

The Sounds of Stonehenge | Black Hole Megamerger

ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC ■ SEPTEMBER 26, 2020



Surviving the Bite

Researchers develop new weapons
against deadly snake venoms



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Rafael Menegucci/iStock/Getty Images Plus



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When the human body outwits a deadly virus

With humankind focused on surviving the SARS-CoV-2 virus, I find it oddly reassuring to think about other deadly foes we've faced. Some, like the virus that caused the 1918 influenza pandemic, waned as people developed immunity. Others, like HIV, continue to threaten, killing 690,000

people worldwide last year.

It's been more than 40 years since doctors in the United States started seeing young men become terribly ill with rare cancers and pneumonia. In 1982, these mysterious infections were given a name: acquired immune deficiency syndrome, or AIDS. In 1983, human immunodeficiency virus, or HIV, was identified as the culprit.

I'm old enough to remember when having AIDS was a death sentence. I saw friends suffer and die. Now, antiretroviral drugs can help keep infected people healthy for many years, reducing the amount of virus in their bodies to levels too low to infect others. And medications can protect people from getting infected in the first place (*SN: 11/23/19, p. 16*). We haven't vanquished HIV, but decades of effort by scientists around the world has substantially reduced HIV's toll, and changed our view of the disease from hopeless to manageable.

In this issue, we report on a study that reveals a triumph of the human immune system: A person appears to have subdued HIV without any medication at all (Page 6). This person, dubbed an "elite controller," appears to harbor no functional HIV virus. And there are signs this isn't unique. A second elite controller studied had just one functional copy of the virus.

For those of us who have been on the infectious disease beat for years, this is a "wow" of a study. I was eager to find out more, so I called Tina Hesman Saey, the *Science News* writer who covered this report. "I knew that there were people who didn't have detectable levels of virus in their blood," Saey said. "But I didn't know that they could do that without drugs."

Saey, who has a Ph.D. in molecular biology and covers genetics, especially appreciates the clever way that the elite controllers' immune systems defanged HIV: by sequestering the virus in a kind of genetic prison, the inactive parts of cellular DNA. "They were specifically embedded in the heterochromatin; it's just locked up super tight so nothing in there gets out," she said. Saey also appreciates the colossal amount of effort by the scientists to figure this out, examining more than 1.5 billion blood cells from the body of the first elite controller, and more than 1 billion from the second. "I was awed by the number of cells that they looked at."

So decades after HIV first emerged as a killer, humankind is still making discoveries about how the body fights it. With the new coronavirus, we're in the early stages of the learning process, even though it often feels like we've been waiting forever to figure out this particularly wily foe. Scientists have made progress with treatments, many groups are racing to test potential vaccines, and multiple countries have shown that even without a vaccine, it's possible to contain the virus and return to a close-to-normal life. We're not where we want to be, but we're making progress. — *Nancy Shute, Editor in Chief*

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Halfway into our ambitious trek through the rain forest I had to remind myself that “Nothing good comes easy.” These days it seems that every business trip to Brazil includes a sweltering hike through overgrown jungles, around cascading waterfalls and down steep rock cliffs. But our gem broker insisted it was worth the trouble. To tell you the truth, for the dazzling emeralds he delivered, I’d gladly go back to stomping through jaguar country.

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Excerpt from the October 3, 1970 issue of *Science News*

50 YEARS AGO

Clues from a chemical

An experimental drug's effects on the sexual behavior of certain animals is arousing interest among investigators.... The drug, para-chlorophenylalanine... reduces the level of a naturally occurring neurochemical, serotonin, in the brain of rats, mice and dogs.... Little is known about how serotonin acts in the brain, and investigators quickly recognized that PCPA could be used to study this brain chemical.

UPDATE: PCPA helped establish serotonin's role in regulating sexual desire, as well as sleep, appetite and mood. The chemical messenger has become key to one common class of antidepressant drugs called selective serotonin reuptake inhibitors. Identified in 1974, SSRIs work by increasing the brain's serotonin levels. But such drugs can hinder sexual desire. One SSRI that failed to relieve depression in humans found a second life as a treatment for sexual dysfunction. Approved by the U.S. Food and Drug Administration in 2015, this "little pink pill," sold as Addyi, may boost sex drive in women by lowering serotonin in the brain's reward centers.

SOAPBOX

Biology textbooks don't reflect the field's diversity

Charles Darwin. Carolus Linnaeus. Gregor Mendel. They're all men. They're all white. And their names appear in every biology book included in a recent analysis of college textbooks. According to the survey, mentions of white men still dominate biology textbooks despite growing recognition of the scientific contributions of women and people of color.

The good news, the researchers say: Scientists in textbooks are getting more diverse. The bad news: If diversification continues at its current pace, it will take another 500 years for mentions of Black scientists to accurately reflect the number of Black college biology students.

"Biology is still a very white discipline, so the results were not incredibly surprising," says Cissy Ballen, an education researcher at Auburn University in Alabama. By identifying scientist names in textbooks and determining when the featured research was published, Ballen and her colleagues looked at trends in seven of the most commonly used college biology textbooks in the United States. The team published its findings in the June 24 *Proceedings of the Royal Society B*.

For featured research published between 1900 and 1999, only about 9 percent of scientists mentioned were women, the team found, and 3 percent were people of color. But for featured research published between 2000 and 2018, women got 25 percent of the mentions, and people of color 8 percent. Some of this was representative; the number of women mentioned was proportional to the number of tenured women in the U.S. academic biology workforce over time, based on U.S. National Science Foundation data. Data on the number of tenured people of color was not available.

But the numbers were not representative of the biology student body. Based on the change in diversity in featured research from the 1900s to 2018, Ballen



Recent shifts have included more diverse scientists, but college biology textbooks still lag behind student diversity.

and colleagues extrapolate that it will take 28 years for textbooks to catch up with student diversity when it comes to mentioning women scientists, about 50 years for Asian scientists, 30 years for Hispanic/Latino scientists and nearly 500 years for Black scientists. Scientists in some groups — such as Black women — were never mentioned in the books at all.

One factor is that most biology textbooks are presented as a history of science, Ballen says. No women from the 1600s to 1900 were mentioned in the books surveyed. "That's 300 years of just white men in textbooks," she says. As a fix, textbooks could illustrate more concepts with modern examples. Today, "both women and scientists of color have greater access to biology, they are more accessible for textbook authors and publishers to find, and more prominent in their field."

Who's mentioned is only one aspect of the diversity problem, says biochemist Mark Lee of Spelman College in Atlanta. "Publishers could make sure they have representation that is diverse on the writing team," he says. But Lee isn't waiting for more diverse textbooks. Professors have to bring in extra content and support diverse populations of students, he says. Then, students will "see science being done by individuals like them." — *Bethany Brookshire*



Modernizing biology textbooks could boost diversity, researcher Cissy Ballen argues.

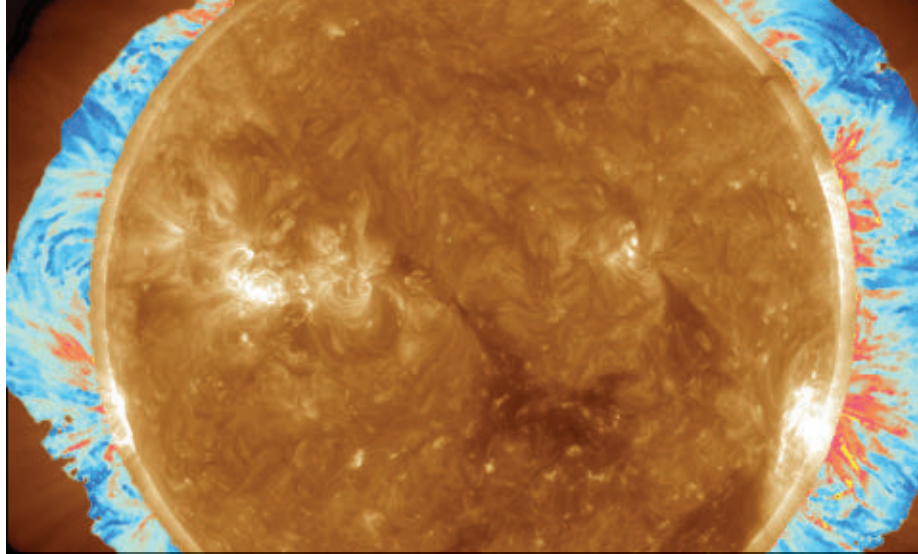
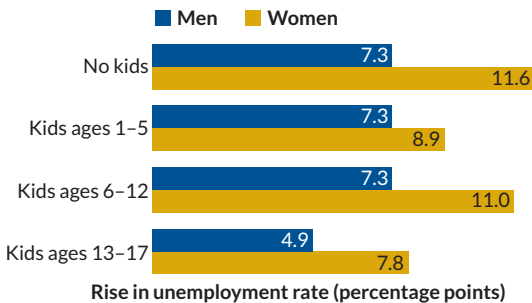
SCIENCE STATS

COVID-19 worsened gender inequality in U.S. workforce

The pandemic has left millions of people across the United States unemployed. Women have been particularly hard-hit, researchers report August 3 in *Socius*.

Researchers compared U.S. Census Bureau labor market surveys for February and April. Among married, heterosexual couples, the unemployment rate for women with no kids rose from 2 percent in February to 13.6 percent in April — an increase of 11.6 percentage points (see graph). For men with no kids, the rate jumped 7.3 percentage points from 2.2 percent in February to 9.5 percent in April. Women were walloped partly because they are concentrated in service jobs, the researchers say. For couples with kids, mothers also appear to have shouldered more child care. — *Sujata Gupta*

Change in U.S. unemployment rates among married, heterosexual couples, February–April 2020



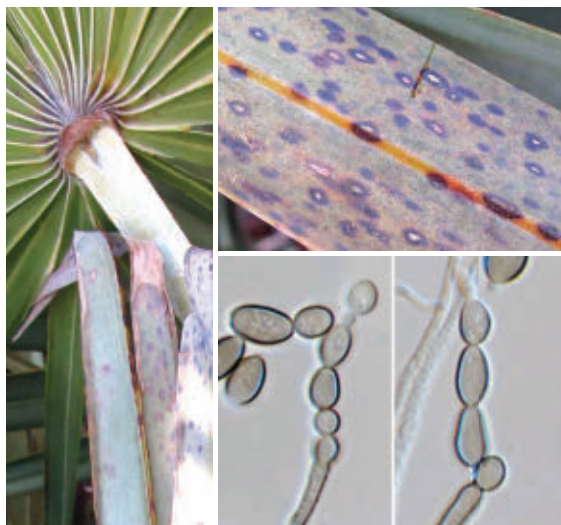
PICTURE THIS

Solar cartographers chart magnetic field

The sun’s wispy upper atmosphere, or corona, is an ever-changing jungle of sizzling plasma. But mapping the strength of the magnetic field that largely controls that behavior has proved elusive — until now.

Solar physicists used a coronagraph, an instrument that blocks out the sun’s bright disk, to measure the speed and intensity of waves rippling across plasma in the corona. The waves’ velocities can be used to infer the strength of the magnetic field (colored fringes above; lower strength is blue and higher strength is yellow). “This is the first time we’ve mapped the coronal magnetic field on a large scale,” says Steven Tomczyk of the High Altitude Observatory of the National Center for Atmospheric Research in Boulder, Colo., who designed the coronagraph.

The corona’s magnetic field is weak, between 1 and 4 gauss — a few times the strength of the magnetic field at Earth’s surface, the team reports in the Aug. 7 *Science*. Making a map is a big step toward continuously tracking the corona’s magnetic field, which could improve forecasts of solar outbursts that can shut down satellites. — *Lisa Grossman*



Named during the pandemic, this new fungal species got a COVID-19-inspired name. *Diabolocoviddia claustris* (asexual spores, bottom right) grows on the leaves of a saw palmetto (left) in Florida, causing spots (top right).

THE NAME GAME

Pandemic inspires names for new fungi


Never mind that they’re not viruses. Catching the trend of cocktails called quarantinis and racehorse names like Flatten the Curve, two fungal species now have monikers born out of the struggle to keep research alive during the coronavirus pandemic.

Fungal leopard spots found on saw palmetto leaves turned out to be new to science, mycologist Pedro Crous and colleagues reported in the July *Persoonia*. As the pandemic raced across Europe, Crous — working mostly from home instead of in his lab at Westerdijk Fungal Biodiversity Institute in Utrecht, Netherlands — named the fungus *Diabolocoviddia claustris*. *Diabolocoviddia* means “devilish COVID.”

Biologist Danny Haelewaters was grounded at Purdue University in West Lafayette, Ind., socially distant from his coauthor, André De Kesel of Belgium’s Meise Botanic Garden, when he chose the epithet *Laboulbenia quarantenae* for a new fungal species, reported July 30 in *MycKeys*. Found in the botanic garden on a kind of ground beetle, the fungus looks like a warped banana with antlers. The species reproduces only via sex, which is weirdly simple for a fungal lifestyle. — *Susan Milius*

FROM TOP: Z. YANG ET AL./SCIENCE 2020; L.C. LANDIVAR ET AL./SOCIOUS 2020; P.W. CROUS ET AL./PERSOONIA 2020

News



In some people infected with HIV (the green buds shown emerging from a human cell in this colorized electron micrograph), the virus gets confined to genetic prisons.

GENES & CELLS

A person's immune system beat HIV 'Elite controller' has kept the virus at bay for decades

BY TINA HESMAN SAEY

Some rare people may be able to cure themselves of HIV infections.

Unlike two infected people who have previously had levels of HIV particles drop to undetectable after bone marrow transplants (*SN*: 3/30/19, p. 6), a person may have cleared functional HIV with no outside help. If true, it would be the first known case of a spontaneous cure.

Analysis of over 1.5 billion blood cells from a patient known as EC2 found no functional HIV copies, researchers report online August 26 in *Nature*. The person still had some nonfunctional virus copies. While no one can say for sure that intact virus isn't hiding somewhere in the body, the finding suggests that some people's immune systems can essentially eliminate the pernicious and persistent virus.

A second person, EC1, had just one functional copy of HIV in over a billion analyzed cells. That copy was stuck in the genetic equivalent of a supermax prison. That genetic lockup may be key to naturally controlling the virus.

EC1 and EC2 are a special subset of a rare group of people called elite controllers, who maintain very low or undetectable levels of infectious HIV particles in their blood without drugs. These people have no symptoms and no clear signs of damage from HIV. "It's not even that we're talking about a few months or a few years. It's extremely long-term," says

Satya Dandekar, an HIV researcher at the University of California, Davis School of Medicine who wasn't involved in the study. In contrast, for 99.5 percent or more of the world's more than 35 million HIV-infected people, drugs are the only way to keep the virus in check.

It's been difficult to figure out how elite controllers quash the virus, says Dandekar, because no one has recorded the first fight scenes between HIV and an elite controller's immune system. By the time anyone recognizes an elite controller, the immune system has already won.

About a quarter of elite controllers have genetic variants in key immune system genes that may help them get a handle on the virus, says Joseph Wong, a virologist at the University of California, San Francisco who wasn't involved in the study. But that explains only a minority of elite controllers, he says.

To find a broader explanation, scientists looked at HIV embedded in DNA from 64 elite controllers and 41 HIV-infected people taking antiviral drugs. Elite controllers had maintained undetectable virus levels without drugs from one to, in EC2's case, 24 years. The median was nine years.

A retrovirus, HIV stores genetic information as RNA. An enzyme called reverse transcriptase copies those RNA instructions into DNA, which can then insert into the host's DNA. Reverse

transcriptase is error prone, often resulting in defective or incomplete copies of the virus. So the researchers went into the study thinking that elite controllers might be loaded with these nonfunctional versions, which can't make infectious virus, says Xu Yu, an immunologist at the Ragon Institute of Massachusetts General Hospital, MIT and Harvard.

"To our surprise, that's not the case," she says. Instead, most elite controllers had more intact virus than expected. Only EC2 had no functional virus copies at all. So the team looked to see where the virus had landed in patients' DNA.

In most infected people, human proteins shepherd HIV into or near genes, says Monica Roth, a virologist at Rutgers' Robert Wood Johnson Medical School in Piscataway, N.J. But in the elite controllers, the virus was trapped in gene-poor parts of the genome. The genes that HIV did land near or in were wrapped in the molecular equivalent of razor wire, which prevents the genes from being turned on. Collectively those inactive, tightly guarded parts of the genome are known as heterochromatin. Plunking HIV in heterochromatin "is like putting it in the trunk, and then locking the trunk," says Roth, who was not involved in the work.

Yu's team investigated whether elite controllers have a propensity for steering the virus toward heterochromatin. But in lab dishes, proteins in elite controllers' cells directed HIV toward genes.

"It's probably not that [elite controllers] just got lucky at the beginning of the infection" to get HIV trapped in heterochromatin, says Yu's Ragon Institute colleague Mathias Lichtenfeld, a virologist and infectious diseases physician. Instead, the team thinks elite controllers' immune systems eliminated cells making functional virus, leaving behind broken copies and intact versions locked in heterochromatin. Exactly how the immune system manages that feat is unknown.

Roth says that idea is "intriguing" but lacks evidence. Thus how elite controllers achieve their status stays a mystery. Once the mechanism is solved, she says, "maybe you can figure out what goes wrong in everyone else and fine-tune it." ■

Midsized black holes really do exist

Gravitational waves reveal a record-breaking merger

BY EMILY CONOVER

The biggest. The farthest. The most energetic. A new detection of gravitational waves from two colliding black holes has racked up multiple superlatives.

And it marks the first definitive sighting of an intermediate mass black hole, one with a mass between 100 and 100,000 times the sun’s mass. That midsized black hole was forged when the two progenitor black holes coalesced to form a larger one with about 142 solar masses. It significantly outweighs all black holes previously detected via gravitational waves, ripples that wrinkle spacetime in the aftermath of extreme events.

“This is the big guy we’ve been waiting for,” says Emanuele Berti, a physicist at Johns Hopkins University who was not involved with the research.

Detected May 21, 2019, the gravitational waves came from a source about 17 billion light-years from Earth, making this the most distant confirmed detection. Because of the universe’s expansion, that distance corresponds to a travel time of about 7 billion years, meaning the grav-

itational waves were emitted when the universe was about half its current age.

It’s also the most energetic event yet seen, radiating about eight times the equivalent of the sun’s mass in energy, says astrophysicist Karan Jani of Vanderbilt University in Nashville, a member of the LIGO Scientific Collaboration.

The event dethrones the previous record-holder, a collision that occurred about 9 billion light-years away that radiated about five solar masses’ worth of energy and created a black hole of 80 solar masses (*SN: 1/19/19, p. 10*).

Researchers with LIGO, the Advanced Laser Interferometer Gravitational-Wave Observatory, in the United States and Advanced Virgo in Italy reported the new detection September 2 in two papers in *Physical Review Letters* and the *Astrophysical Journal Letters*.

While scientists knew of black holes with tens of solar masses and others with millions or billions of solar masses, the intermediate echelon remained elusive. Previous purported sightings of such black holes have been questioned. But

for the new event, “there’s no doubt,” says astrophysicist Cole Miller of the University of Maryland in College Park, who was not involved with the research.

The black hole’s progenitors were themselves heftier than any seen colliding before — at about 85 and 66 times the mass of the sun. That has scientists puzzling over how this smashup came to be.

Normally, physicists expect that the black holes in these mergers would each have formed in the collapse of a dying star. But in the new event, the larger of the pair is so big that it couldn’t have formed that way. The known processes that go on within a star’s core mean that stars that are the right mass to form such a big black hole would blow themselves apart completely, rather than leave behind a corpse.

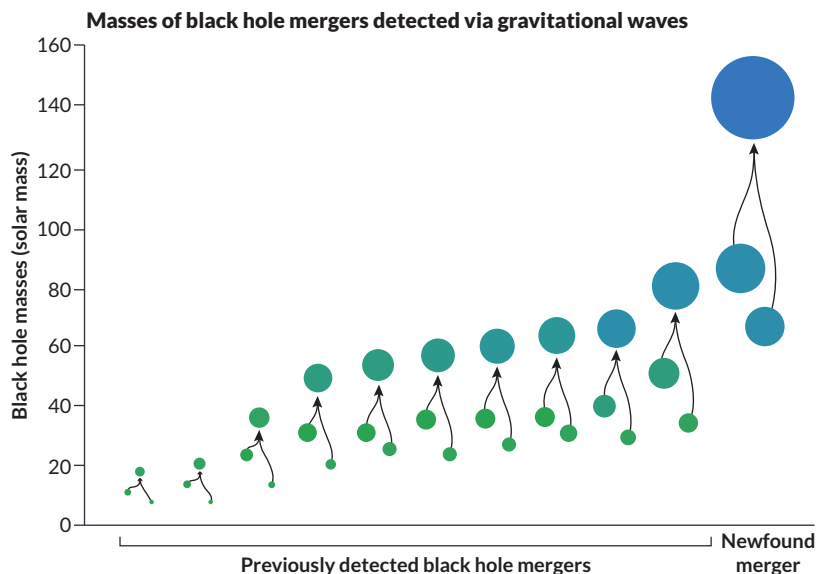
Perhaps one or both of the black holes formed from an earlier round of mergers, within a crowded cluster of stars and black holes. That would make for a family tree that began with black holes light enough to form from collapsing stars.

But there’s a problem with that idea. Each time black holes merge, that coalescence provides a kick to their velocity, which would normally launch the resulting black hole out of the cluster, preventing further mergers. However, mergers as massive as the new event seem rare, given that LIGO and Virgo have detected only one. Maybe, Miller says, the kick is sometimes small enough that the black holes can stay within their cluster.

The May 21 gravitational wave event had previously been reported as an unconfirmed candidate, allowing astronomers to look for flashes of light in the sky that may have resulted from the collision. Some scientists had suggested that the waves might have been associated with a flare from the center of a distant galaxy (*SN: 8/1/20, p. 8*). But that galaxy is much closer than the distance now pinpointed, making the explanation less plausible.

The longer LIGO and Virgo observe the heavens, the more the bounty of unusual events will grow, Miller says. “We are going to have a set of ‘gosh, didn’t expect that’ type of events, which are thrilling to think about and extremely informative about the universe.” ■

Megamerger On May 21, 2019, gravitational wave observatories detected two merging black holes. The duo created a black hole much larger than those found in previous mergers. Below, colored circles represent the relative sizes of black holes; bluer colors represent bigger black holes.



R. HURTY/IPAC/CALTECH, MIT, LIGO

BODY & BRAIN

Drugs aim to treat COVID-19 early

Promising medicines may prevent serious illness

BY TINA HESMAN SAEY

“The sooner, the better” is an adage that’s especially true when treating viruses.

Usually, drugs that tamp down a viral infection are given within the first couple of days of symptoms. But with the novel coronavirus, the only two drugs known to help — an antiviral called remdesivir, and steroids such as dexamethasone — are given only to people hospitalized with COVID-19.

Those drugs may keep seriously ill people from dying and help them recover faster, but it would be far better to keep people from getting so sick in the first place, scientists say. To that end, they’re testing a number of drugs that could be taken as soon as someone tests positive.

Of course, scientists are also frantically working to get vaccines ready for the general public (*SN*: 8/1/20, p. 6). But even with the pedal-to-the-metal speed at which vaccine developers are working, it still may take months to years for vaccines to be readily available to everyone. “We can’t count on that, so we need another tool in our toolkit,” says Lisa Danzig, a vaccine developer and the medical adviser for the COVID-19 Early Treatment Fund. Businessman and philanthropist Steve Kirsch established the fund to pay for outpatient clinical trials, with the goal of reducing hospitalization and death from COVID-19 by 75 percent.

Researchers are testing a variety of existing drugs that might be repurposed to fight the coronavirus early in infections. None have been proven yet, and much of the federal and private funding for clinical trials has gone for treating the severely ill. Kirsch’s fund has started to fill that gap, for instance, by paying for a trial of hydroxychloroquine as a possible preventive for people exposed to the virus. That study found no benefit of taking the drug (*SN*: 7/4/20 & 7/18/20, p. 8).

Even such negative results are important, Danzig says. “The important thing is to get the data, so we can say ‘yes’ or ‘no,’ and we can get together and prioritize resources.”

The most promising early treatments for COVID-19 may either block the coronavirus’s entry into cells or stop the virus from replicating.

No entry

To slip into human cells, the coronavirus needs to pick a molecular lock, and there are two ways to do that. Recent studies with human lung cells suggest that the virus prefers the route that relies on a protein-cutting enzyme called TMPRSS2 to snip the knobby-looking spike protein studding the virus’ surface. That cut allows the virus to fuse with the cell membrane and dump genetic material into the cell. Once inside, the virus can multiply.

In lab studies, a drug called camostat mesylate can block that process by stopping TMPRSS2 from snipping the spike protein. “It’s a drug that has been used for decades,” says Stefan Pöhlmann, a virologist at the German Primate Center in Göttingen. The drug is used in Japan for treating pancreatitis, and studies indicate it is generally safe. Pöhlmann and colleagues reported preliminary data on August 5 at bioRxiv.org suggesting that the drug, along with a chemical it breaks

down to, has antiviral activity against the coronavirus and is likely to work at doses commonly given to patients.

The drug may have its best shot of stopping coronavirus if it’s given as early as possible in the infection. One outpatient clinical trial, along with a study in hospitalized patients, is already under way in Denmark. Another trial is set to start soon at Yale School of Medicine to treat people newly infected with the virus.

Replication wreckers

Once the virus has made its way into cells, it starts making copies of itself. Several drugs, including remdesivir, interfere with that process. Remdesivir is given intravenously to hospitalized patients, but its maker, Gilead Sciences Inc. in Foster City, Calif., has developed an inhaled form that might be used at home in newly diagnosed people, and perhaps as a preventive treatment.

Still, remdesivir is complicated to make and supplies are limited, so researchers are testing other drugs that might also throw wrenches into the coronavirus’s replication machinery.

One such drug is favipiravir. Originally developed as an anti-influenza drug and stockpiled in Japan for use in a flu pandemic, favipiravir has already been authorized for emergency use in Russia and India and for experimental

Potential early treatments These are some of the drugs that might be able to treat COVID-19 at the earliest stages of infection, perhaps heading off severe illness.

Drug name	Also used to treat	How it works	How it is taken
Camostat mesylate	Pancreatitis and postoperative acid reflux	Interferes with an enzyme to block viral entry into cells	Pill
Remdesivir	Coronavirus in hospitalized patients	Mimics an RNA building block to shut down viral replication	Inhaled
Favipiravir	Influenza	Mimics an RNA building block to shut down viral replication	Pill
EIDD-2801	Not applicable (experimental)	Mimics an RNA building block to shut down viral replication	Pill

use in China for treating COVID-19. Like remdesivir, favipiravir mimics a building block of the virus's genetic material, RNA. When the look-alike is incorporated into a growing strand of RNA, the drug stops production of the RNA and prevents viral replication.

Favipiravir has at least one advantage over the intravenous version of remdesivir. "It's in a pill form, and it's not a very big pill," says Yvonne Maldonado, an infectious diseases epidemiologist at Stanford School of Medicine who is leading a trial of favipiravir. The study will test the drug against a placebo in an outpatient setting.

Already favipiravir has been studied in the United States for treating flu, and it didn't work better than the current drug for that illness, oseltamivir (Tamiflu). Clinical trials suggest favipiravir is safe for short-term use, but some concerns about the drug leading to birth defects have led to recommendations that pregnant women probably shouldn't take it.

Maldonado and colleagues will enroll patients within 72 hours of getting a positive COVID-19 test. Participants will take the pills twice a day for 10 days, and nasal swabs will be used to determine whether the drug is reducing the amount of virus the person is producing, which may stop transmission to others.

An experimental drug known as EIDD-2801 also mimics an RNA building block and can be taken as a pill. The drug's Miami-based maker, Ridgeback Biotherapeutics, has teamed with global pharmaceutical company Merck to test the drug. The drug is now in Phase II trials to test safety, dosage and efficacy against the coronavirus, including an outpatient study in North Carolina.

An experimental compound also made by Gilead and being tested against coronavirus infections in cats might also hold promise against COVID-19 in people (*SN: 9/12/20, p. 10*).

Results of these early tests may be known soon. If any of them pan out, larger clinical trials would be needed to establish efficacy. And if these drugs don't prove effective, there are many other medicines in the works. ■

HUMANS & SOCIETY

Voting by mail boosts turnout slightly

Democrats and Republicans benefit equally from mail-in ballots

BY SUJATA GUPTA

Mandatory mail-in voting leads to a slight uptick in voter turnout — for both Democrats and Republicans.

That's the conclusion researchers came to after analyzing more than 40 million individual voting records from Utah and Washington — states that have switched almost exclusively to mail-in voting in recent years — as well as nearly 30 years of nationwide county-level voting data.

The finding, published August 26 in *Science Advances*, suggests the widespread belief that mail-in voting benefits one party over another is false, says political scientist Michael Barber of Brigham Young University in Provo, Utah. "Neither party is hurt," he says.

Utah and Washington do not reflect U.S. voting patterns as a whole. But because Washington leans blue and Utah red, the states demonstrate how mail-in voting could affect voter turnout by party.

Due to the ongoing pandemic, many states have made mail-in voting easier. But some voters are wary of the process. A Gallup poll from May found that only 40 percent of Republican respondents favored their state allowing all residents to vote by mail; 83 percent of Democrats favored mail-in voting.

Barber and John Holbein, a political scientist at the University of Virginia in Charlottesville, combed through multiple datasets to see how mail-in voting has influenced voter turnout overall and by party in recent decades. The researchers first identified counties in six states that adopted more universal mail-in voting procedures from 1992 to 2018, including limiting or eliminating in-person voting.

Using census data, the pair identified the total number of eligible voters in counties that adopted mail-in voting and those nationwide that did not. The team then compared voter turnout across counties by looking at election data show-

ing how many eligible voters actually cast a ballot in each midterm or presidential election during that quarter century. The researchers also compared turnout within a given county before and after the implementation of a vote-by-mail policy. Another dataset enabled an evaluation of each party's share of votes per county.

The researchers then drilled down into individual voting patterns for Utah from 2012 to 2018 and Washington from 2002 to 2016, finding that voter turnout increased slightly. The county-level analysis had similar results, showing that

The belief that mail-in voting favors one party is false.

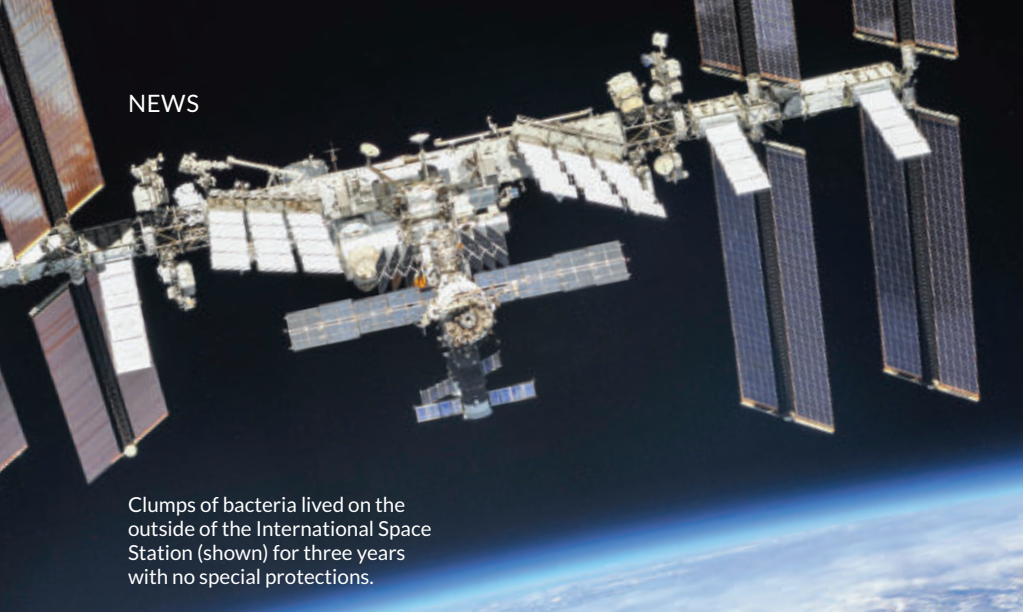
mail-in voting led to a 1.8 to 2.9 percentage point increase in voter turnout.

Partisan vote shares in counties with mail-in voting tilted 0.7 percentage points in favor of Democrats. But with a margin of error between -0.7 and 2 percentage points, that increase was not statistically significant and could go either way in any given election, Barber says.

Such a broad geographic analysis can ignore smaller communities, says Jean Schroedel, a political scientist at Claremont Graduate University in California. Her work shows that mail-in voting disenfranchises Native Americans on reservations, many of whom lack regular mail access. "Native people don't trust voting — full stop — but they really don't trust voting by mail," Schroedel says.

Even if states sort out how to protect the votes of vulnerable community members, such as by keeping some physical polling places open, the findings may do little to allay other concerns, Barber says. Those fears include the U.S. Postal Service's ability to keep pace with an influx of mail and the possibility of mail-in ballots getting thrown out for having an allegedly faulty signature or arriving late.

"I don't know what's going to happen in 2020 with vote by mail," Barber says. "This has gotten so unnecessarily messy." ■



Clumps of bacteria lived on the outside of the International Space Station (shown) for three years with no special protections.

LIFE & EVOLUTION

Bacteria can survive for years in space

Microbes may be able to spread life via interplanetary travel

BY JONATHAN LAMBERT

Outer space is not friendly to life. Extreme temperatures, low pressure and radiation can degrade cell membranes, destroy DNA and kill any life-forms that somehow find themselves in the void.

But by banding together, some bacteria can withstand that harsh environment, shielded from the extremes of space by the group's outer layers. Microbes huddled at the heart of balls of bacteria as thin as five sheets of paper survived on the exterior of the International Space Station for three years, scientists report August 26 in *Frontiers in Microbiology*. Such microbial arks may be able to drift among planets and spread life, a concept known as panspermia.

Previous research has shown that microbes can survive in space when embedded within artificial meteorites. But this is the first study to show that microbes can survive this long without protection, says microbiologist Margaret Cramm of the University of Calgary in Canada, who wasn't involved in the study. "It suggests life can survive on its own in space as a group," she says, providing another possible avenue for panspermia. It also adds weight to the worry that human space travel could unintentionally introduce life to other planets.

In 2015, Akihiko Yamagishi, an astrobiologist at the Institute of Space and

Astronautical Science in Sagami-hara, and his colleagues sent into space dried pellets of *Deinococcus*, a radiation-resistant bacterium that thrives in extreme places, such as in the stratosphere. Bacteria were stuffed into wells in metal plates, which an astronaut affixed to the exterior of the space station. Samples were sent back to Earth each year.

Back home, the team rehydrated the pellets, gave the bacteria food and waited for growth. After three years in space, bacteria in 100-micrometer-thick pellets largely didn't make it. Radiation had fried the bacteria's DNA, the team found. Outer layers of 500- and 1,000-micrometer-thick pellets were dead too. But those dead cells shielded inner microbes, with about 4 percent of microbes in those larger pellets surviving, Yamagishi says.

Extrapolating from the data, Yamagishi says that bacteria in 1,000-micrometer-thick pellets could survive eight years floating in space. "That's enough time to potentially get to Mars," he says.

How exactly microbial clumps could get expelled into space is unclear. They might get ejected by thunderstorm-induced perturbations to Earth's magnetic field, or kicked up by meteorites hitting Earth, Yamagishi says. If microbial life is ever discovered on Mars, he hopes to look for evidence of such a cosmic journey. "That's my ultimate dream." ■

EARTH & ENVIRONMENT

Carbon dioxide linked to quakes

Gas rising from the mantle may trigger seismic activity

BY MARIA TEMMING

Italy may owe some of its seismic activity to carbon dioxide bubbling up from deep underground.

The country's central Apennine Mountains region has been rattled by several destructive earthquakes in recent years, including the devastating magnitude 6.3 quake that wracked the city of L'Aquila in 2009 (*SN*: 8/29/09, p. 26). A new decade-long record of natural carbon dioxide emissions in the area reveals that spikes in releases of CO₂ coincided with the biggest earthquakes. That finding hints that CO₂ rising toward Earth's surface can change pressure along faults to trigger earthquakes, researchers report August 26 in *Science Advances*. Understanding the relationship between CO₂ and seismicity could someday lead to better forecasts of earthquake risks.

Earth releases CO₂ when tectonic forces melt carbonate rock in the mantle. Freed CO₂ rises, gathers in pressurized pockets in Earth's crust and seeps into groundwater that feeds springs. Previous studies have noted that the gas tends to escape in seismic hot spots. But without long-term emissions records in quake-prone areas, no one knew exactly how the timing of CO₂ emissions compared with earthquake occurrence.

From 2009 to 2018, researchers measured the carbon content of springwater fed by the Velino aquifer, which is near the epicenter of the 2009 L'Aquila quake and sits atop a reservoir of CO₂ in Earth's crust. Those data show that jumps in CO₂ emissions happened at about the same time as strong earthquakes, and emissions dropped off when quakes were smaller and farther between. When the region was hit by quakes of magnitude 6 or higher, the Velino aquifer springs released more than 600 metric tons of CO₂ per day. During more seismically

quiet periods, the springs emitted some 400 to 500 tons of CO₂ daily.

Still, these data do not conclusively show whether rising CO₂ helps incite earthquakes, or if ground shaking simply brings more CO₂ to the surface, says Andrea Billi, a geologist at the Italian National Research Council in Rome who was not involved in the work. “It’s a chicken-and-egg problem.” Continuously monitoring these types of emissions in the Apennines and other seismically active regions, such as in California and

Japan, could reveal whether rising gas is a precursor or product of quakes, he says.

Study coauthor Giovanni Chiodini, a geologist at the Italian National Institute of Geophysics and Volcanology in Bologna, thinks “there is feedback between the two.” Continuous buildup of carbon dioxide underground, he says, could drive earthquakes, which fracture Earth’s crust and allow more CO₂ to creep upward, which in turn generates more quakes.

If uprisings CO₂ does aggravate seismic

activity in some areas, then tracking the chemistry of local springwater may offer forecasters a new tool to assess risks, which scientists did not have when the deadly earthquake took L’Aquila by surprise in 2009, Billi says.

In the wake of that disaster, six Italian scientists and a government official were convicted of manslaughter for failing to adequately warn the public of seismic risks in the region — although the defendants were later acquitted or got reduced sentences. ■

ATOM & COSMOS

Earth’s building blocks weren’t dry

Inner solar system may have supplied the mantle’s water

BY CHRISTOPHER CROCKETT

Earth’s deep stores of water may have been locally sourced, not trucked in from far-flung regions of the solar system.

An analysis of meteorites from the inner solar system — home to the four rocky planets — suggests that Earth’s building blocks provided enough water to account for all the water buried within the planet. What’s more, the water produced by the local primordial material likely shares a close chemical kinship with Earth’s deep water reserves, thus strengthening the connection, researchers report in the Aug. 28 *Science*.

Earth is thought to have been born in an interplanetary desert, too close to the sun for water ice to survive. Many researchers suspect that ocean water got delivered toward the end of Earth’s formation by ice-laden asteroids that wandered in from cooler, more distant regions of the solar system (*SN*: 5/16/15, p. 18). But the ocean isn’t the planet’s largest water reservoir. Researchers estimate that Earth’s interior holds several times as much water as is on the surface.

To test whether the material that formed Earth could have provided this deep water, cosmochemist Laurette Piani of the University of Lorraine in

Vandœuvre-lès-Nancy, France, and colleagues analyzed meteorites known as enstatite chondrites. Thanks to many chemical similarities with Earth rocks, these relatively rare meteorites are widely thought to be good analogs of the dust and space rocks that formed Earth’s building blocks, Piani says.

Her team measured the abundance of hydrogen in these meteorites — a proxy for how much water they could produce — and calculated that local interplanetary debris had the potential to deliver at least three times as much water as is found in all the oceans. The meteorites don’t contain water, but they house enough of the raw ingredients to create water when heated, Piani says.

Those raw ingredients would provide a close match to the type of water found in Earth’s mantle. A smattering of all water molecules on Earth contains a heavy variant of hydrogen known as deuterium. The ratio of deuterium to hydrogen in the enstatite chondrites lies within the range measured in Earth’s deep water. That similarity, the team argues, makes a strong case for local building blocks being the source of much of the planet’s water.

“This work is something I wanted to do myself or had been waiting for someone to do,” says Lydia Hallis, a planetary scientist at the University of Glasgow in Scotland. In 2015, she led a team that measured the deuterium abundance in lava plumes that tap deep into Earth’s mantle (*SN*: 12/12/15, p. 12). “I’m really happy that [the new data] sits within the



A new study of enstatite chondrites (one shown), a type of meteorite similar to the material that formed Earth, suggests that Earth’s primordial building blocks could have provided the planet with water.

region where our previous data from deep mantle samples is sitting.”

Hallis and others stress that these new measurements are difficult. Once the meteorites hit the ground, they quickly absorb hydrogen from Earth’s environment. The researchers “did a really good job of picking the right meteorites and making the right measurements,” she says. “This is pretty convincing that this hydrogen that’s measured is from the enstatite chondrites rather than from terrestrial contamination.”

The enstatite chondrites could have also contributed a lot of water to the oceans as well — but they are not the full story. The deuterium-hydrogen ratio in ocean water, which is a bit higher than that of mantle water, is better matched to the ratio found in icy asteroids from the outer solar system. “We still need a bit of water coming from the outer solar system,” Piani says. So, while local materials may have delivered the bulk of Earth’s water, the oceans were likely topped off a bit later by collisions with remote space rocks. ■

EARTH & ENVIRONMENT

What set off California's August fires?

Lightning lit a spark in a landscape primed by climate change

BY CAROLYN GRAMLING

Between August 16 and August 19, a thunderstorm system in California brought as many as 12,000 bursts of lightning, many of which sparked devastating wildfires. By the end of the month, these fires had burned more than 530,000 hectares across the state.

That is “an unbelievable number to say out loud, even in the last few years,” says UCLA climate scientist Daniel Swain. California wildfires in 2018 had blazed across a total of 794,438 hectares, setting what was then a new record.

But 2020 has already surpassed that measure as of the first week of September, even before the fire-promoting winds of autumn began. The culprits behind this fiery 2020, scientists say, are a bit of bad luck and a landscape primed for fire devastation due to climate change.

Before the August “dry lightning” storms, the western United States was experiencing a prolonged and record-breaking heat wave — including one of the highest temperatures ever measured on Earth, at Death Valley, Calif., which reached about 54° Celsius (about 130° Fahrenheit) on August 16. California was also suffering from extreme dryness. Those conditions bear the fingerprints of climate change, Swain says.

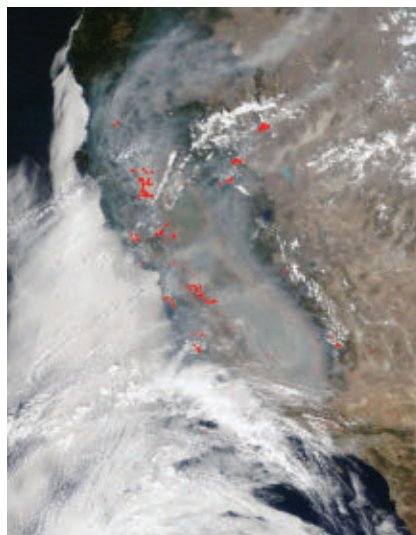
Both California's average heat and dryness have become more severe due to climate change, dramatically increasing the likelihood of extreme wildfires. In

the September *Environmental Research Letters*, Swain and colleagues report that over the last 40 years, average autumn temperatures increased across the state by about 1 degree C, and statewide precipitation dropped by about 30 percent. That, in turn, has more than doubled the number of autumn days with extreme fire weather conditions since the early 1980s.

Although fall fires in California tend to be more wind-driven, and summertime fires more heat-driven, studies show that the mark of climate change is present in both, Swain says. “A lot of it is very consistent with the long-term picture that scientists were suggesting would evolve.”

Though the stage had been set by the climate, the particular trigger for the latest fires was the series of dry lightning storms, which resulted from a strange

Smoke engulfed California on August 24, as more than 650 wildfires blazed across the state (red dots indicate likely fire areas).



Unusual dry lightning storms combined with very dry vegetation and a severe heat wave to ignite hundreds of wildfires across California in August, including in Lake County (shown).

confluence of two key conditions, each in itself rare for the region and time of year. “‘Freak storm’ would not be too far off,” Swain says.

The first factor was plumes of moisture from tropical storms far to the south, which managed to travel north to California on the wind and provide just enough moisture to form clouds.

The second unusual condition was a small atmospheric ripple, the remnants of an old thunderstorm complex in the Sonoran Desert. That ripple, Swain says, was just enough to kick-start mixing in the atmosphere; such vertical motion is the key to thunderstorms. The resulting clouds were stormy but very high, their bases at least 3,000 meters above the ground. Those clouds produced plenty of lightning, but most rain would have evaporated during the long, dry journey down.

Possible links between climate change and the conditions that led to such dry lightning storms would be “very hard to disentangle,” Swain says. “The conditions are rare to begin with, and not well modeled from a weather perspective.”

But, he adds, “we know there's a climate signal in the background conditions that allowed that rare event to have the outcome it did.” ■

To bloom, dodders may spy on hosts

Parasitic plant may use stolen signals to sense flowering time

BY JONATHAN LAMBERT

A dodder begins its life looking like a tapeworm.

The tiny plant, which will never grow leaves or roots, elongates in a spindly spiral. Round and round it swirls, searching for a host plant. When the dodder finds one, it latches on and infiltrates the host with tiny tubes that siphon off water and nutrients. The parasitic dodder grows, eventually covering its victim in a tangled, threadlike web of orange or yellow stems. Then, when the host plant flowers, so does the dodder, setting the stage for the sinister cycle to begin again.

But that last part, reproduction, has remained a mystery. Normally, flowering plants use their leaves to sense when the environmental conditions are right for flowering. So how does a parasitic plant with no leaves sense when to flower? By eavesdropping, a new study suggests, using a chemical signal from the dodder's host as its own.

Australian dodder plants (*Cuscuta australis*) absorb the chemical that triggers flowering, a protein called Flowering Locus T, or FT, from their hosts and use it to flower synchronously, researchers



An Australian dodder, wrapped around a soybean plant, is flowering in conjunction with its host and has begun producing seed capsules. Dodders may use a chemical signal from the host to induce their own reproduction.

report online August 31 in the *Proceedings of the National Academy of Sciences*. This synchronization maximizes the dodder's growth and reproduction, and may help explain how dodder plants have spread around the world, parasitizing organisms as different as alfalfa and acacia trees.

"Synchronizing flowering really makes sense for these plant parasites," says Jianqiang Wu, a botanist at the Chinese Academy of Sciences' Kunming Institute of Botany. If a dodder flowers too soon, it won't grow as large as it could have and will produce fewer seeds. Too late and its host may have already died, leaving the dodder with less nutrients to support flowering.

Wu previously demonstrated that dodders exchange many chemical signals with their hosts, and had a hunch

that the parasites might be picking up on a host's flowering signal. So in a laboratory greenhouse, Wu and colleagues let three species of dodders loose on plants with different flowering times, confirming that all the parasites shifted their flowering time to match their host.

When the researchers experimentally disabled the host's FT gene, dodders no longer flowered. Then, the team attached a fluorescent protein to the host's flowering protein and saw it glow in Australian dodder tissues, confirming that the parasites were taking up the chemical cue. The flowering protein also seemed to activate flowering-related genes in the dodder, which the researchers say is further evidence that FT kick-starts the whole process.

"Dodder and host plant synchronization has never been so clearly shown as in this paper," says James Westwood, a plant pathologist at Virginia Tech in Blacksburg. But there might still be more to the story, he says. "There are examples of dodders flowering when their host isn't flowering," he says, so it remains unclear whether the parasites sometimes use other signals to flower.

If it turns out that dodders truly use only FT from the host to induce flowering, Westwood says, that would be a simple and elegant example of how evolution has entwined plant parasites with their hosts. But he thinks more research is needed: "Biology is rarely that simple." ■



The orange stems of a dodder plant entwine themselves with the green host plants, siphoning off water and nutrients. More than 100 dodder species parasitize other plants around the world.



Acoustical engineer Trevor Cox works with a scale model of Stonehenge in a sound chamber in England.

HUMANS & SOCIETY

Stonehenge enhanced sounds within

Scale model re-creates the monument's ancient acoustics

BY BRUCE BOWER

Welcome to Soundhenge. Better known as Stonehenge, this ancient monument in southern England created an acoustic space that amplified voices and improved the sound of any music being played for people standing within the massive circle of stones, a study suggests.

Because of how the stones were placed, that speech or music would not have projected beyond Stonehenge into the surrounding countryside, or even to people standing near the stone circle, scientists report in the October *Journal of Archaeological Science*.

Acoustical engineer Trevor Cox and colleagues used laser scans of the site and archaeological evidence to construct a physical model one-twelfth the size of the actual monument. That was the largest possible scale replica that could fit inside an acoustic chamber at the University of Salford in England, where Cox works. This room simulated the acoustic effects of the open landscape surrounding Stonehenge and the compacted ground inside the monument.

Stonehenge Lego, as Cox dubbed the model, was assembled assuming that Stonehenge's outer circle of standing sarsen stones — a type of silcrete rock

found in southern England — had originally consisted of 30 stones. Stonehenge today includes 63 complete stones, including 17 standing sarsen stones in the outer circle. Based on an estimated total of 157 stones placed at the site around 4,200 years ago, the researchers 3-D printed 27 stones of all sizes and shapes. Then, the team used silicone molds of those items and plaster mixed with other materials to re-create the remaining 130 stones. Simulated stones were constructed to minimize sound absorption, much like actual stones at Stonehenge, Cox says.

Finally, the team placed speakers and microphones at various points inside and just outside Stonehenge Lego. Each speaker emitted chirping sounds that swept from low to high frequencies. Sound frequencies were modulated so that the speakers' sounds interacted with the model stones much as natural sounds behave at actual Stonehenge.

Despite many gaps between stones, sounds briefly lingered inside the model. Reverberation time, a measure of the time it takes sound to decay by 60 decibels, averaged about 0.6 seconds inside the model for midfrequency sounds. That effect would have boosted the ability

to hear voices and enhanced sounds of drums or other musical instruments, Cox says. For comparison, reverberation time is about 0.4 seconds in a living room, two seconds in a large concert hall and eight seconds in a large cathedral.

Stonehenge Lego did not project sounds into the surrounding area or boost the quality of sounds coming from external speakers. And sounds did not echo in the scale model. Inner groups of simulated stones obscured and scattered sounds reflected off the outer sarsen circle, blocking echo formation.

Previous research on Stonehenge's acoustics was incomplete, says Timothy Darvill, an archaeologist at Bournemouth University in England who has excavated at Stonehenge but did not participate in the new study. That work includes sound measurements taken at what remains of Stonehenge today and at a Stonehenge replica in Washington state made of concrete. Another acoustic study employed a computer model of the ancient site.

The new study was “carefully and rigorously done,” but questions remain about sonic effects, says Rupert Till, a musicologist at the University of Huddersfield in England who conducted some of the previous research. A wider range of acoustic measures is needed, for instance, to detect echo effects in the scale model that are also present at Stonehenge, Till argues. Further research also needs to untangle why “Stonehenge hums when the wind blows hard,” he says.

It's not known what, if any, ceremonies or activities occurred at Stonehenge. The site did serve as a cemetery between about 5,000 and 4,400 years ago. Cox cautions that designers of Stonehenge were likely less concerned about acoustics than about issues such as treatment of the dead and astronomical alignments.

Whatever people did at Stonehenge, the study “shows that sound was fairly well-contained within the monument and, by implication, [Stonehenge] was fairly well insulated from sounds coming in,” Darvill says. Hearing sounds of some kind circulating inside the monument “must have been one of the fundamental experiences of Stonehenge.” ■



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FEATURE

Antivenom production currently relies on a century-old method: Snakes like these saw-scaled vipers are milked for venom, which is injected into horses and other animals. Neutralizing antibodies produced by the horses are then harvested for bite victims.



Snakebite Solutions

Progress against snake venoms may prevent tens of thousands of life-changing injuries and deaths
By Christie Wilcox

When Nigerian physician Garba Iliyasu was 10, a venomous snake bit a family member. The man survived, but “it was quite severe,” Iliyasu recalls. “[He] was bleeding profusely... From the nose. From the mouth. From the ear.”

Since then, Iliyasu, a specialist in infectious and tropical diseases, has tended to hundreds of snakebite victims at Kaltungo General Hospital, a health care hub for the surrounding Gombe State. During the two annual peaks in snakebite cases — the spring planting and autumn harvest seasons — “we see like six, seven to 10 patients in a day, on average,” he says. The hospital has only a few dozen beds. “Most times, you see patients on the floor.”

In the Western world, snakebites are a minor issue. In the United States and Europe, cases are rare and hardly ever fatal. Even in Australia — notorious for its deadly, venomous snakes — bites account for just a handful of annual deaths.

But in sub-Saharan Africa, about 270,000 people are bitten every year, resulting in more than 55,000 cases of post-traumatic stress disorder, over 14,700 amputations and about 12,300 deaths, Iliyasu and colleagues estimated in *Toxicon* in March 2019. Add in India and other snakebite hot spots and the annual numbers rise to more than 2 million bites that need clinical treatment, according to the World Health Organization. Between 80,000 and 138,000 victims die, and about three times that number have a life-changing disability.

Snakebites are “a neglected disease that affects the neglected section of the society,” Iliyasu says. The worst effects occur in mostly poor, rural communities that depend on farming and herding. Visit these places, he says, and “you will see how devastating the effect of snakebite is.” Victims are often the primary breadwinners of their households, so every death and disability contributes to the cycle of poverty.

But snakebites are finally getting the attention they’ve long needed. In 2017, the WHO officially recognized snakebites as a neglected tropical disease. That designation has led to an influx of funding for innovative research; the largest, more than \$100 million, came in 2019 from the Wellcome Trust.

Effective snakebite treatments do exist, and those antivenoms are considered the “gold standard” of care. If a victim receives the right antivenom soon after a bite — within an hour or two — then the chances of survival are “very, very high,” says Nicholas Casewell, a biomedical scientist at the Liverpool School of Tropical Medicine in England.

But that “if” looms large, with big challenges remaining, including the difficulties of speedy access to care and the fact that most antivenoms work against just a few of the hundreds of dangerous species of venomous snakes. Antivenoms are also “a technology that has seen limited innovation for 120 years,” says Andreas Laustsen, a biotech researcher and entrepreneur at the Technical University of Denmark in Kongens Lyngby.

2.7

million

Venomous snakebites per year estimated worldwide

SOURCE: WHO



Left: A snakebite victim is in a coma and on dialysis to remove excess fluid and toxins from the blood. Right: Bit by a spitting cobra, this goat herder in Baringo County, Kenya, had to sell his herd to pay for treatment. Months later, the wound had not healed.

OPPOSITE: JEFF ROTMAN/ALAMY STOCK PHOTO; THIS PAGE, FROM LEFT: MEDICSHOTS/ALAMY STOCK PHOTO; N. CASEWELL

Now, researchers from disparate fields of science are coming together to reimagine the way snakebites are managed. Casewell, Laustsen and others are tweaking current treatments, repurposing pharmaceuticals and even engineering toxin-stopping nanoparticles. The work offers hope that people everywhere, even in remote areas, will eventually be able to safely coexist with snakes.

A tarnished gold standard

There's a saying in snakebite care that "time is tissue." The longer it takes to stop a snake's venom from moving through the victim's body, the more damage occurs. Destruction begins from the moment of a bite, and the cocktail of proteins and other molecules in the venom will continue to ravage until the immune system produces enough antibodies to remove or destroy those toxins. The problem is, by the time antibodies have ramped up, it's often too late.

The tissue maxim is especially true for bites from vipers and other snakes with venoms that target the blood and soft tissues and thus tend to cause more physical damage. But speed is also important for bites from snakes with paralytic venoms, such as the Indian cobra (*Naja naja*) and southern Africa's black mamba (*Dendroaspis polylepis*). Their nerve cell-targeting toxins will progressively slow muscles until the lungs and heart stop working.

That's where antivenoms come in. They speed

up the immune system's clearance of toxins, because antivenoms are, themselves, antibodies pulled from the blood of large animals, usually horses, that have been injected with venom. When given soon after a snakebite, antivenoms work well.

But for myriad reasons, fast delivery often doesn't happen.

In rural communities, there may be relatively few health care providers who can stock and administer the intravenously delivered drugs, which often require refrigeration. In India, for instance, the staff in rural public health clinics rarely have the resources or training to safely administer the drugs and monitor for treatment side effects.

Patients are often sent several hours away to larger regional hospitals with more expertise. "A lot of [bite victims] die on the way," says Kartik Sunagar, an evolutionary biologist at the Indian Institute of Science in Bangalore. Sunagar wrote about the challenges of developing antivenoms with Casewell, Laustsen and venom scientist Timothy Jackson of Liverpool in the August *Trends in Pharmacological Sciences*.

Once a patient arrives at a hospital, delays can still occur, Laustsen says, because medical staff wait until they're completely sure someone needs antivenom before administering it. A large portion of snakebites are "dry," which means no venom is injected, so antivenom isn't always required.

Deciding which antivenom to use can be difficult. To glom on to and remove toxic substances, antibodies need to match their target almost exactly. And since each snake species makes its own unique blend of toxins, most venoms need a specific antivenom. Because bite victims can rarely reliably identify the species that bit them, doctors must wait for clear signs of damage to emerge to determine the right antivenom.

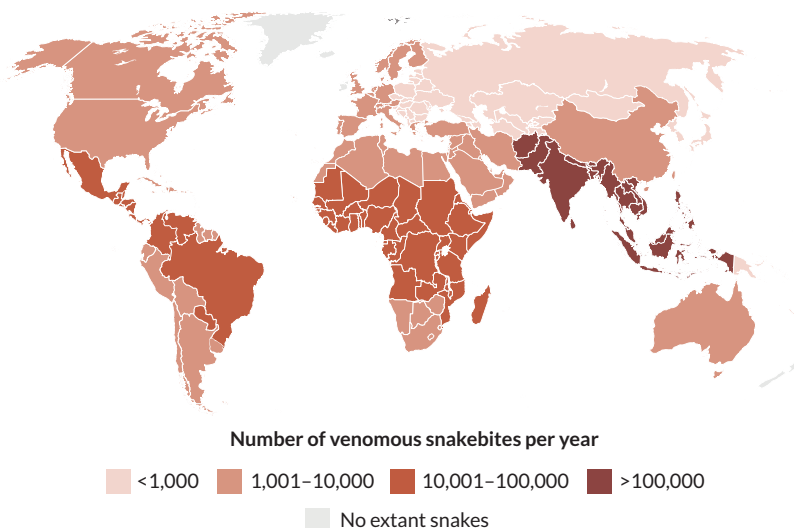
A "better safe than sorry" approach may seem warranted, but injecting antivenom when it's not needed or if it's the wrong kind can put the patient at even greater risk. As helpful as horse-derived antibodies can be, "the human immune system will recognize them as foreign," Laustsen notes, and may launch an attack. This reaction to the antivenom itself can be life-threatening if not treated promptly.

Friendlier options

For the last decade or so, researchers have been working to take horses out of the equation to make antivenoms safer — and maybe more affordable.

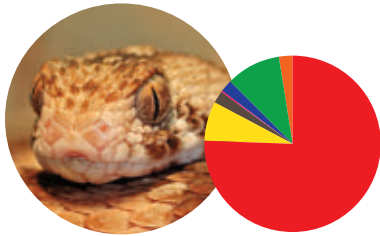
Clear danger Venomous snakebites, a neglected tropical disease, do the most damage in South and Southeast Asia, sub-Saharan Africa and parts of Central and South America. SOURCES: A. KASTURIRATNE ET AL/PLOS MEDICINE 2008; W. SURAWEEERA ET AL/ELIFE 2020

Global burden of venomous snakebites



Toxin groups found in snake venoms

Carpet viper (*Echis ocellatus*)



Russell's viper (*Daboia russelii*)



Toxin groups

- Snake venom metalloproteinases
- Snake venom serine proteases
- Phospholipase A2s
- L-amino acid oxidases
- Cysteine-rich secretory proteins
- Disintegrins
- Kunitz-type serine protease inhibitors
- C-type lectins
- Other

Toxin group name	Main molecular action	Potential effects on the body			
		Immune system	Blood	Tissue	Nervous system
Phospholipase A2s	Cut up certain fats	Intense inflammation (redness and swelling)	Bruising and bleeding	Muscle damage; kidney failure	Acute, intense pain; paralysis
Metalloproteinases	Cut up certain proteins	Painful swelling	Blood vessel damage; bruising and bleeding, especially internal	Skin blistering and visible wounds	Paralysis
Serine proteases	Cut up certain proteins	Mild, painful swelling	Bruising and bleeding, internal or external	No known effect	Mild pain
Three-finger toxins	Block or activate other proteins	No known effect	Bruising and bleeding, internal and external	Racing heart and cardiac arrest; visible wounds	Numbness; paralysis

Mixed bag Snake venoms often contain dozens to hundreds of individual toxins (two snakes' venom blends shown above), but most fall into recognizable groups. Four of the most common and pernicious groups and their toxic effects are listed at left. SOURCES: L.-O. ALBULESCU ET AL/BIORXIV.ORG 2020; C.R. FERRAZ ET AL/FRONTIERS IN ECOLOGY AND EVOLUTION 2019

Laustsen is exploring a couple of approaches to avoiding the body's reactions to horse-made antibodies.

One option is to produce "humanized" antibodies in the lab by replacing the ends of a human antibody gene with the venom-neutralizing parts from an effective equine antibody gene, so the patient's body wouldn't see the antibody proteins as foreign. But, even better, he hopes to discover effective fully human antibodies. With both approaches, he says, "you would remove at least 90 percent of all the side effects."

Taking horses out of the mix may also open the door for designing antibodies that work against venoms from more than a few species. Laustsen and colleagues described one promising approach July 1 in *Scientific Reports*. The key is to take human antibody genes and insert them into bacteria-infecting viruses, which build the antibodies into their shells.

Since large databases of human antibody genes already exist, a whole variety of different human antibodies can be inserted into viruses for high-

throughput testing to find antibodies that can bind to — and perhaps neutralize — venom toxins.

As a proof of concept, Laustsen's team tested 40 billion antibodies from people, and identified one particularly exciting candidate: It protected human cells in lab dishes from more than a dozen lethal toxins from three cobra species.

Once the most broadly effective antibodies are found, Laustsen hopes to copy a page from the insulin-production handbook. For diabetes treatment, insulin used to be extracted from the pancreases of animals; now, it's made by engineered bacteria in large fermentation tanks. A similar process could work to produce broad-spectrum antivenom, he says.

Moving antibody production out of animals could also have another important benefit: lower production costs. Right now, "antivenom is one of the most expensive drugs that you can find in the rural areas," explains Muhammad Hamza, a medical doctor who, like Ilyasu, splits his time between research at Nigeria's Aminu Kano Teaching Hospital and treating patients at the regional

treatment center in Gombe State. Many of Hamza’s patients could be saved by antivenom, he says, but they can’t afford to pay for it. If the government hasn’t kept the clinic stocked with free medicine, patients die.

In Nigeria, a vial of antivenom costs around \$60 to \$70, Iiyasu says. He’s seen patients sell their animals, homes and farms to pay for treatment.

Antivenoms engineered without animals would save patients money because the ideal mix of antibodies would be more potent. At least 70 percent of the antibodies in current antivenoms don’t neutralize venom toxins at all, Iiyasu notes. As a result, it often takes several vials of antivenom — sometimes as many as 10 — to treat a bite patient. Boosting the percentage of neutralizing antibodies in each vial would go a long way toward making antivenoms affordable, Iiyasu says — and that’s why he’s excited to see the move away from animal-based production.

A pill for snakebite

Other researchers are turning to existing drugs to expand options for snakebite treatments.

Venom toxins generally cause harm by performing specific molecular actions, such as cutting up certain proteins or fats within cells. Targeted molecules that interfere with that nefarious work could potentially stop the toxins.

The idea of using drugs other than antibodies to inhibit venom toxins isn’t new. But it wasn’t until

the molecular and genetic technology revolutions of the late 20th century that scientists could really deconstruct venoms to figure out which components are responsible for a venom’s worst effects. “We now have a very good handle on what the toxins are,” Casewell says.

It’s unlikely that one drug, or even a combination, would be able to neutralize the diversity of harmful toxins present in snake venoms and work as effectively as traditional antivenoms. But Casewell’s aim isn’t to replace antivenoms; he wants to safely slow down the most pernicious venom toxins to buy patients time to get to a clinic.

He and colleagues have so far focused on metalloproteinases — toxins that chop up proteins and are major players in the lethal and destructive nature of tissue-destroying venoms, such as those in saw-scaled vipers (*Echis* spp.). Casewell’s group picked a few drugs already on the market that bind up the metal ions that these proteinases need to function, and right off the bat, the drugs were surprisingly successful.

The group demonstrated that an existing small molecule drug used to treat heavy metal poisoning could reduce the deadly damage of viper bites in lab animals (*SN*: 6/6/20, p. 12). And when paired with another drug that inhibits a family of toxins that chew up certain fats, the drug was even more powerful. In animal tests, the combination neutralized the venoms of a more diverse collection of five snake species from all over the world.

The work is “quite exciting,” Casewell says, because it means small molecule drugs might be able to overcome the problem of geographic fragmentation — each venom needs its own antidote — that keeps antivenom markets too small and nonlucrative for pharmaceutical companies to invest in.

As a bonus, such small molecules are available in pill form and don’t need refrigeration or expert administration, making them easier to distribute in rural communities. In that way, such drugs could become an important “bridge to care,” Iiyasu says.

Next generation of treatments

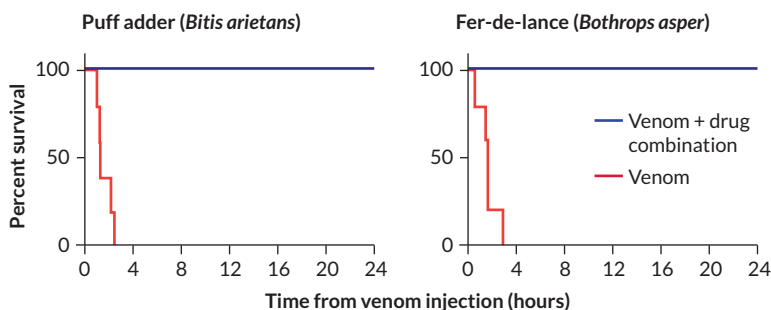
While pills alone may never be a stand-alone treatment for snakebites, there are other alternatives to conventional antivenoms, says Shih-Hui Lee of the University of California, Irvine. “We can use a polymer.”

Lee and colleague Kenneth Shea are new to the field of snakebite treatment. “We’re not snake

Drug duo Two drugs together — the PLA2 inhibitor varespladib, and the metallo-proteinase inhibitor marimastat — saved mice from lethal doses of five different snake venoms (results against two of the venoms shown below). Even when the drugs were given 15 minutes after the venom injection, the mice lived (blue lines). Mice that didn’t get the drugs died within four hours (red).

SOURCE: L.-O. ALBULESCU ET AL/BIORXIV.ORG 2020

Effect of two-drug combination in mice injected with snake venom



venom people,” Shea admits. They’re not even biologists. The two are materials scientists. But their approach to overhauling antivenom is so out of the box that it’s getting noticed.

Both spent much of their careers designing carbon polymers — essentially, plastic nanoparticles — with specific, desirable properties. After a while, the duo started to wonder if their designer plastics, which could bind to certain parts of proteins, could mimic the actions of antibodies.

Shea started with melittin, a bee venom toxin. To his surprise, the polymer nanoparticles worked. When injected into mice shortly after the injection of a life-threatening dose of melittin, the particles bound up enough of the toxin to save the animals’ lives, Shea and colleagues reported in the *Journal of the American Chemical Society* in 2010.

Those results helped him recruit Lee to the antivenom project and convince well-respected snakebite expert José María Gutiérrez of the University of Costa Rica in San José to collaborate. With his help, Shea and Lee set their sights on phospholipase A2s, a large family of toxins found in many deadly snake venoms.

Once again, Lee says, the polymer nanoparticles neutralized the toxins. In 2018, the particles proved effective against another family of snake toxins called three-finger toxins. The “plastic” antibodies saved mice from cobra venom, and healthy mice that received them had no adverse reactions, the team reported in *PLOS Neglected Tropical Diseases*.

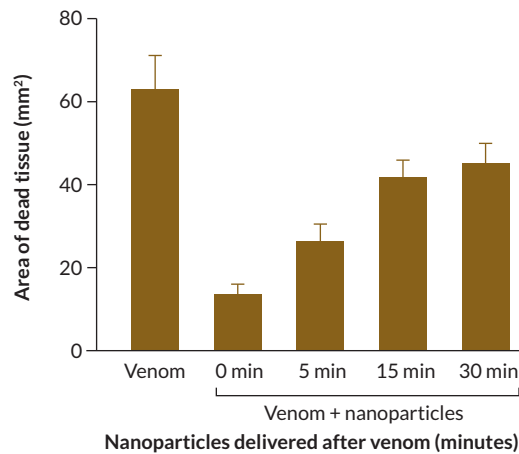
There are still some design challenges to overcome before testing the polymers in people. The team wants to put these synthetic antibodies into injectable devices — much like an EpiPen — but right now, the nanoparticles are probably too big. So the next hurdle is to make them smaller and more able to travel from the injection site in a muscle to the surrounding tissues.

But the biggest challenge is convincing funding agencies that synthetic antibodies should be on the table. The hesitancy is understandable, Shea says, as there’s nothing like these nanoparticles on the market. “This is untested, so there has to be an element of faith in this,” he says.

Still, Shea and Lee believe in their creation. Producing a broad-spectrum antivenom with the nanoparticles “is technically much less challenging” than with biological antibodies, Shea says, so if the team can secure investors, he thinks the nanoparticles have the potential to be “a quite cheap antidote.”

Others are stepping out of the box, as well.

Nanoparticles’ effect on tissue death in mice due to cobra venom



Thanks to the influx of funding in the last few years, researchers around the world are trying all sorts of unconventional approaches to snakebite remedies. There are labs hoping to design DNA molecules known as aptamers that act like antibodies. Others are turning to animals, such as opossums, that are naturally immune to venoms in the hopes of translating that immunity into new drugs. All of this work is leading to some truly exciting technological developments, Casewell says.

But none of it will matter if there aren’t also investments in infrastructure and education, Hamza warns. “It is one thing to have the drug... It’s another thing to get it available to the remotest parts of the world.”

He’s more excited about smartphone apps that could tell people in remote areas where the closest available antivenom is, for instance. And something as simple as providing farmers solid boots with instructions on when and why to wear them could prevent countless snakebites from happening in the first place.

With millions of snakebites occurring every year, there’s certainly many opportunities to improve the situation — and all of them need attention, Casewell says. That attention is finally coming. “This is kind of a once-in-a-lifetime moment for snakebites,” he says. ■

Explore more

- Robert A. Harrison *et al.* “The time is now: a call for action to translate recent momentum on tackling tropical snakebite into sustained benefit for victims.” *Transactions of the Royal Society of Tropical Medicine and Hygiene*. December 1, 2019.

Cobra combat

When tested in mice, synthetic nanoparticle antibodies prevented skin tissue death caused by black-necked spitting cobra venom. The nanoparticles were most effective when injected into the wound right after the venom was injected (0 min); the longer the wait, the larger the wound. SOURCE: J. O’BRIEN ET AL./PLOS NEGLECTED TROPICAL DISEASES 2018

FEATURE

Did Life

Begin in a
Place Like
This?



The answer could guide the search for signs of life in other parts of the solar system **By Jack J. Lee**

At Bumpass Hell in California's Lassen Volcanic National Park, the ground is literally boiling, and the aroma of rotten eggs fills the air. Gas bubbles rise through puddles of mud, producing goopy popping sounds. Jets of scorching-hot steam blast from vents in the earth. The fearsome site was named for the cowboy Kendall Bumpass, who in 1865 got too close and stepped through the thin crust. Boiling, acidic water burned his leg so badly that it had to be amputated.

Some scientists contend that life on our planet arose in such seemingly inhospitable conditions. Long before creatures roamed the Earth, hot springs like Bumpass Hell may have promoted chemical reactions that linked together simple molecules in a first step toward complexity. Other scientists, however, place the starting point for Earth's life underwater, at the deep hydrothermal vents where heated, mineral-rich water billows from cracks in the ocean floor.

As researchers study and debate where and how life on Earth first ignited, their findings offer an important bonus. Understanding the origins of life on this planet could offer hints about where to search for life elsewhere, says Natalie Batalha, an astrophysicist at the University of California, Santa Cruz. "It has very significant implications for the future of space exploration." Chemist Wenonah Vercootere agrees. "The rules of physics are the same throughout the whole universe," says Vercootere, of NASA's Ames Research Center in Moffett Field, Calif. "So what is there to say that the rules of biology do not also carry through and are in place and active in the whole universe?"

Lure of the land

At its biochemical core, the recipe for life relies on only a few ingredients: chemical elements, water or other media where chemical reactions can occur and an energy source to power those reactions. On Earth, all of those ingredients exist at terrestrial hot springs, home to some hardy creatures. Great Boiling Spring in Nevada, for example, is

a scalding 77° Celsius, yet microbes manage to eke out an existence in water near the spring's clay banks, researchers reported in 2016 in *Nature Communications*. Such conditions may reflect what it was like on early Earth, so these life-forms are most likely "related to some of the organisms that were originally on this planet," says Jennifer Pett-Ridge, a microbial ecologist at Lawrence Livermore National Laboratory in California.

Microorganisms at hot springs can form communities called microbial mats. Made up of layers of microbes, mats have been found in geothermal areas all over the world, including in Yellowstone National Park, the Garga hot spring in southern Russia and Lassen — home to Bumpass Hell.

Over time, microbial mats can form into stromatolites, structures of microbes and minerals that have accumulated

on top of one another; the layered appearance of a stromatolite reflects the passage of time, like a tree's growth rings. Researchers found evidence of stromatolites in the Dresser Formation, a 3.5-billion-year-old rock feature in the Western Australia outback, along with evidence of hot spring mineral deposits, describing the findings in 2017 in *Nature*

Communications. These findings, plus other signs of past microbes, led the team to suggest that some of the earliest life on Earth flourished in a hot spring environment.

David Deamer, a biophysicist at UC Santa Cruz, has spent four and a half decades exploring how life on our planet may have begun. He started out studying lipids, oily molecules that make up the membranes surrounding cells. Deamer, a big proponent of hot springs as the source of life's start, has shown that conditions at terrestrial hot springs can produce bubblelike vesicles, with an outer layer made up of lipids. Such structures may have been the ancestral precursors of modern-day cells (*SN*: 7/3/10, p. 22).

Bruce Damer, an astrobiologist at UC Santa Cruz who brings a computer science approach to questions about the origins of life, worked with Deamer to test whether conditions at hot springs

"The rules of physics are the same throughout the whole universe. So what is there to say that the rules of biology do not also carry through and are in place and active in the whole universe?"

WENONAH VERCOOTERE

Hot springs, like those at Lassen Volcanic National Park's Bumpass Hell in California (left), provide conditions that may have supported life as it began on Earth.

BLAKE SMITH



Bláhver hot spring — Iceland



Hells Gate — New Zealand



Bumpass Hell — California



In February, astrobiologists Bruce Damer and Luke Steller (shown) performed wet-dry cycling experiments in acidic hot spring pools at Hells Gate in New Zealand.

could drive condensation reactions, which join two molecules into one larger composite.

When water splashes out of a hot spring and evaporates, molecules that were in the liquid could undergo condensation reactions and link up. A subsequent splash would add more molecules that could undergo additional condensation reactions as liquid dries again. Repeated rounds of wetting and drying could produce chains of molecules.

In 2018, Damer set up shop at an active geothermal area in New Zealand, named along the usual theme — Hells Gate — to test that hypothesis. He prepared vials with ingredients needed to assemble strands of RNA, a nucleic acid that acts as a messenger during protein synthesis and may have catalyzed chemical reactions involved in the origins of life on early Earth (*SN: 4/10/04, p. 232*). The concoction included two of the four RNA building blocks — the nucleotides that link together to form RNA chains.

Damer stood the open vials in a metal block, roughly the size of two CD cases stacked together, and set the contraption into a near-boiling hydrothermal pool. To simulate the sometimes-wet, sometimes-dry burbling of the primordial Earth, Damer squirted acidic hot spring water into the vials, let them dry out and then repeated the wet-dry cycle several more times. When he brought the vials back to the lab, he found that they contained RNA-like strands that were 100 to 200 nucleotides long.

These results, reported in December 2019 in *Astrobiology*, indicate that complex molecules can form at hot springs, supporting the hypothesis that life on Earth may have developed in such an environment. In 2020, Damer returned to Hells Gate with Deamer and colleagues to confirm Damer's results and do more wet-dry cycling studies.

Cycles of wetting and drying, thought to promote the assembly of biomolecules, can happen at the edges of geothermal pools, such as Bláhver hot spring in Iceland, Hells Gate in New Zealand and California's Bumpass Hell.

CLOCKWISE FROM TOP LEFT: IMAGEBROKER/ALAMY STOCK PHOTO; B. DAMER; JOSHUA HAWLEY/ISTOCK/GETTY IMAGES PLUS; JOE BENNING/ALAMY STOCK PHOTO



NASA's Laurie Barge simulates an alkaline hydrothermal vent in an acidic ocean to explore the chemistry of ancient oceans. The conditions produce chimney structures (left) similar to the limestone chimneys found at the Atlantic Ocean's Lost City (right). The chemistry of these vents supports microbial life.



Nicholas Hud, a chemist at Georgia Tech in Atlanta, studies the origins of life from a slightly different perspective: He explores how DNA and RNA nucleotides originated. He agrees that molecules are more likely to link together by condensation reactions on land, where wet-dry cycles can occur, than in the ocean. These reactions produce water; the formation of such a chemical bond isn't energetically favorable when there's already a lot of water around. "The best place to form that is in a hot, dry place," Hud says. "The worst place to form it is in a wet, hot place."

Underwater visions

Yet, wet, hot environs are just the place for life to originate, other evidence suggests. At hydrothermal vents on the deep, dark ocean floor, heated water spews into seawater that's just a few degrees Celsius above freezing (*SN*: 7/23/16, p. 8).

In 2017, researchers found fossils in 3.77-billion-year-old rocks from Quebec that originated from the ancient ocean floor and had signs of hydrothermal activity (*SN*: 4/1/17, p. 6). The researchers claim that the distinct structures resemble those of microbes, suggesting that deep-sea environments may have supported some of the earliest life on Earth.

These environments can be extreme: Some vents belch dark plumes of water as hot as 400° C. However, if vents played a role in nurturing early forms of life, it likely happened at milder vents. For example, Lost City is a hydrothermal area in the middle of the Atlantic Ocean where the fluid streaming from vents ranges in temperature from 40° to 90° C. The region is named for dramatic limestone chimneys that rise as much as 60 meters above the seafloor.

These spires are home to microbes that feed

off the products of a chemical reaction known as serpentinization. "Hydrothermal vents are interesting because they are at the interface of water and rock," says astrophysicist Laurie Barge of NASA's Jet Propulsion Laboratory in Pasadena, Calif.

A chemical reaction between water and rock at sites like Lost City makes the water coming out of vents more alkaline than the water in the ocean, which has a higher concentration of positively charged hydrogen ions. The resulting gradient from alkaline to more acidic water is like the difference between the positive and negative ends of a battery and can serve as an energy source for chemical activity.

To study the conditions at underwater vents, Barge creates simulated environments in the lab that, she says, "can mimic what you see in the natural world." To represent an ocean on early Earth, she fills an inverted glass bottle with an acidic mixture containing iron but no oxygen. One end of a plastic tube pokes through the narrow end of the bottle, connected to a steady supply of a basic, or alkaline, solution just like a vent.

When Barge and colleagues injected an alkaline vent solution containing RNA nucleotides into an ocean-simulating bottle, individual RNA nucleotides linked up into short chains. These strands were only three or four nucleotides long, but the results suggest that the conditions at deep-sea vents could have supported reactions that led to the emergence of life on Earth, the researchers proposed in 2015 in *Astrobiology*.

Problems with both

To Deamer, there are big barriers to putting life's pieces together near underwater vents: The vastness of the ocean would dilute molecules so they wouldn't be concentrated enough to drive chemical



Plumes of water vapor, plus compounds containing carbon, nitrogen and oxygen, spew from the frozen surface of Enceladus, a moon of Saturn, as captured by NASA's Cassini spacecraft. Hydrogen in the plumes is evidence of hydrothermal activity in the ocean beneath the ice, similar to deep-sea vents on Earth.

"I think we have to admit that there might be more than one little torturous path that might have been traversed in order for life to begin."

DAVID DES MARAIS

reactions. Also, there are "no wet-dry cycles underwater." In his view, repeated evaporation is needed to pull together enough molecules to bump into each other and react to form longer chains. Plus, unlike a hot spring's freshwater, salty ocean water inhibits the formation of membranes and reactions that link together molecules, he says.

However, Deamer's hot springs theory has its critics as well. DNA and RNA strands are composed of alternating phosphate and sugar molecules, but sugars "are profoundly unstable in hot spring environments," says David Des Marais, an astrobiologist at NASA's Ames Research Center.

And it may be too soon to rule out wet-dry cycles underwater. "You can have a little bit of water get stuck in a pore," says Bill Brazelton, a marine microbiologist at the University of Utah in Salt Lake City. And then, because the serpentinization reaction at a vent uses up water in making other molecules, "you can have these cycles of dehydration inside a rock underneath the ocean."

It may be impossible to nail down how life truly began on Earth: Most geologic records of what actually happened during Earth's earliest days have long disappeared. There are numerous alternative hypotheses for where life began, beyond terrestrial hot springs and deep-sea vents. Recent research, for example, suggests that asteroid impacts could have sent superheated seawater into the crust to produce hydrothermal systems resembling hot springs (*SN: 7/4/20, p. 10*).

"I think we have to admit that there might be more than one little torturous path that might have been traversed in order for life to begin," Des Marais says.

Life beyond Earth

Researchers are using what they've learned about how and where life may have originated on Earth to guide the search for biological signatures beyond our planet. There are several promising locales in our solar system.

"One of the things that NASA is really interested in knowing is whether or not there could be life in the subsurface oceans of the icy moons, like Europa and Enceladus," says Batalha, of UC Santa Cruz. Scientists have evidence that the two moons, one orbiting Jupiter and the other, Saturn, have oceans of salty, liquid water beneath their icy shells (*SN Online: 6/14/19*).

These moons are intriguing because, along with liquid water, both have plumes of water erupting from their surfaces (*SN: 6/9/18, p. 11*), suggesting ongoing hydrothermal activity. NASA's Cassini space probe even identified compounds containing carbon, nitrogen and oxygen within Enceladus' plumes, some of the ingredients of amino acids, the building blocks of proteins. Europa and Enceladus fascinate astronomers because activity on their ocean floors may resemble the hydrothermal vents found on our own planet and may provide the chemical conditions to support life (*SN: 4/18/15, p. 10*).

Icy moons may also promote condensation reactions. "Even if you were on an icy moon, you might have ... freezing and thawing of ice," Barge says. "So, I think it's important to say, if wet-dry cycling is important, then we should look for any environment in the solar system that might be able to promote oscillating conditions of dehydration."

But to find signs of past life, Damer and Deamer believe Mars is a more promising place to look. Mineral deposits indicate the presence of hot springs and hydrothermal activity in the planet's past, which would have sustained the wetting and drying cycles that the two researchers see as crucial for condensation reactions to get life going.

Missions to the Red Planet are already under way. NASA's Perseverance rover will be searching for signs of ancient life, such as telltale minerals in rock samples, at Mars' Jezero crater when the mission lands in February 2021 (*SN: 7/4/20 & 7/18/20, p. 30*). Though at least 54.6 million kilometers separate them, Mars and Bumpass Hell may not be so different. ■

Explore more

- Bruce Damer and David Deamer. "The hot spring hypothesis for an origin of life." *Astrobiology*. April 2020.



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Schrödinger's Web
Jonathan P. Dowling
CRC PRESS, \$40.95

BOOKSHELF

A physicist previews the quantum internet

When news broke last year that Google's quantum computer Sycamore had performed a calculation faster than the fastest supercomputers could (*SN*: 12/21/19 & 1/4/20, p. 29), it was the first time many people had ever heard of a quantum computer.

Quantum computers, which harness the strange probabilities of quantum mechanics, may prove revolutionary. They have the potential to achieve an exponential speedup over their classical counterparts, at least when it comes to solving some problems. But for now, these computers are still in their infancy, useful for only a few applications, just as the first digital computers were in the 1940s. So isn't a book about the communications network that will link quantum computers — the quantum internet — more than a little ahead of itself?

Surprisingly, no. As theoretical physicist Jonathan Dowling makes clear in *Schrödinger's Web*, early versions of the quantum internet are here already — for example, quantum communication has been taking place between Beijing and Shanghai via fiber-optic cables since 2016 — and more are coming fast. So now is the perfect time to read up.

Dowling, who helped found the U.S. government's quantum computing program in the 1990s, is the perfect guide. Armed with a seemingly endless supply of outrageous anecdotes, memorable analogies, puns and quips, he makes the thorny theoretical details of the quantum internet both entertaining and accessible.

Readers wanting to dive right in to details of the quantum internet will have to be patient. "Photons are the particles that will power the quantum internet, so we had better be sure we know what the heck they are," Dowling writes. Accordingly, the first third of the book is a historical overview of light, from Newton's 17th century idea of light as "corpuscles" to experiments probing the quantum reality of photons, or particles of light, in the late 20th century. There are some small historical inaccuracies — the section on the Danish physicist Hans Christian Ørsted repeats an apocryphal tale about his "serendipitous" discovery of the link between electricity and magnetism — and the footnotes rely too much on Wikipedia. But Dowling accomplishes what he sets out to do: Help readers develop an understanding of the quantum nature of light.

Like Dowling's 2013 book on quantum computers, *Schrödinger's Killer App*, *Schrödinger's Web* hammers home the nonintuitive truths at the heart of quantum mechanics.

Early versions of the quantum internet are here already, and more are coming fast. So now is the perfect time to read up.

For example, key to the quantum internet is entanglement — that "spooky action at a distance" in which particles are linked across time and space, and measuring the properties of one particle instantly reveals the other's properties. Two photons, for instance, can be entangled so they always have the opposite polarization, or angle of oscillation.

In the future, a user in New York could entangle two photons and then send one along a fiber-optic cable to San Francisco, where it would be received by a quantum computer. Because these photons are entangled, measuring the New York photon's polarization would instantly reveal the San Francisco photon's polarization. This strange reality of entanglement is what the quantum internet exploits for neat features, such as unhackable security; any eavesdropper would mess up the delicate entanglement and be revealed.

While his previous book contains more detailed explanations of quantum mechanics, Dowling still finds amusing new analogies, such as "Fuzz Lightyear," a canine that runs along a superposition, or quantum combination, of two paths into neighbors' yards. Fuzz helps explain physicist John Wheeler's delayed-choice experiment, which illustrates the uncertainty, unreality and nonlocality of the quantum world. Fuzz's path is random, the dog doesn't exist on one path until we measure him, and measuring one path seems to instantly affect which yard Fuzz enters even if he's light-years away.

The complexities of the quantum web are saved for last, and even with Dowling's help, the details are not for the faint of heart. Readers will learn how to prepare Bell tests to check that a system of particles is entangled (*SN*: 9/19/15, p. 12), navigate bureaucracy in the Department of Defense and send unhackable quantum communications with the dryly named BB84 and E91 protocols. Dowling also goes over some recent milestones in the development of a quantum internet, such as the 2017 quantum-secured videocall between scientists in China and Austria via satellite (*SN*: 10/28/17, p. 14).

"Just like the classical internet, we really won't figure out what the quantum internet is useful for until it is up and running," Dowling writes, so people can start "playing around with it." Some of his prognostications seem improbable. Will people really have quantum computers on their phones and exchange entangled photons across the quantum internet?

Dowling died unexpectedly in June at age 65, before he could see this future come to fruition. Once when I interviewed him, he invoked Arthur C. Clarke's first law to justify why he thought another esteemed scientist was wrong. "The first law is that if a distinguished, elderly scientist tells you something is possible, he's very likely right," he said. "If he tells you something is impossible, he's very likely wrong."

Dowling died too soon to be considered elderly, but he was distinguished, and *Schrödinger's Web* lays out a powerful case for the possibility of a quantum internet. — *Dan Garisto*

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△

Tahnee Harrell unpacks equipment funded by a STEM Research Grant from the Society. Equipment from grants like hers can be used to enhance student learning through at-home research.



△

Ruth Amos, an alumna of the Society's International Science and Engineering Fair, built a platform that raises up through the roof of a car.



△

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AUGUST 15, 2020

Birds of a fossil feather

Four-winged Microraptor, perhaps one of the earliest flying dinosaurs, may have molted just a bit at a time — similar to modern songbirds, Carolyn Gramling reported in “Dinosaur shed feathers bit by bit” (SN: 8/15/20, p. 12).

Reader **Jan Voelker** asked if the dinosaur may somehow be related to the pileated woodpecker.

It’s hard to say just how closely related *Microraptor* might have been to woodpecker ancestors, **Gramling** says. Woodpeckers, along with toucans and honeyguides, belong to a biological order called Piciformes. “The evolutionary origins of the Piciformes are still quite murky,” she says. “There just isn’t a whole lot in the fossil record about their ancestors, although there are fossils of modern-looking Piciformes dating as far back as the Oligocene Epoch, which spanned 33.9 million to 23 million years ago.” But Piciformes are members of Aves, the biological class that includes all modern birds and that evolved from small feathered dinosaurs living during the Mesozoic Era, 252 million to 66 million years ago. *Microraptor*, which lived some 120 million years ago alongside ancient birds, is distantly related to Aves.

Eyes on the sky

A new X-ray map of the entire sky looks deeper into space than any other X-ray map, Maria Temming reported in “Marvel at the most comprehensive X-ray map of the sky yet” (SN: 8/15/20, p. 30).

Reader **Bob Garfield** wondered how the image was made. “Is this a composite of a complete, 360-degree image of the sky or is the device looking in one general direction?” **Garfield** asked.

It’s a composite image of the entire sky, **Temming** says. “The telescope rotates continually to look at each point in the sky for 150 to 200 seconds on average and then moves on. Scientists stretch out the spherical view of the whole sky into this distended, ellipse-type shape so you can see it all at once on a 2-D surface,” she says.

Old dog, new math

A new formula for converting a dog’s age into human years is based on a comparative study of biological aging in Labrador retrievers and people, Bethany Brookshire reported in “Calculating a dog’s age takes a bit more math” (SN: 8/15/20, p. 5).

Reader **Sue Jordan** wondered how old her 13-year-old dog, a male black Lab and border collie mix, would be in human years according to the new equation.

“He’s around 72 years old in human years,” **Brookshire** says. “Keep in mind that the study doesn’t apply fully to all dogs, as it was done only in Labrador retrievers.” Collies and Labs might age at different rates. “As scientists do more of these comparisons, they will probably come up with different equations for different breeds,” she says.

“That 72 is a rough estimate; no one can say exactly how old your pup is in human years. But no matter what, I bet he’s great,” **Brookshire** says.

On the clock

A theoretical universal cosmic clock that may beget time must tick faster than a billion trillion trillion times per second, Emily Conover reported in “A cosmic clock would tick fast” (SN: 8/15/20, p. 9).

Reader **Lou Puls** wondered if the limitation on the rate at which the fundamental clock might tick could explain the arrow of time, or the idea that the total entropy (or disorder) in the universe can only increase over time.

That’s a good question, **Conover** says. “When I interviewed physicist Martin Bojowald of Penn State for this study, I asked him the same thing. Sadly, he said that, at the moment, there’s no connection. It seems there’s no way to explain the arrow of time with this fundamental clock. At least, not yet,” she says.

Correction

The x-axis of the graph in “Methane pollution soars to new highs” (SN: 8/15/20, p. 8) was incorrectly labeled. Instead of “metric tons per year,” it should say “million metric tons per year.”

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Toy boats defy gravity by floating upside down

Going bottom-up is no problem for a boat on the underside of levitated liquid.

In a container, liquid can be levitated over a layer of gas by shaking the container up and down. The repeated, upward jerking motion keeps fluid from dripping into the air below. Lab experiments have revealed a curious consequence of this antigravity effect: Objects can float along the bottom of the levitated liquid as well as along the top, researchers report in the Sept. 3 *Nature*.

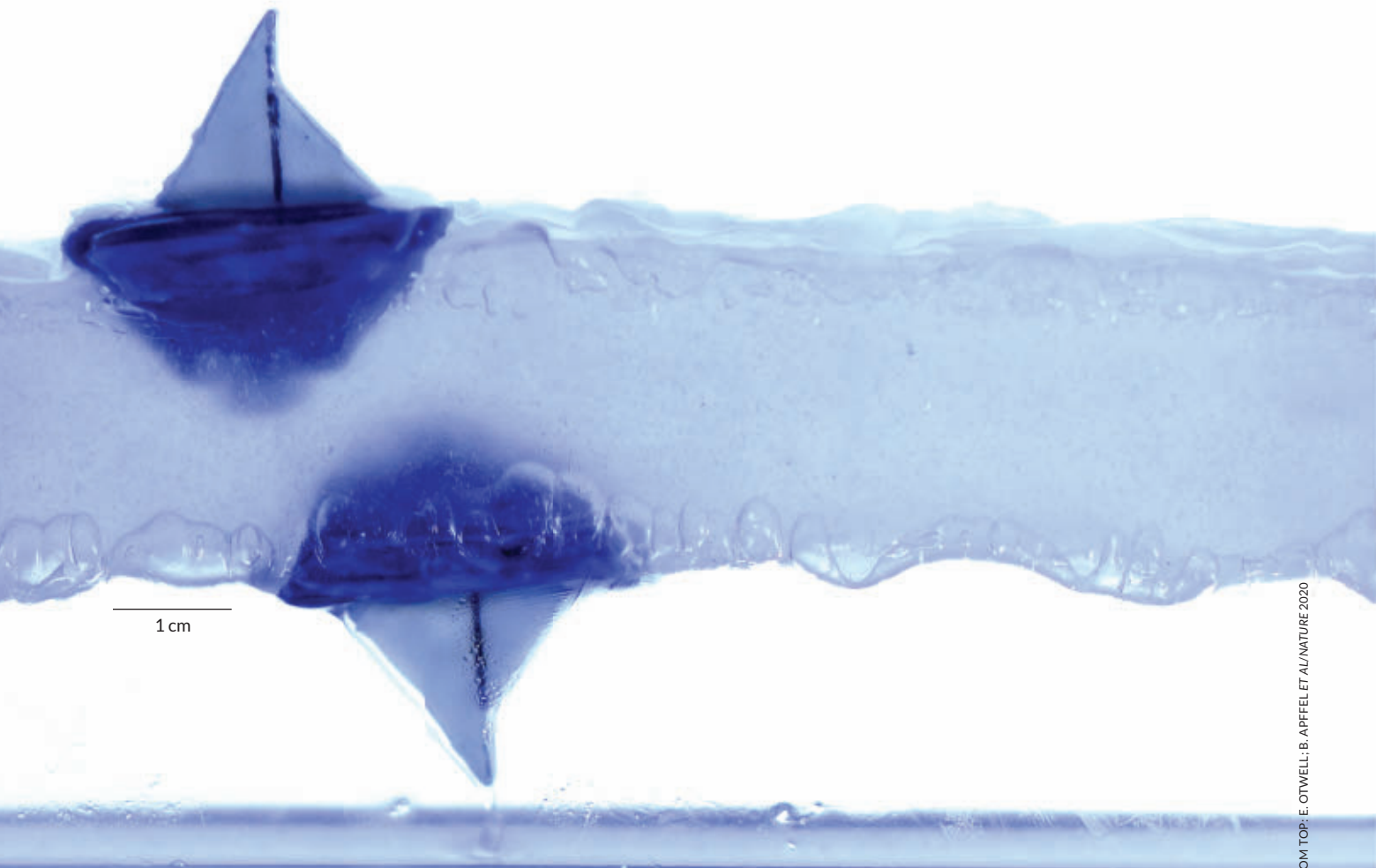
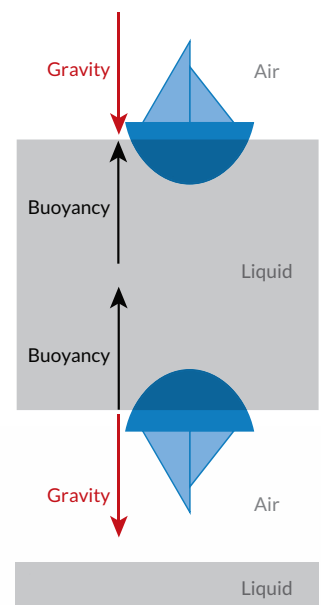
Physicist Emmanuel Fort of the École Supérieure de Physique et de Chimie Industrielles in Paris and colleagues observed this effect (shown below) by injecting a layer of gas underneath either silicone oil or glycerol and shaking the container that held the substances. The researchers used these thick liquids because keeping fluids aloft requires vigorous shaking, and a layer of a runny liquid like water would slosh apart more easily.

Toy boats bobbed along the bottom of the levitated liquid because, like boats floating right-side up along the top, the toys were partially submerged. Any object submerged in a liquid experiences a skyward, buoyant force whose strength depends on the amount of space an object takes up in the liquid. That physical law was discovered by the ancient Greek mathematician and inventor Archimedes.

So if the right amount of the upside-down boat is submerged, the team found, that upward force is strong enough to counteract gravity pulling the boat down (illustrated at right). As a result, the boat floats. Bet Archimedes didn't see that coming.

— *Maria Temming*

Buoyancy explains how a top-down boat floats on levitated liquid





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