-organic frameworks, or MOFs, have an open, honeycomb-like structure. Water molecules are the right size and shape to soak into the MOFs' pores. A bonus: The internal arrangement of electrical charges in the new MOFs also attracts water. In tests at the Mojave Desert in California, one high-performing MOF worked well. A kilogram of it would have collected 0.7 liters (3 cups) of water from the very dry air. To release that water, just heat the MOF. — *Sid Perkins*

Read more: www.sciencenewsforstudents.org/water-from-air

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APRIL 25, 2020

Milky Way matters

Computer simulations and observations of nearby galaxies helped astrophysicists determine that the Milky Way stretches nearly 2 million light-years across, ***Ken Croswell*** *reported in "Astronomers find Milky Way's edge"* (SN: 4/25/20, p. 8).

Reader **John Montany** thought that the Milky Way must be more massive than previously thought. "I have read other articles that have reported discoveries of previously unknown mass in the universe," **Montany** wrote. "Taken collectively, are these discoveries changing theories of dark matter as an explanation for gravitational observations?"

No, **Croswell** says, the new work does not suggest the Milky Way has more mass and doesn't change estimates for how much dark matter the universe has. "Most astronomers believe that dark matter explains such observations as the high velocities of stars in dwarf galaxies and the high velocities of galaxies in galaxy clusters," he says. "Without the gravitational force exerted by this dark matter, stars in typical dwarf galaxies would escape their galactic homes, and galaxies in galaxy clusters would escape their abodes as well."

Rainforest reservations

A sediment core analysis revealed that a rainforest flourished near the South Pole around 92 million years ago, ***Carolyn Gramling*** *reported in "A rainforest once grew in Antarctica"* (SN: 4/25/20, p. 14).

Reader **Dennis McHenry** wondered if the researchers accounted for continental drift. "Ninety million years ago, the Antarctic wasn't quite where it is now," he wrote. **McHenry** also wondered if Earth's axial tilt 90 million years ago would have kept Antarctica in darkness for months at a time. "It isn't only the cold that prevents forests, but also the lack of light for many months of the year," he wrote.

The latitude where this forest once existed, 82° S, is a paleolatitude, **Gramling** says. Researchers determined this ancient location based on calculations of where and how quickly tectonic plates have moved over the last 90 million years. "The drill site is a bit closer to the South Pole, but the ancient site was within about 1,000 kilometers of the pole, even when accounting for the movements of the plates," she says.

As for axial tilt, the angle of the tilt changes on a 41,000-year cycle, between a minimum of 22.1 degrees and a maximum of 24.5 degrees. "Although that cycle can impact climate, a site at 82° S would still have been plunged into darkness for months each winter," **Gramling** says. "That makes it even more remarkable that temperatures remained warm enough for the forest to thrive, and it's why the researchers determined that such high carbon dioxide levels as well as a basically ice-free continent were both necessary conditions."

COVID-19 Q&A

Science News *reporters* ***Tina Hesman Saey***, ***Aimee Cunningham***, ***Jonathan Lambert*** *and* ***Erin Garcia de Jesus*** *are following the latest research to keep you up to date on the coronavirus pandemic. The team is answering reader questions about COVID-19.*

"Is there something different about coronaviruses whereby we do not have long-lasting immunity once infected?" reader **Bob Schalhoub** asked.

That's a million-dollar question. When a virus infects a person, the body typically mounts an immune response to fight off the infection. Once the virus is gone, certain cells help the immune system recognize the virus if it attacks again. But that memory tends to fade over time for some viruses, like coronaviruses, and not for others, like measles virus. Scientists don't fully understand why there's a difference.

Because of this short memory, people can be repeatedly infected by cold-causing coronaviruses, studies have shown. It's unclear whether that's the case for coronaviruses that have caused outbreaks, including the new coronavirus. The SARS outbreak was contained before that question could be explored. And MERS doesn't offer helpful insights because it infects so few people a year.

Join the conversation

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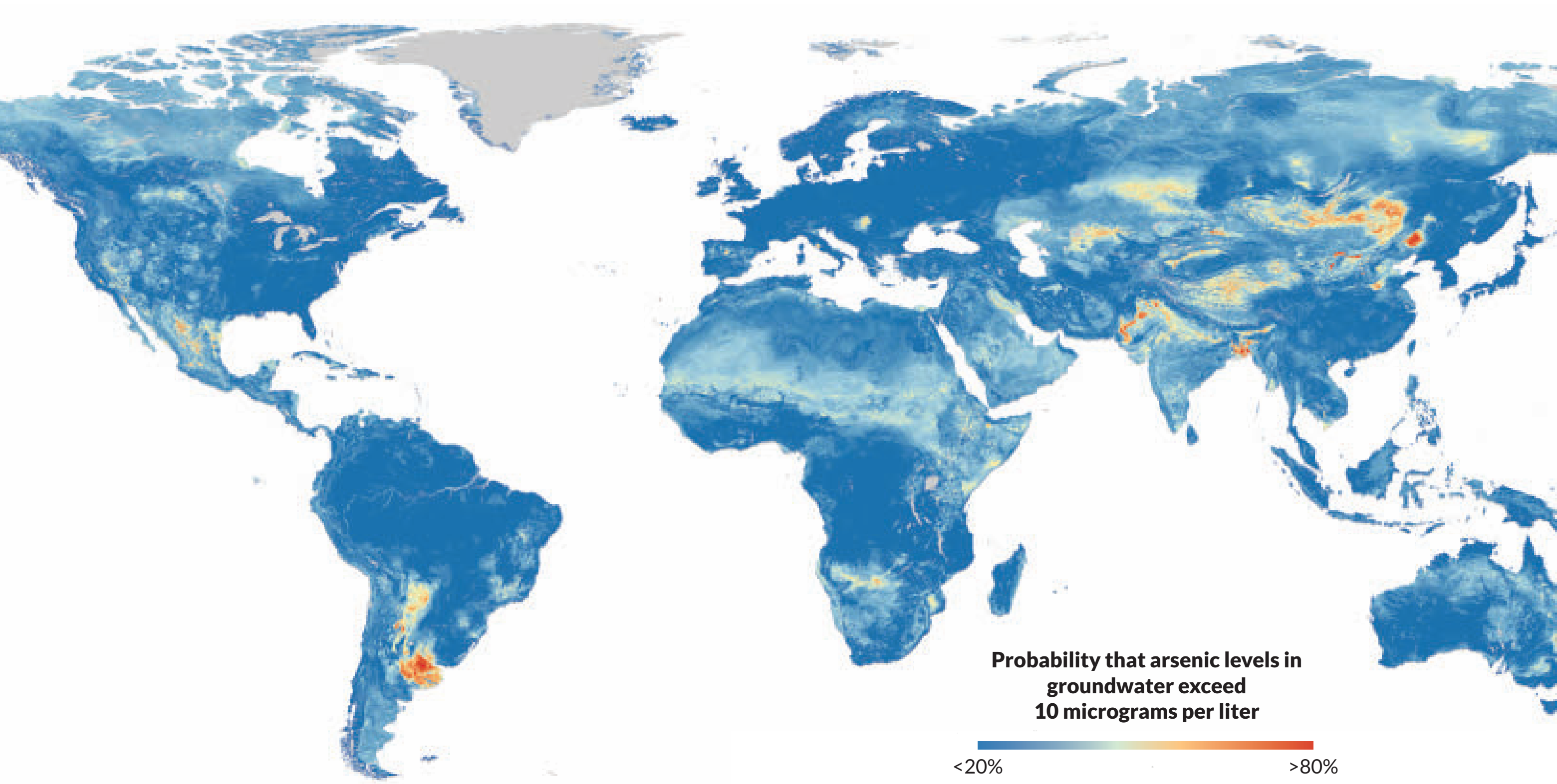


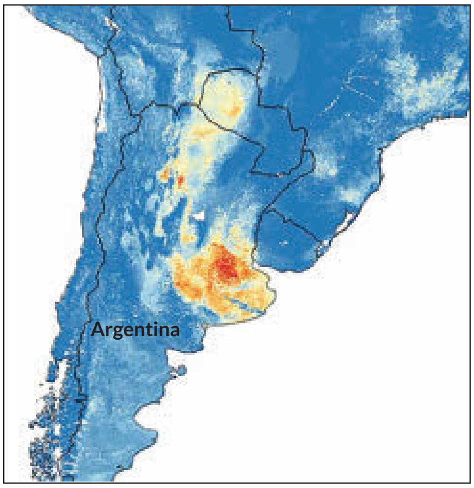
Mapping arsenic risk in groundwater

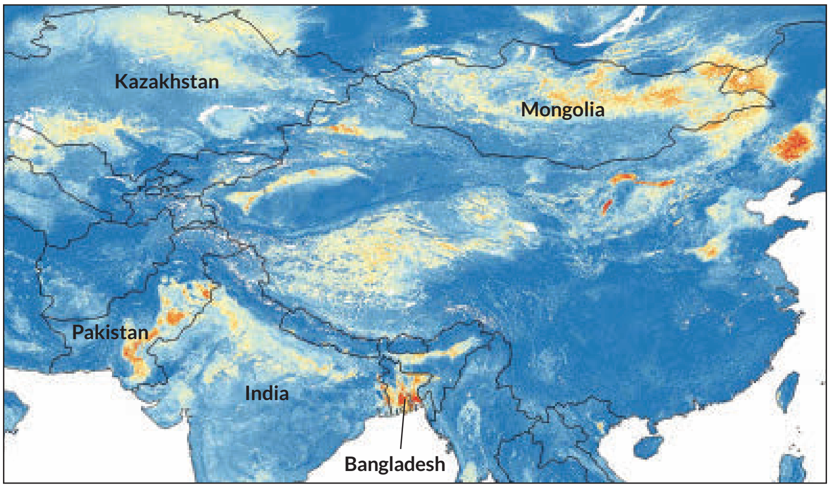
Up to 220 million people globally may be at risk of drinking arsenic-contaminated groundwater. That estimate is based on a global map (above) that predicts where arsenic concentrations in groundwater are most likely to exceed 10 micrograms per liter, a safe drinking water limit set by the World Health Organization. Red shows areas with a high probability of exceeding that limit; dark blue indicates a low probability.

Arsenic exists in tiny amounts in many types of soil and rock. People can be exposed to the harmful element when it leaches into groundwater. Long-term exposure to levels above safe drinking water limits can lead to skin lesions and cancer.

Data on arsenic in groundwater are lacking for many places. So environmental scientist Joel Podgorski and hydrologist Michael Berg, both of the Swiss Federal Institute of Aquatic Science and Technology in Dübendorf, combined climate, environmental and geologic data from almost 80 studies and machine learning to make the map, described in the May 22 *Science*. The result is "the first truly global risk map of arsenic contamination in groundwater," Podgorski says.

The map shows known hot spots, including in Argentina (below left), the Indus River Valley in Pakistan (below right) and the Ganges-Brahmaputra Delta in Bangladesh and India, and highlights possible elevated risk in less studied areas, including in Kazakhstan and Mongolia. *— Carolyn Gramling*





ALL: J. PODGORSKI AND M. BERG/*SCIENCE* 2020

We can help slow the spread together when we take these steps:

- Avoiding close contact
- Staying home
- Handwashing for 20+ seconds
- Disinfecting frequently touched surfaces
- Wearing a cloth face covering in public

Learn ways to protect yourself and others at coronavirus.gov