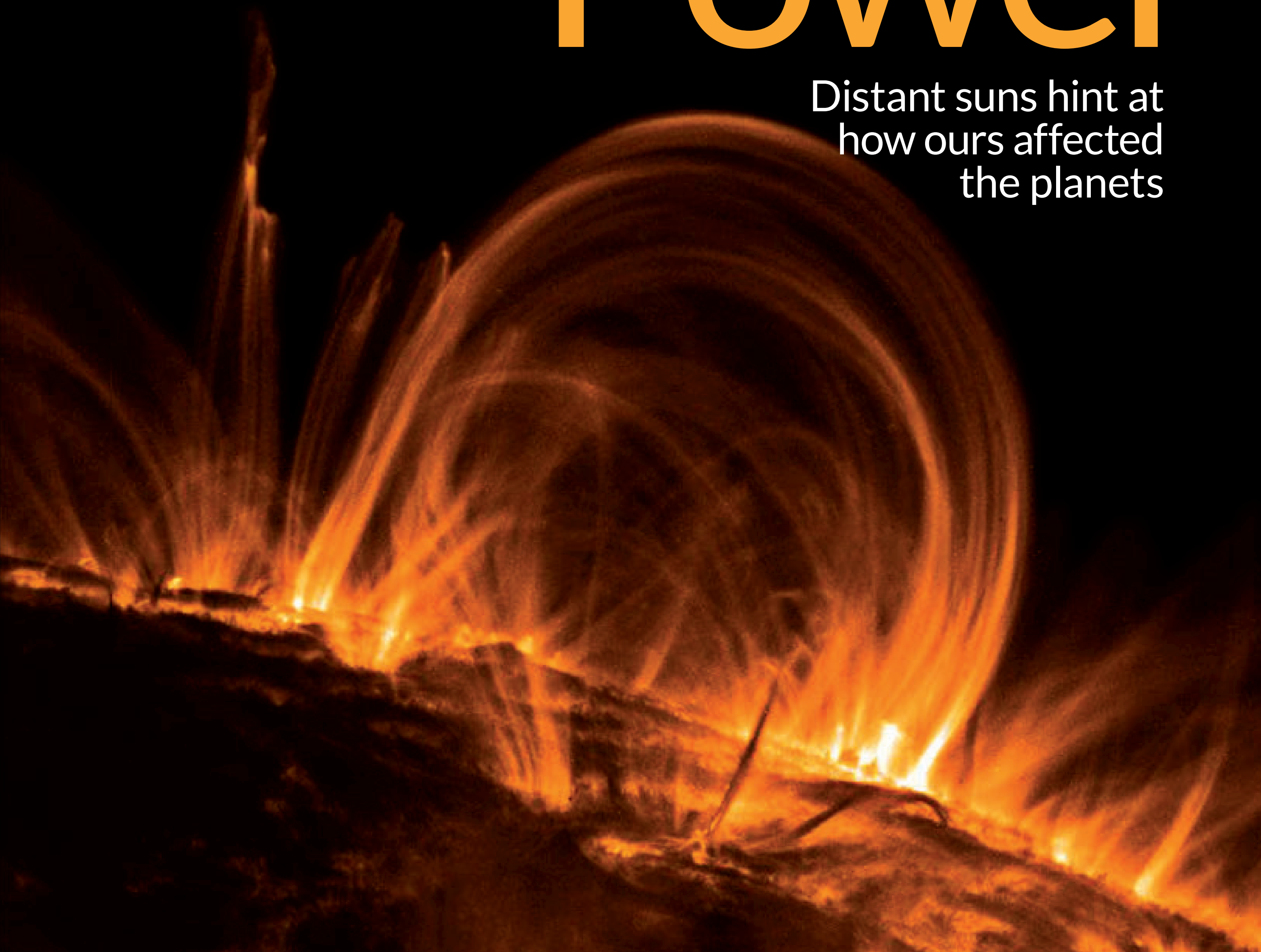
The Face of an Early Hominid | Carbon Nanotube Computer Chips

Science News

MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC ■ SEPTEMBER 28, 2019

Star Power

Distant suns hint at how ours affected the planets



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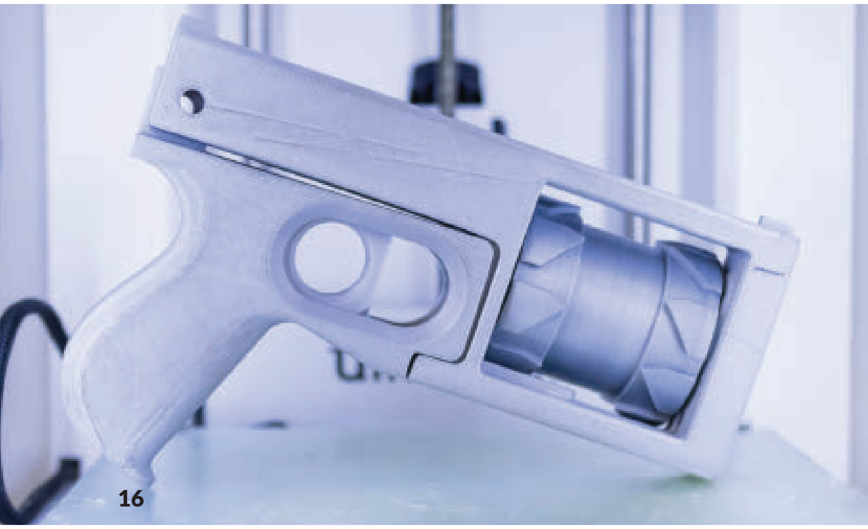
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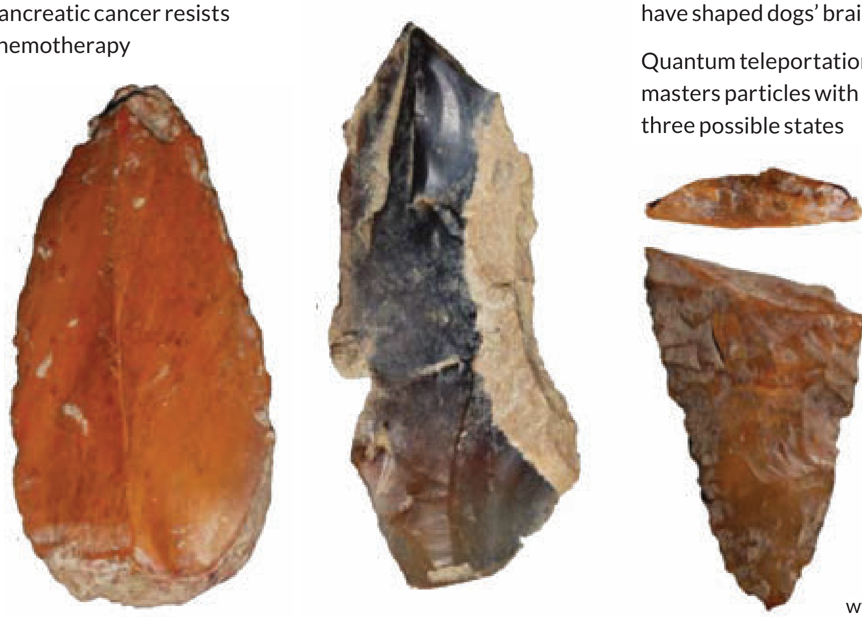
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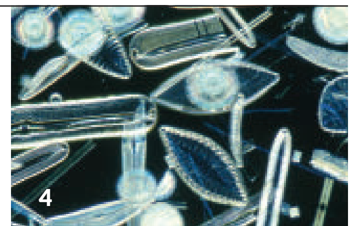
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Departments

COVER Flares and loops of high-energy light burst from the sun (shown), as well as other stars.
M. Aschwanden et al, LMSAL, TRACE, NASA

FROM TOP: MEGAN WOLFE/UNIV. OF MISSISSIPPI; M.I. WALKER/SCIENCE SOURCE; L.G. DAVIS ET AL/*SCIENCE* 2019

Finding the stories and growing the next crop of science journalists

We get a lot of press releases about new research and products. But one recent missive caught our attention. It got us thinking about how handguns created by a 3-D printer could be used as a type of phantom gun, to evade traditional criminal investigations. We knew just the person to check it out: intern Carolyn Wilke.

Wilke recently graduated from Northwestern University in Evanston, Ill., with a Ph.D. in environmental engineering. She knew that 3-D printing has the potential to make all kinds of manufacturing, from medical devices to food, cheaper and more accessible.

But she was surprised to find out that some people are using the printers to make plastic guns that could skirt standard law enforcement techniques, and she was intrigued to learn how chemistry plays into this new area of ballistic forensics.

"You're always one step behind the people pushing the technology," she says. To keep up, "you really have to get into the lab."

Her article "Ghost Guns" (Page 16) details that work, with researchers in Mississippi and Lausanne, Switzerland, printing plastic handguns and firing them in the lab to identify the guns' chemical fingerprints. Fortunately, 3-D printed guns aren't in wide use, but the risk they pose illuminates the unintended effects of new technologies, and how scientists might respond.

Wilke's article is just one example of how interns help make *Science News*. Our interns work as professional journalists from the day they walk in the door, and they work hard. In return, we put a great deal of effort into helping them build skills, gain experience and learn about career options.

Over the years, many of our former interns have gone on to become leaders in science journalism, including Laura Helmuth, the *Washington Post* health, science and environment editor who is also on the board of Society for Science & the Public, our nonprofit publisher. A few other notables include Nadia Drake, contributing writer for *National Geographic*; science reporter Dan Vergano at BuzzFeed News; and William Broad, senior writer at the *New York Times*.

I'm always sad to see interns go, but I gain comfort knowing that I'll be able to watch them thrive and prosper for years to come. Fortunately, we'll have Wilke with us a bit longer. She's now working for *Science News for Students*, our news site for youth ages 9 and up, while staff writer Bethany Brookshire is on sabbatical as a Knight Science Journalism Fellow at MIT. When I asked Wilke why she decided to leave research for journalism, she had three words ready: "Love of learning." Rather than being an expert in one thing, she relishes being able to learn about many different fields of science.

That pretty much sums up what I love about journalism, and about covering science in particular. I learn something new every day, not just from sources but also from our writers, who know so much about so many things. Best of all, we get to share what we learn with you. *— Nancy Shute, Editor in Chief*

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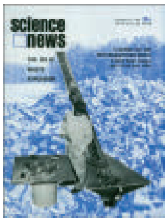


Excerpt from the September 27, 1969 issue of *Science News*

50 YEARS AGO

Pinning down the weed

New research hints that marijuana may have serious physiological effects.... The possibility that marijuana is teratogenic, causing damage to unborn children, is a specter that as yet cannot be put down.... [T]here is already some information indicating that THC readily crosses the placenta and enters the fetus.

UPDATE: Marijuana use by pregnant women is on the rise, with some using it to treat morning sickness. In a national survey of 4,000 pregnant women in the United States, marijuana use roughly doubled from 2002 to 2017, from 3.4 percent to 7 percent, researchers reported in the June 18 *JAMA*. In a different study in the same issue, self-reported marijuana use by pregnant women in Canada was linked to a greater risk of premature birth. A study in rats, presented in Orlando, Fla., at the Experimental Biology 2019 meeting in April, found that cannabis given to a pregnant rat may change the nerve connections in an offspring's hippocampus, a brain region that plays a role in learning and memory.

The odd biology of pufferfish (*Takifugu niphobles* shown) goes far beyond rapid swelling of a spiky belly.

IT'S ALIVE

Pufferfish are far more than goofy spiked balloons

For certain pufferfish, flirting on the sand of a moonlit beach is irresistible — never mind the need for water to live. When it's time to mate, hundreds of male grass pufferfish (*Takifugu niphobles*) and maybe one female will jump around on Asian shores. The males release sperm onto the watery sand, where a female discharges eggs. Waves then wash the fertilized eggs back to sea. But that's not the only way some of the 200 or so species in the puffer family take courtship to extremes.

NAME GAME

By Zeus! Newfound moons of Jupiter get names

Meet Jupiter's new moons. Five Jovian satellites reported in 2018 now have names, the International Astronomical Union announced August 26. Scientists found the moons when looking for a theoretical Planet Nine orbiting beyond Neptune (*SN: 8/18/18 & 9/1/18, p. 10*). The researchers solicited names in a Twitter contest, noting that the 79 known moons of Jupiter (planet shown) must be named for descendants or consorts of the Roman god Jupiter, or Zeus in Greek. Still, some people couldn't resist suggesting Moony McMoonFace. — *Lisa Grossman*

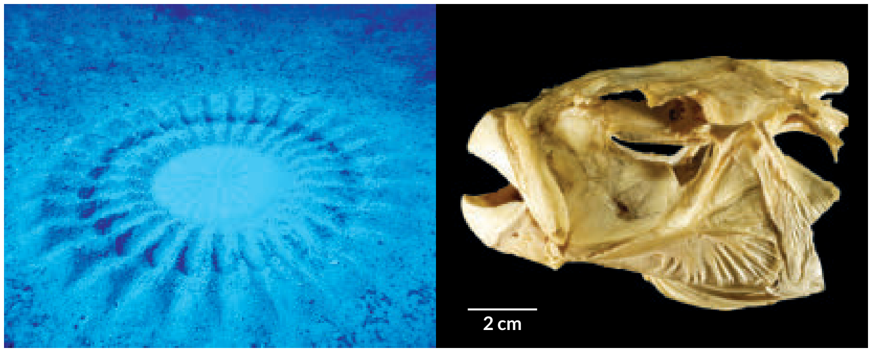
And the winning names are...

Pandia	A daughter of Zeus and the moon goddess Selene, Pandia is the goddess of the full moon. One of the groups to propose this name was the astronomy club of Lanivet Community Primary School in England, whose mascot is the similar-sounding panda.
Ersa	Sister of Pandia, Ersa is the goddess of dew. Several people suggested this name, including 4-year-old moon "expert" Walter, who got the judges' attention with a song listing the largest moons of the solar system in size order.
Eirene	The goddess of peace, Eirene is the daughter of Zeus and Themis, a Greek Titaness who personifies divine order, justice and law.
Philophrosyne	A granddaughter of Zeus, Philophrosyne is the spirit of welcome and kindness.
Eupheme	Sister of Philophrosyne, Eupheme is the spirit of praise and of good omens.

FROM TOP: G. FRASER; JPL-CALTECH/NASA, SWRI, MSSS, KEVIN M. GILL

Sand underwater holds allure as well. Males of a species not recognized until 2014 turned out to be the architects of mysterious underwater versions of crop circles. These white-spotted pufferfish (*Torquigener albomaculosus*) spend days plowing and fin flapping sand into great symmetrical rosettes as welcome mats for female visitors.

For some in the pufferfish family, though, courtship can be brutal. "Sometimes, the male will bite with these really sharp beaks on the abdomen of the females," says Gareth Fraser, an evolutionary developmental biologist at the University of Florida in Gainesville.

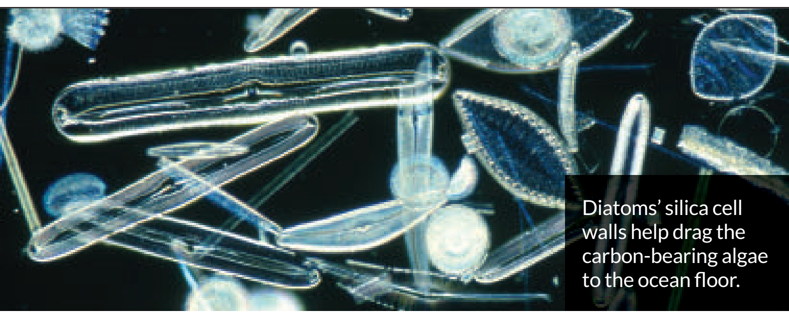


A species of *Torquigener* pufferfish spends days creating a decorative ring on the seafloor (left) to entice a mate. A side view of a *Monotrete* pufferfish head (right) reveals big teeth that chop prey.

It was those strange, parrotlike beaks that first nibbled Fraser's scientific curiosity. A baby puffer's first teeth seem unremarkably vertebrate, but as the young fish grows up, the rows of pointy bits give way to two big teeth that stretch sideways along each jaw. The result is a set of long, sharp-edged blades, with which adult puffers "can slice a fish in half and then feast on it," Fraser says. Aquarists need to feed their pufferfish plenty of hard-shelled mollusks to wear down the blades, or else trim them back with a fish version of a nail clipper. If the beaks overgrow, the fish can't eat.

In the catalog of intimidating body parts, pufferfish are perhaps best known for turning into spiky balls when outraged. These spines perk upright when puffers gulp water to balloon out their abdomens. Some of the same gene networks that put feathers on birds and hairs on mammals turn out to put the protective spines on puffers, Fraser and colleagues reported July 25 in *iScience*.

Those spines have evolved from the scales that covered distant fish ancestors. Between today's skinny spines, modern pufferfish are totally naked. Try not to stare. — *Susan Milius*



Diatoms' silica cell walls help drag the carbon-bearing algae to the ocean floor.

CLIMATE THREATS

Acidification puts carbon cycle at risk

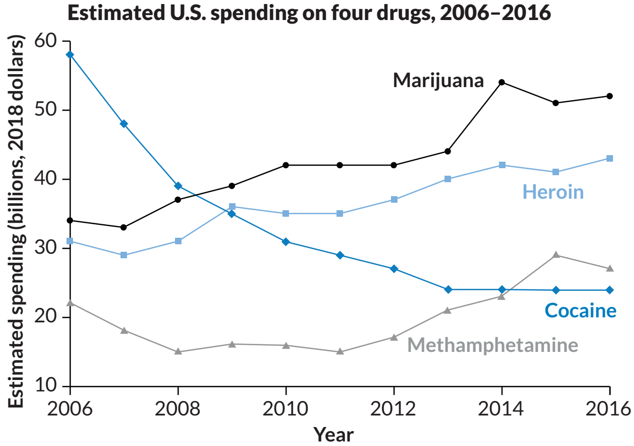
Blooms of microscopic algae known as diatoms act as a biological pump in the ocean, adding oxygen to the atmosphere and drawing carbon dioxide out. To protect against predators, diatoms build houses of glass — cell walls of silica. When diatoms die, the walls act as a ballast, and the creatures sink and sequester the carbon. But as oceans absorb CO_2 from the atmosphere (*SN: 6/8/19, p. 24*), they become more acidic. And that can slow the rate at which diatoms build their silica walls. Thinner walls mean lighter diatoms that are less likely to move carbon to the deep ocean, scientists report August 26 in *Nature Climate Change*. In the lab, diatoms made at least 60 percent less silica after 12 days in seawater with a pH of 7.45 than those in seawater with a pH of 8.1. Greenhouse gas emissions are now on track to cause the average ocean pH to drop from about 8.1 to about 7.8. — *Carolyn Gramling*

SCIENCE STATS

U.S. spending on marijuana and heroin is steadily on the rise

Drug use, often illicit, is hard to study. But an analysis of surveys, overdose records and other sources released August 20 by the Rand Corporation reveals some trends, including how much money is spent on drugs in the United States. While cocaine spending has fallen, marijuana outlays are up. Total spending on four top drugs can reach $146 billion a year. — *Carolyn Wilke*

Estimated U.S. spending on four drugs, 2006–2016



SOURCE: G. MIDGETTE *ET AL*/RAND CORPORATION 2019

CLOCKWISE FROM TOP LEFT: HIROSHI KAWASE; G.J. FRASER *ET AL*/*PNAS* 2012; E. OTWELL; M.I. WALKER/SCIENCE SOURCE

News

HUMANS & SOCIETY

Early hominid now has a face

Skull offers a fuller view of Lucy's possible ancestors

BY BRUCE BOWER

In a remarkable evolutionary windfall, fossil hunters have discovered neatly fitting halves of a nearly complete, 3.8-million-year-old hominid skull. This unexpected specimen shines some light on poorly understood early members of the human evolutionary family.

The skull, unearthed at Ethiopia's Woranso-Mille site, has been classified as *Australopithecus anamensis*. That species is the oldest known in a hominid genus that includes *A. afarensis*, known best for Lucy's 3.2-million-year-old skeleton.

Yohannes Haile-Selassie, a paleoanthropologist at the Cleveland Museum of Natural History, and colleagues describe the fossil in two papers published online August 28 in *Nature*.

"This specimen provides the first glimpse of the face of *Australopithecus anamensis*," Haile-Selassie said during an Aug. 27 news conference. The skull also includes the first good example of an *A. anamensis* braincase.

"This is the specimen we have been waiting for," says paleoanthropologist Carol Ward of the University of Missouri in Columbia, who was not part of the Woranso-Mille team.

Until now, fossils of *A. anamensis* consisted of partial upper and lower jaws, isolated teeth, a braincase fragment and lower-body bones. Those specimens, found in Kenya and Ethiopia, date to between 4.2 million and 3.9 million years ago.

Then, on February 10, 2016, a member of the Woranso-Mille team noticed the lower part of a hominid skull protruding from eroding sediment. Later that day, Haile-Selassie found the braincase about three meters away.

Geoscientist Beverly Saylor of Case Western Reserve University in Cleveland led an effort to date the fossil by estimating the ages of nearby volcanic rock layers and studying reversals of Earth's magnetic field recorded in the site's sediment.

A digital reconstruction of the skull helped establish its species. The braincase has some features, such as a long, narrow shape and a roughly chimpanzee-sized brain, similar to those of even older hominids such as *Sahelanthropus tchadensis* and *Ardipithecus ramidus*. But forward-projecting cheek bones recall those of some later hominids, such as 2.5-million-year-old *Paranthropus aethiopicus*. That species belonged to an African line of big-jawed, small-brained hominids that died out about 1 million years ago. It's hard to know if traits shared with *P. aethiopicus* arose independently or signal an evolutionary relationship.

Many of the Woranso-Mille skull's features differ from those of Lucy's kind, Haile-Selassie says. For instance, *A. anamensis* possessed a sloping face, unlike the flat faces of *A. afarensis*.

Crucially, the skull differs enough from a roughly 3.9-million-year-old hominid forehead bone discovered in East Africa in 1981 to assign that bone, known as the Belohdelie frontal, to *A. afarensis*, Haile-Selassie contends. If so, *A. anamensis* — now dating from 4.2 million to 3.8 million years ago — and Lucy's kind — dating from 3.9 million to 3 million years ago — overlapped for at least 100,000 years. That scenario contradicts the idea that *A. anamensis* evolved directly into Lucy's kind, with the earlier species disappearing as it morphed into its descendant species.

Instead, a large *A. anamensis* group might have become isolated from other members of its species and then evolved into an early version of *A. afarensis*, Haile-Selassie speculates. In that case, other *A. anamensis* groups would have coexisted for a while with Lucy's species.

While the new skull "fills a critical gap in *Australopithecus* evolution," the evolutionary status of the Belohdelie frontal remains unknown, says paleoanthropologist William Kimbel of Arizona State University's Institute of Human Origins in Tempe. More *A. anamensis* skulls are needed to assess whether the Belohdelie frontal has traits more typical of that species or of Lucy's, Kimbel says.

Paleoanthropologist Berhane Asfaw of Rift Valley Research Service in Addis Ababa, Ethiopia, agrees. Asfaw described the Belohdelie frontal in a 1987 paper. Frontal bone shapes vary considerably in Lucy's species, which includes four partial skulls, he says. "We don't know what kind of face the Belohdelie frontal had."

The Woranso-Mille skull highlights how little is known about the relationship between *A. anamensis* and Lucy's species, Ward says. ■

A 3.8-million-year-old fossil of an *Australopithecus anamensis* skull offers hints about what the hominid looked like (artist's reconstruction, right).

FROM LEFT: DALE OMORI/CLEVELAND MUSEUM OF NATURAL HISTORY; MATT CROW/CMNH, JOHN GURCHE

MATH & TECHNOLOGY

Computer chip milestone reached

Prototype's transistors are carbon nanotubes, not silicon

BY MARIA TEMMING

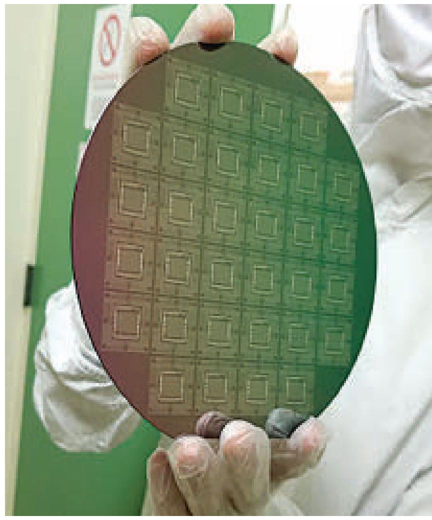
Inside a new microprocessor, the transistors — tiny electronic switches that collectively perform computations — are made with carbon nanotubes, rather than silicon. By devising techniques to overcome the nanoscale defects that often undermine individual carbon nanotube transistors, researchers have created the first computer chip that uses thousands of these switches to run programs.

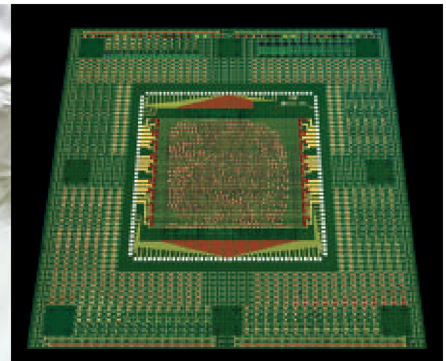
The prototype, described in the Aug. 29 *Nature*, is not as speedy or as small as commercial silicon devices. But carbon nanotube computer chips may ultimately give rise to a new generation of faster, more energy-efficient electronics.

This is "a very important milestone in the development of this technology," says Qing Cao, a materials scientist at the University of Illinois at Urbana-Champaign who was not involved in the work.

Generally, the heart of a transistor is a semiconductor component made of silicon, which can act either like an electrical conductor or an insulator. A transistor's "on" and "off" states, when current is flowing through the semiconductor or not, encode the 1s and 0s of computer data. By building leaner, meaner silicon transistors, "we used to get exponential gains in computing every single year," says Max Shulaker, an electrical engineer at MIT. But "now performance gains have started to level off," he says. Silicon transistors can't get much smaller and more efficient than they already are.

Because carbon nanotubes are almost atomically thin and ferry electricity so well, they make better semiconductors than silicon. In principle, carbon nanotube processors could run three times faster while consuming about one-third as much energy as their silicon predecessors, Shulaker says. But until now, carbon nanotubes have proved too finicky to construct complex computing systems.





Computer chips made with carbon nanotubes (an array of such chips on a wafer, at left; a single chip, above) could one day lead to faster, more energy-efficient electronics.

BOTH: G. HILLS *ET AL*/*NATURE* 2019

One issue is that when a network of carbon nanotubes is deposited onto a computer chip wafer, the tubes tend to bunch together in lumps that prevent the transistor from working. It's "like trying to build a brick patio with a giant boulder in the middle of it," Shulaker says. His team solved that problem by spreading nanotubes on a standard computer chip made of silicon, then using vibrations to gently shake unwanted bundles off the layer of nanotubes.

Another problem the team faced is that each batch of semiconducting carbon nanotubes contains about 0.01 percent metallic nanotubes. Because metallic nanotubes can't properly flip between being conductive and insulating, these defects can muddle a transistor's readout.

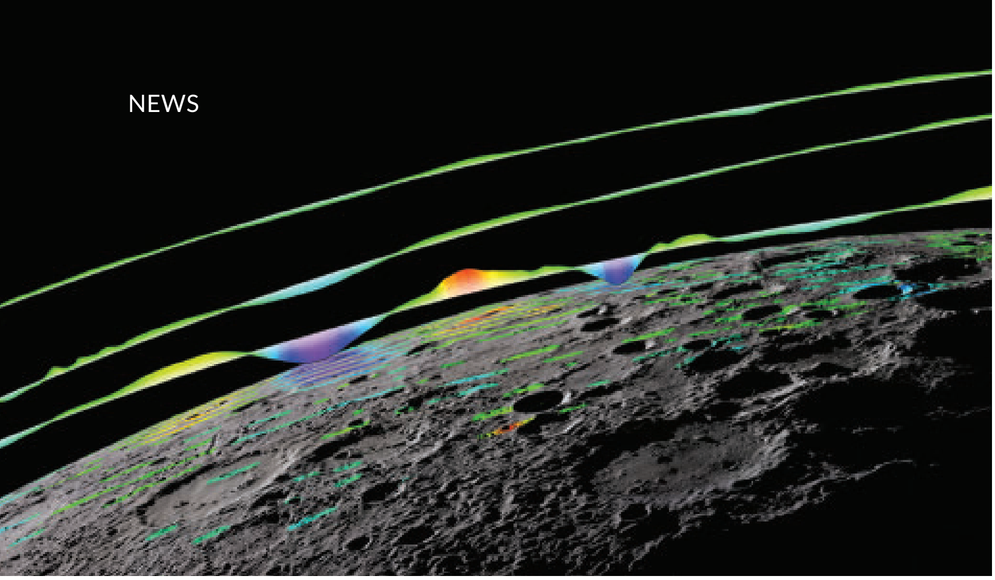
In search of a work-around, Shulaker and colleagues analyzed how badly metallic nanotubes affected different transistor configurations, which perform various kinds of operations on bits of data. The researchers found that defective nanotubes affected the function of some transistor configurations more than others — similar to the way a missing letter can make some words illegible but leave others mostly readable. So Shulaker and colleagues carefully designed microprocessor circuitry to avoid transistor configurations that were most susceptible to metallic nanotube glitches.

"One of the biggest things that impressed me about this paper was the cleverness of that circuit design," says Michael Arnold, a materials scientist at the University of Wisconsin–Madison.

With more than 14,000 transistors made of carbon nanotubes, the resulting microprocessor executed a simple program to write a message that began, "Hello, world!" — the first program that many newbie computer programmers learn to write.

The newly minted carbon nanotube microprocessor isn't yet ready to unseat silicon chips as the mainstay of modern electronics. Each transistor is about a micrometer across, compared with current silicon transistors that are tens of nanometers across. And each transistor in this prototype can flip on and off about a million times each second, whereas silicon transistors can flicker billions of times per second. That puts the nanotube transistors on par with silicon components produced in the 1980s.

Shrinking the nanotube transistors would help electricity zip through them with less resistance, allowing the devices to switch on and off more quickly, Arnold says. And aligning the nanotubes in parallel, rather than using a randomly oriented mesh, could also increase the electric current through the transistors to boost processing speed. ■



NASA's MESSENGER spacecraft has detected magnetic signals at Mercury. (Red and orange represent field lines pointing out into space; blue and purple are lines pointing inward.)

ATOM & COSMOS

How Mercury's core stays toasty

Iron sulfide layer might explain the planet's magnetic field

BY LISA GROSSMAN

Mercury's core may be wearing a metal jacket. New experiments suggest the planet's innards stay warm thanks to an insulating layer of iron sulfide, which could help to explain how the small world has held onto its magnetic field.

Rocky planets generally get their magnetic fields from the churning motion of liquid metals in a gooey core, a process called convection. But small worlds like the moon and Mars seem to have cooled down quickly, freezing their cores and shutting off their fields (*SN: 9/19/15, p. 5*).

Mercury, however, has defied expectations. "Many people thought it was a dead planet," says mineral physicist Geeth Manthilake of Clermont Auvergne University in Clermont-Ferrand, France.

But in the 1970s, NASA's Mariner 10 spacecraft found that Mercury, the puniest planet in our solar system, generated a weak magnetic field. That field — only about 1 percent of the strength of Earth's — has probably been active for as long as 3.9 billion years, almost the age of the solar system.

The question of what kept Mercury's core warm has long puzzled scientists. Now, Manthilake and colleagues have proposed an explanation: The liquid part of the core is surrounded by a layer of iron sulfide that lets heat out much more slowly than previously assumed, the team reports August 21 in the *Journal of Geophysical Research: Planets*.

"Based on lab experiments, we got some data to explain how, actually, you can generate such a low magnetic field and sustain it for such a long time," says Manthilake.

The team measured how efficiently an alloy made of iron and sulfur can carry electricity, and by extension, heat. Previous work suggests that Mercury's core has a solid deep interior, plus a liquid outer layer made mostly of iron, sulfur and silicon. But like oil and water, those elements don't mix thoroughly. As the planet cooled, the more-buoyant iron-sulfur compound would have separated and floated to the top of the core, forming a separate layer.

The researchers put a few milligrams of iron with varying concentrations of sulfur in a chamber with high temperature

BODY & BRAIN

Mouth drops offer peanut protection

The allergy treatment rivals a similar capsule approach

BY ESTHER LANDHUIS

A no-fuss immune therapy involving liquid drops placed under the tongue could protect people with peanut allergies from reacting if exposed.

Results from a small study of the treatment — called sublingual immunotherapy, or SLIT — rival those of a similar treatment that also builds allergy tolerance by exposing sufferers to small, daily doses of an allergen, researchers report September 4 in the *Journal of Allergy and Clinical Immunology*. But in that approach, called oral immunotherapy, or OIT for short, doses are swallowed rather than administered under the tongue (*SN: 12/22/18 & 1/5/19, p. 12*).

The new study shows SLIT is "pretty much equivalent to OIT in terms of protection from accidental food exposures," says Brian Schroer, director of allergy and immunology at Akron Children's Hospital in Ohio, who was not involved with the research.

SLIT's delivery method through the mouth's mucous membrane means that much smaller doses can be used than with the oral treatment, says Edwin Kim, a pediatric allergist and immunologist at the University of North Carolina's School of Medicine in Chapel Hill. SLIT also produced milder side effects, such as a mouth itch lasting up to 15 minutes, compared with OIT, which occasionally has caused allergic reactions that required epinephrine, Kim and colleagues report. And while patients need a two-hour rest period after OIT, those receiving a sublingual dose need only hold it under their tongues for two minutes. And "then you're in the clear to go about your day," Kim says.

The sublingual approach is approved for use in tablet form in the United States to treat a small number of environmental allergies, such as pollen, ragweed and dust mite allergies. For peanut allergies, which affect an estimated 2 percent of kids, it needs further testing in larger studies,

NASA'S SCIENTIFIC VISUALIZATION STUDIO

and pressure at the SOLEIL Synchrotron facility in Gif-sur-Yvette, France. Using a beam of X-rays, the team measured the composition of the iron sulfide alloy as it formed inside the chamber.

When the amount of sulfur in the iron was increased, the conductivity decreased by up to a few orders of magnitude. So iron sulfide at the top of Mercury's core could act like a lid on a pot, keeping heat inside, the team argues.

The lab result on its own doesn't solve the mystery of Mercury's magnetic field, says planetary scientist Steven Hauck of Case Western Reserve University in Cleveland, who was not involved in the work. For one thing, the conductivity measurements disagree with previous measurements of iron sulfide's conductive powers.

Scientists also don't know how much sulfur is in Mercury's iron sulfide layer, or how thick that layer is. Future missions to the planet, such as the European and Japanese BepiColombo mission, arriving at Mercury in 2025, may help nail down those details.

But the new work offers "an important contribution" to the discussion, Hauck says. "Understanding the thermal conductivity of the core is a really important piece of info to be able to make future steps." ■

says Christina Ciaccio, a pediatric allergist at the University of Chicago School of Medicine who has helped run studies for companies developing other peanut allergy treatments. "Would I fault someone in private practice for trying it in the right patient? Probably not," she says.

In the new study, children ages 1 to 11 received daily doses of liquefied peanut protein that increased gradually over a year until leveling off at two milligrams daily for up to four more years. Of the 37 kids who completed the trial, 32 could safely eat 750 milligrams of peanut protein, the amount found in two to three peanuts. Twelve children could tolerate 5,000 milligrams, and many maintained that tolerance after two to four weeks of stopping treatment. ■

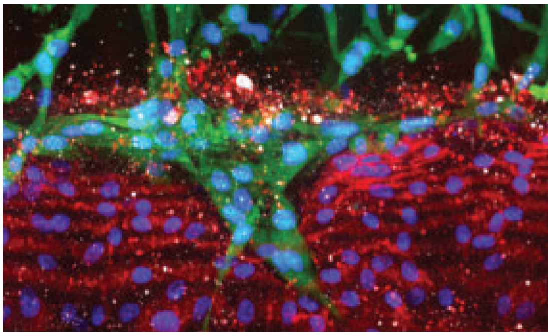
DUC-HUY NGUYEN AND ESAK LEE

GENES & CELLS

Pancreatic cancer kills blood vessels

Study may explain why chemotherapy doesn't reach tumors

BY ALEX FOX


Pancreatic cancer cells (green) invade and kill the blood vessels (whose endothelial cells are in red) that would otherwise deliver chemotherapy drugs, new research finds.

Pancreatic cancer tends to be nearly impossible to treat. This may be because its tumors destroy the surrounding blood vessels that doctors typically rely on to deliver anticancer drugs, new research shows.

Armed with this finding, researchers have zeroed in on how the most common type of pancreatic tumors kill neighboring blood vessel cells. When the team knocked out part of a molecular messaging system underlying the tumor's deadly progression, its growth slowed, and the density of surrounding blood vessels increased in mice and in human cells in a dish, the team reports August 28 in *Science Advances*.

A drug that does the same thing in humans "could rescue the blood vessels around the tumor and allow us to deliver drugs to the patient that would shrink the tumor mass, which is currently impossible to do," says Duc-Huy Nguyen, a molecular biologist at Weill Cornell Medicine in New York City who did the research while at the University of Pennsylvania.

Pancreatic cancer is among the deadliest cancers: More than 90 percent of the estimated 56,770 Americans who will be diagnosed with the disease in 2019 are predicted to die within five years. Cancer of this potato-sized organ has long puzzled researchers. The tumors appear to spread via the bloodstream, yet the tumors have little to no blood supply.

The organ's hard-to-access location deep in the belly makes close observation of pancreatic cancer challenging. So Nguyen and colleagues embedded live human pancreatic cancer cells and human endothelial cells, a type of cell lining blood vessels, in small silicone chips. This so-called "organ on a chip" had two channels running through a gel made of the protein collagen. The researchers put pancreatic cancer cells in one channel to mimic a tumor and endothelial cells to mimic a blood vessel in the other channel.

After four days, the pancreatic cancer cells sent tendrils into the gap between the channels that ensnared the "blood vessel." Eight hours after contact with tumor cells, endothelial cells started dying. Within seven days, the cancer cells had killed and replaced endothelial cells across 20 percent of the artificial vessel. The researchers observed the same brutal sequence of events in live mice.

"Explaining why drugs weren't able to reach pancreatic cancer cells is ... quite a coup," says Charles Saxe, a cancer cell biologist with the American Cancer Society based in Atlanta who was not involved in the study.

The researchers then hunted for the mechanism by which the tumors kill endothelial cells. They ultimately identified the ALK7 receptor protein, known to interact with a group of proteins called transforming growth factor beta. These proteins have been implicated in stimulating tumor growth in other cancers. More studies will be needed to find out if the results hold in human patients with pancreatic cancer.

Drugs that inhibit ALK7's activity are already being tested. So when it comes to pancreatic cancer, the new findings "could have a clinical impact as soon as two years from now," Saxe says. ■

Bulbous rock formations inside Spain's Artà Caves offer clues to ancient sea level rise.

EARTH & ENVIRONMENT

Caves offer glimpse of sea level rise

Ancient crystal growths hint at future effects of climate change

BY LUCAS LAURSEN

The future of sea level rise may be written into the walls of coastal Spanish caves.

Mineral "bathtub rings" deposited inside the limestone Artà Caves on the island of Mallorca show how high seas rose during the Pliocene Epoch — when Earth was about as warm as it's expected to get by 2100. Those deposits suggest that seas were around 16 meters higher on average than they are today, researchers report August 30 in *Nature*.

That measurement provides the most precise peek yet into what may be in store as climate change causes ice sheets to melt and oceans to rise over hundreds to thousands of years. Previous estimates of sea levels during the Pliocene, 5.3 million to 2.6 million years ago, gave similar results. But those relied on more indirect dating methods or failed to incorporate information about the subsequent rise and fall of Earth's crust.

For the new research, Oana-Alexandra Dumitru, a geochemist at the University of South Florida in Tampa, and colleagues turned to aragonite and calcite deposits on stalactites and stalagmites in the Artà Caves — "a very protected environment," Dumitru says. Called phreatic overgrowths, the deposits accumulate as brackish seawater laps against rock. Similar features have been found on the island of Sardinia and in Mexico and Japan.

Seawater washing into the caves left behind mineral deposits at heights from 14.7 to 23.5 meters above today's sea level, Dumitru's team found. One deposit corresponds with a warm period that lasted from about 3.3 million to 3 million years ago. Global temperatures during that time were 2 to 3 degrees Celsius warmer than in modern, preindustrial times — and resemble forecasts for the year 2100. Global mean sea levels then were 16.2 meters higher than today, Dumitru's team calculates.

"We still may not know exactly how much sea level rose," says Alan Haywood, a paleoclimatologist at Leeds University in England. But with results like these, "we're getting more confidence that we're in the right ballpark." ■

BODY & BRAIN

Vaping suspected in six U.S. deaths

It's unclear what device or product may be responsible

BY AIMEE CUNNINGHAM

U.S. health officials have reported six deaths from severe lung illnesses possibly tied to vaping, with over 450 cases of these lung injuries reported in 34 states and one U.S. territory as of September 10. That's more than double the 215 cases reported as of August 30.

Whether a specific vaping substance or type of device is behind the illnesses is not clear, federal and state health authorities announced September 6 in a news conference. "So far, no definitive causes have been established," said Dana Meaney-Delman of the lung injury response group at the U.S. Centers for Disease Control and Prevention in Atlanta.

The New York State Department of Health is eyeing one possible substance: High levels of vitamin E acetate had been found in some vape products that contained cannabis and were used by people who became ill. A dietary supplement and an ingredient in some skin care products, vitamin E acetate could be toxic when inhaled.

But it is too early to focus on any one substance, federal officials cautioned. The Food and Drug Administration is testing more than 120 samples from vaping products for a broad range of chemicals. "No one substance or compound, including vitamin E acetate, has been identified in all of the samples tested," said Mitch Zeller, director of the FDA's Center for Tobacco Products in Silver Spring, Md.

In the meantime, details on some patients have been released. In Illinois and Wisconsin, the 53 cases of severe lung illness reported as of August 27 largely involved young people who were otherwise healthy before falling ill. Almost all were hospitalized, with about a third needing ventilator support to breathe.

In North Carolina, five patients with illnesses potentially linked to vaping developed a noninfectious form of pneumonia that occurs when oils or fat-containing substances enter the lungs and provoke inflammation.

For now, health officials are encouraging people not to use e-cigarettes. ■

ANTONI MERINO

MATTER & ENERGY

New skyrmion lifts data storage hopes

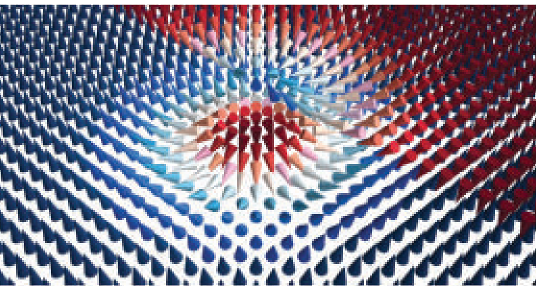
Physicists create the tiny whorls in a synthetic antiferromagnet

BY EMILY CONOVER

Magnetic swirls called skyrmions have gotten a new twist.

Scientists have created a version of the atomic whirlpools, in which the tiny magnetic fields of individual atoms in a material arrange into a swirl pattern. Known as antiferromagnetic skyrmions, the new structures have some advantages that could make them easier to work with than previously found varieties, researchers report September 2 in *Nature Materials*. Such a development could bolster hopes for using skyrmions to store data and to create smaller, speedier hard drives (*SN: 2/17/18, p. 18*).

A newly created antiferromagnetic skyrmion is marked by a swirling pattern in the orientation of atoms' magnetic fields (illustrated in this cutaway view with field orientation indicated by colored cones).



Skyrmions have already been created in ferromagnets, materials in which the tiny magnetic field of each atom aligns with its neighbors'. Those aligned fields are the source of some magnets' ability to affix kids' doodles to the fridge. In antiferromagnets, each atom's magnetic field points opposite to its neighbor's, canceling out the magnetic field.

The researchers created a synthetic antiferromagnet by layering magnetic materials so that each layer's magnetization canceled out the other. By tweaking the properties of each layer, the team optimized the conditions for producing skyrmions, and then imaged them using magnetic force microscopy.

"This was really a tour de force kind of effort," says materials scientist Axel Hoffmann of the University of Illinois at Urbana-Champaign.

Scientists think skyrmions could improve on standard hard drives by packing more data into less space. For that, skyrmions have to be small. Some types of the magnetic whorls can be as large as hundreds of nanometers in size — they won't cut it. The researchers predict that they could shrink the antiferromagnetic skyrmions to 10 nanometers or below.

"This is the regime of skyrmion size that becomes really interesting," says physicist Vincent Cros of Unité Mixte de Physique CNRS/Thales in Palaiseau, France, a coauthor of the study.

Scientists can move skyrmions within a material via electric currents to shuttle data around. That could avoid the need for the fragile moving parts found in typical hard drives. Skyrmions tend to speed off at an angle to the input current, though, making them hard to control. Antiferromagnetic skyrmions, with their alternating orientations, should travel in line with the current. ■

WILLIAM LEGRAND

ATOM & COSMOS

General relativity illuminates pulsar

Astronomers get a novel look at dead star's radio beams

BY EMILY CONOVER

Finally, scientists have their finger on the pulse.

Spinning dead stars, known as pulsars, blast out powerful beams of radio waves. As a pulsar spins, its beams sweep past Earth, producing a pulsating signal similar to a lighthouse's flashes. Astronomers now have mapped the structure of the beams of one pulsar, using observations made over decades. The technique relies on Albert Einstein's theory of gravity, or general relativity, and simultaneously reconfirms that the theory is correct, the scientists report in the Sept. 6 *Science*.

The result let researchers "view the beam of a pulsar in a whole new way," says astrophysicist Victoria Kaspi of McGill University in Montreal, who was not involved with the new study.

Pulsars are a type of neutron star, a dense remnant left behind when a star explodes. Powerful magnetic fields direct radio waves from a pulsar outward in beams. Typically, those beams pass by Earth at a fixed angle, and scientists can glimpse only a single slice through a beam as it rotates — like viewing a lighthouse beacon through a tiny slit.

But the newly mapped pulsar, known as PSR J1906+0746, is unusual: It orbits with another neutron star, about 20,000 light-years from Earth (*SN: 1/23/16, p. 16*). According to general relativity, if a pulsar spins at an angle misaligned with the pair's orbit — which this one does — the pulsar's axis will rotate like a wobbling top, or precess. This precession let scientists catch different slices of the beam by observing the pulsar over time.

"From this we can learn many things about the structure of the emission," says Gregory Desvignes of the Max Planck Institute for Radio Astronomy in Bonn, Germany. Desvignes and colleagues monitored the intensity of the beam and its polarization, the orientation of the wiggling of the electromagnetic waves that make it up. The polarization validated a 50-year-old theory about the geometry of pulsars and their magnetic fields.

And in a win for Einstein, the pulsar precessed at a rate of about 2.2 degrees per year — in agreement with the predictions of general relativity.

"You look at it and you go, 'Oh wow, isn't that wonderful?'" Kaspi says.

The results also revealed some unexpected features of the pulsar. Rather than circular beams often assumed for pulsars, this pulsar's beams are elongated. And the pulsar's angle is changing so much that in 2028, its beams will disappear from Earth's view, researchers predict. ■

NEWS

Changing the makeup of the community of gut microbes living in koalas may give them a taste for other types of eucalyptus plants.

LIFE & EVOLUTION

Fecal transplants may shift koala diets

Tweaking gut microbiomes could make the animals less picky

BY CAROLYN WILKE

A tale of fecal transplants Down Under hints that microbes could help choosy koalas expand their diets.

When koalas were given capsules loaded with gut bacteria, the koalas' microbial communities changed, and some of their diets shifted too. The fecal transplants transferred microbes from koalas that mostly ate messmate eucalyptus to koalas that usually munched a different type of eucalyptus. In some cases, treated koalas upped their messmate intake, scientists report August 21 in *Animal Microbiome*.

"The more that [the microbial community] changed, the more messmate they ate, which suggests that the microbiome is influencing what the koalas are able to eat," says Michaela Blyton, an animal ecologist and microbiologist at the University of Queensland in Brisbane, Australia.

Some koalas eat several types of eucalyptus, while others stick to one. A restricted diet can be dangerous. A population boom in southern Australia's Cape Otway led koalas to chow through their preferred manna gum (*Eucalyptus viminalis*) by 2013, killing many trees. Though messmate (*E. obliqua*) was available, koalas there starved to death. A tool to help make the animals less choosy could be useful for conservation.

Blyton and colleagues wondered if changing koalas' gut microbiomes — the collection of bacteria and other microbes in the digestive tract — could help the marsupials adapt in a pinch. Gut microbes let koalas digest eucalyptus, which varies in protein and fiber content and in the types of toxins in the leaves. The team tracked koalas that ate messmate, collected poop and extracted microbes. The microbes were put into pills.

A dozen manna gum–eating koalas brought into the lab had their microbiomes monitored for a few days. Half of the koalas were then given fecal transplants from messmate eaters, and half were given fecal transplants from manna gum eaters as a control. Koalas received pills for nine days, and gut microbes were monitored for 18 more days.

Messmate consumption didn't differ greatly between groups. But koalas that received fecal transplants from messmate eaters ate more of that eucalyptus once their gut bacteria more closely resembled messmate eaters' gut bacteria. How well the fecal transplants took hold varied among koalas, says Blyton, who mostly worked on the project while at Western Sydney University. One koala increased its messmate intake to nearly half of its total food consumption.

"The ability to change the microbiome of an animal like a koala is pretty impressive," says animal physiologist Kevin Kohl of the University of Pittsburgh. Fecal transplants have been done more often and with greater success in sterile lab rodents than in wild animals, which come with their own microbiomes.

But Kohl isn't quite convinced that fecal transplants caused koalas to chomp more messmate. It's "hard to disentangle whether it was the microbiome [changing] the food intake or the food intake changing the microbiome," he says. ■

BODY & BRAIN

Cells in lab dishes form brain waves

Nerve cell firings resemble those seen in newborn babies

BY LAURA SANDERS

It's baby's first brain wave, sort of.

As lentil-sized clusters of nerve cells grow in a lab dish, they begin to fire off rhythmic electrical signals. These oscillations share some features with those found in the brains of human babies, researchers report online August 29 in *Cell Stem Cell*.

Three-dimensional spheres of human brain cells, called cerebral organoids, are extremely simplistic models of the human brain. Still, the organoids, grown from easy-to-obtain skin samples, may offer a better way to study how a brain is made, and how that process can go wrong (*SN: 3/3/18, p. 22*).

"The field is white-hot," with fast progress in both making and understanding brain organoids, says John Huguenard, a neuroscientist at Stanford University who was not involved in the study.

Finding this sort of coordinated electrical activity in organoids' nerve cells, or neurons, is a first, he says. "The neurons are growing up and becoming mature enough where they can not only start to behave like neurons and fire individually, but now they can be coordinated."

Researchers coaxed stem cells into forming some of the neurons that make up the outer layer of the brain. These cortical organoids grew in lab dishes that held arrays of electrodes printed along the bottom. The arrays allowed the scientists to monitor electrical activity as the organoids developed.

After two months, the electrodes started picking up neural waves, or collective behavior that comes from many neurons firing signals in tandem. By four to six months, the electrical activity in the lab-grown cells had reached levels "never seen before," says coauthor Alysson Muotri, a neuroscientist at the

UNIV. OF QUEENSLAND

University of California, San Diego. Those signals suggest that neurons in the organoids had made billions of connections, he says.

At nine months, the organoids showed electrical activity that echoed the brain activity of newborn babies. Mathematical models suggest that "the organoid is evolving in the same way as the human baby brain would," says Muotri.

Although the organoids can live in the lab for several years, electrical activity plateaus around nine months, Muotri says. Further refinements would be needed for the organoids to develop more fully.

The organoids, each about a millionth the size of a human brain, lack the complex combination of cells that help shape neural waves in people. Muotri and his colleagues are exploring ways of boosting the complexity, perhaps by adding more types of cells or a blood supply. And the scientists are stimulating the organoids, delivering signals akin to those that neurons might receive from other brain regions or the outside world — forces known to sculpt the growing brain.

The research "provides a starting framework for analyzing how these neural networks form," says neuroscientist Mark Hester of Nationwide Children's Hospital in Columbus, Ohio, who also studies electrical signals created by maturing brain organoids. It's important to remember, though, that these organoids are not the real thing, but merely a model, he says. "It's not a miniaturized brain that we're looking at." ■

These 10-month-old brain organoids show signs of coordinated neural activity that in some ways resembles that of a newborn baby.

HUMANS & SOCIETY

Idaho site predates ice-free corridor

Tools add to the debate over the settlement of the Americas

BY BRUCE BOWER

America's first settlers may have coasted in. Northeast Asians traveled down North America's Pacific coast and then eastward into the continent more than 1,500 years before an inland, ice-free corridor opened up, researchers say.

That conclusion, reported in the Aug. 30 *Science*, rests on discoveries at a site in western Idaho called Cooper's Ferry. Stone tools excavated there point to repeated human visits between about 16,560 and 15,280 years ago, says a team led by archaeologist Loren Davis of Oregon State University in Corvallis.

Those tools look much like stone artifacts that were made around that time in what's now Japan, Davis' group says. Asian toolmakers could have reached Idaho only by first heading down the Pacific coast, the researchers contend, possibly by combining canoe travel with walking.

Stone tools dating to as early as about 16,500 years ago at an Idaho site resemble those from around the same time in Japan.

How North America's first settlers arrived, and when, is hotly debated. And the Idaho finds don't appear to cool that conflict. One long-standing idea is that the melting of ice sheets cleared a path from what's now Alaska into the heart of North America by about 14,800 years ago. People could have reached Florida and South America a few hundred years later.

But some scientists have argued that colonizers from Asia arrived earlier, primarily traveling by canoe down the Pacific coast before moving inland. Evidence from Texas places people there about 15,000 years ago (*SN: 11/24/18, p. 10*). And an ice-free path along Alaska's coast may have formed by about 17,000 years ago (*SN: 6/23/18, p. 13*).

The Idaho tools lack the signature grooved bases of points made by well-known Clovis hunters, who arrived in the Americas about 13,250 years ago. Clovis people were once thought to be North America's first inhabitants, but Cooper's Ferry joins a growing number of pre-Clovis sites.

The findings are intriguing, but "much more work needs to be done to establish the nature and age of the occupations," says archaeologist Ben Potter of the University of Alaska Fairbanks, who favors the ice-free corridor idea.

The tools' ages were determined using radiocarbon dating of burned wood and bone fragments in the sediment, along with analyses of the time since sediment was last exposed to sunlight. Though a minority of the artifacts may date to as early as about 15,000 years ago, Potter says, sediment dating to 16,000 years ago or more has no direct links to stone tools or other signs of human activity. Dates from one sediment layer range over more than 4,000 years, raising questions about how geologic forces rearranged the site's sediment layers over time, he says.

Even an early arrival at Cooper's Ferry "doesn't refute the idea that the ice-free corridor was a potential migration route well before the Clovis occupation," says archaeologist Vance Holliday of the University of Arizona in Tucson. ■

FROM TOP: MUOTRI LAB/UCTV; L.G. DAVIS *ET AL*/*SCIENCE* 2019

HUMANS & SOCIETY

Denisovan finger is humanlike

A newly described Denisovan finger fossil holds a skeletal surprise, adding to the mystery of this extinct Stone Age crowd.

A decade ago, scientists found a tiny fragment of a fossil pinkie bone in Siberia's Denisova Cave. That bone yielded the first known Denisovan DNA and helped identify the hominids (*SN: 9/22/12, p. 5*). Now paleogeneticist E. Andrew Bennett of Paris Diderot University and colleagues say they've identified the rest of the finger bone, which comes from the right hand of a roughly 13-year-old female Denisovan. The group matched mitochondrial DNA extracted from a segment of the newly identified fossil to DNA from the previously discovered finger bone, indicating that they came from the same individual.

Unexpectedly, this digit physically resembles bones of ancient and recent humans more than those of Neandertals, the scientists report September 4 in *Science Advances*. Yet Denisovans, who inhabited parts of Asia from around 300,000 to 50,000 years ago, had closer genetic ties to Neandertals than to *Homo sapiens*.

The finding raises the possibility that other yet-to-be-found Denisovan body parts may be largely humanlike. So Bennett's team recommends caution in trying to identify Denisovan fossils based on shape alone. *— Bruce Bower*

MATTER & ENERGY

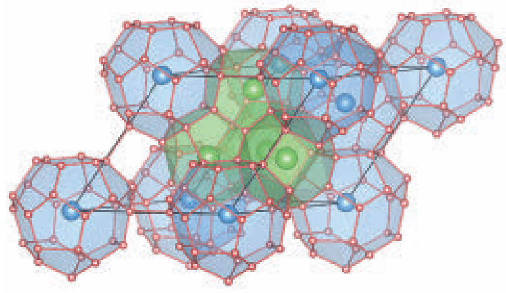
Theory points to a superconductor that might work at 200° Celsius

The steamiest summer day would be no sweat for this potential superconductor.

Scientists have calculated that a hydrogen-rich compound could conduct electricity without resistance at temperatures up to about 200° Celsius — well above the 100° C boiling point of water. If that prediction is confirmed experimentally, the material would stand in stark contrast to all other known superconductors, which must be cooled below room temperature to work (*SN: 12/26/15, p. 25*). A superconductor that can stand the heat could revolutionize how electricity is transmitted and save vast amounts of energy.

The predicted superconductor — a compound of hydrogen, magnesium and lithium — comes with complications, however. It must be squeezed to extremely high pressure, nearly 2.5 million times the pressure of Earth's atmosphere, physicist Hanyu Liu and colleagues, of Jilin University in Changchun, China, report in the Aug. 30 *Physical Review Letters*.

Scientists previously have used similar techniques to predict that a pressurized compound of lanthanum and hydrogen would be superconducting at higher temperatures than any yet known. Lab tests reported in 2018 showed signs of the compound superconducting up to –13° C, a record-breaking temperature (*SN: 10/13/18, p. 6*). *— Emily Conover*



A theoretical type of superconductor, made of atoms of lithium (illustrated as small green spheres), magnesium (blue) and hydrogen (red), could function at temperatures much higher than existing superconductors do.

H. LIU

LIFE & EVOLUTION

Human meddling has likely altered the shapes of dog breeds' brains

Dog breeders have been shaping the way dogs look and behave for centuries. That meddling in canine evolution appears to have sculpted dogs' brains, too.

A brain-scanning study of 62 purebred dogs representing 33 breeds reveals that dog brains are not all alike — offering a starting point for understanding how brain anatomy relates to behavior. Different breeds had different shapes of various brain regions, distinctions that were not simply the result of head shape or the size of the dogs' brains or bodies, researchers report September 2 in the *Journal of Neuroscience*.

Through selective breeding, "we have been systematically shaping the brains of another species," evolutionary neuroscientist Erin Hecht of Harvard University and colleagues write in the report.

The MRI scans were taken of dogs with normal brain anatomy at the Veterinary Teaching Hospital at the University of Georgia in Athens. While the study wasn't designed to directly link brain shape to behavior, the results offer some hints. Researchers identified groups of brain areas, such as smell and taste regions, that showed the most variability between breeds. Those groups are involved in specialized behaviors that often serve humans, such as hunting by smell, guarding and providing companionship, earlier studies have suggested. *— Laura Sanders*

MATTER & ENERGY

In a first, physicists teleport qutrits

Regular old quantum teleportation wasn't enough for scientists. So they've kicked it up a notch.

Previously, physicists had teleported qubits, or quantum bits of information. Just as a standard computer bit has two possible values, 0 or 1, a qubit has two possible states. Now scientists have reported in the Aug. 16 *Physical Review Letters* that they've teleported qutrits, which have three possible states. Both qubits and qutrits have the weird quantum property of being able to exist in multiple states at once. But while a qubit can represent 0 and 1 simultaneously, a qutrit can be 0, 1 and 2.

In quantum teleportation, rather than sending objects from one place to another in *Star Trek* fashion, the properties of a quantum particle are transferred to another, distant particle. Until now, those properties could only be binary. For example, a particle of light, or photon, could be made to take one of two paths through a device — or both at once.

In the new study, the team teleported the properties of photons that had three possible states: The particles could have taken three different paths — or all three at once. Because qutrits carry more information than qubits, the technique could be a boon for quantum communication. *— Emily Conover*

Ghost Guns

Forensic scientists are following the plastic clues left by 3-D printed weapons

By Carolyn Wilke

An assembled plastic Washbear revolver sits inside a 3-D printer at the University of Mississippi in Oxford.

MEGAN WOLFE/UNIV. OF MISSISSIPPI

On December 17, 2017, police responded to reports of gunshots at a Phoenix apartment. When Cleophus Cooksey Jr. answered the door, his mother and stepfather were lying on the living room floor, shot dead. Police arrested Cooksey.

The double homicide seemed like an isolated incident, a violent end to a family dispute. But ballistics evidence gathered at the crime scene told an even bigger story.

Firearms leave telltale markings on the bullet and the cartridge case that's ejected when a pistol or rifle is fired. The U.S. Bureau of Alcohol, Tobacco, Firearms and Explosives catalogs these marks in the National Integrated Ballistic Information Network, or NIBIN.

Police had collected cartridge cases from that Phoenix apartment. Within 48 hours, the NIBIN database revealed ballistics matches that linked weapons used in several other murders during the previous three weeks. Cooksey has been charged with killing eight people.

Although not perfect, ballistics evidence helps police pull suspects off the streets. NIBIN has yielded over 110,000 matches since it was launched in 1999. But a new type of gun — made of plastic using 3-D printers — may bring new challenges for forensics experts.

Use of a 3-D printed weapon "would make it very difficult for NIBIN to detect the signature of that weapon," says Frank Fernandez, a retired police chief based in the Miami area who chairs the firearms committee of the International Association of Chiefs of Police.

Right now, violence involving 3-D printed guns is more of a risk than a reality. The most commonly available 3-D printers, which cost hundreds of dollars, may not print usable guns, and high-end models cost tens of thousands of dollars.

But 3-D printed guns have been confiscated at airport security checkpoints, including a disassembled gun seized July 3 at New York's LaGuardia Airport. And in February, a Texas man who had been prohibited by a judge from possessing firearms was sentenced to eight years in prison for carrying a hit list and a gun with 3-D printed parts.

As 3-D printers improve and costs come down, some experts worry that more people will decide to print guns. Because knowing how to analyze the evidence 3-D printed guns leave at a crime scene may one day become an important skill, researchers are making and firing plastic guns to figure out the forensics of these DIY weapons.

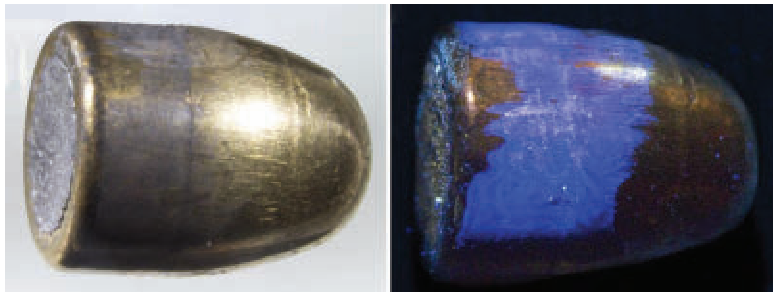
Not a plaything

At less than a pound, the milk-colored pistol looks and feels like a toy. Its parts are formed from plastic spit out with precision by a 3-D printer. But the device shoots real bullets. With two fingers, analytical chemist Oscar "Beau" Black squeezes the trigger, sending a bullet into a target in a laboratory at the University of Mississippi in Oxford.

After a shooter pulls the trigger on a gun — 3-D printed or conventional — a firing pin sets off an explosive substance, which ignites the gunpowder that's packaged with the bullet in a cartridge. The resulting pressure pushes the bullet out of the cartridge and through the gun's barrel. The firing pin leaves a dent on the metal case that holds the cartridge together.

The barrel of a conventional gun typically has spiral "rifling" grooves that spin the bullet to give it more stability during flight. These grooves gouge lines around the circumference of the bullet. The number, angle and direction of the marks may reveal the gun that fired it.

The plastic gun barrels that Black built did not have rifling grooves. But even if a plastic gun did have grooves, the plastic itself would be too soft to dent the bullet.



When the bullet at left, which was shot from a plastic Liberator gun, is put under blue fluorescent light, the plastic polymer from the gun becomes visible (right).

H. HONSBERGER *ET AL*/*FORENSIC SCIENCE INTERNATIONAL* 2019

If a plastic gun were used to commit a crime, tracking down the weapon's maker and the shooter would not be easy. Unlike conventional firearms, plastic guns have no serial numbers for tracking their source, says James Cizdziel, an analytical chemist at the University of Mississippi, where Black is a postdoctoral fellow. That's why printed guns are called ghost guns, he says. Plastic guns can also be taken apart and sometimes destroyed by dissolving their parts in solvents, Black adds.

"The reality ... is that a 3-D [printed] weapon could potentially circumvent a lot of the [existing] security measures," including background checks and metal detectors, Fernandez says. "Anyone can make them and [not] have to go through any type of vetting process."

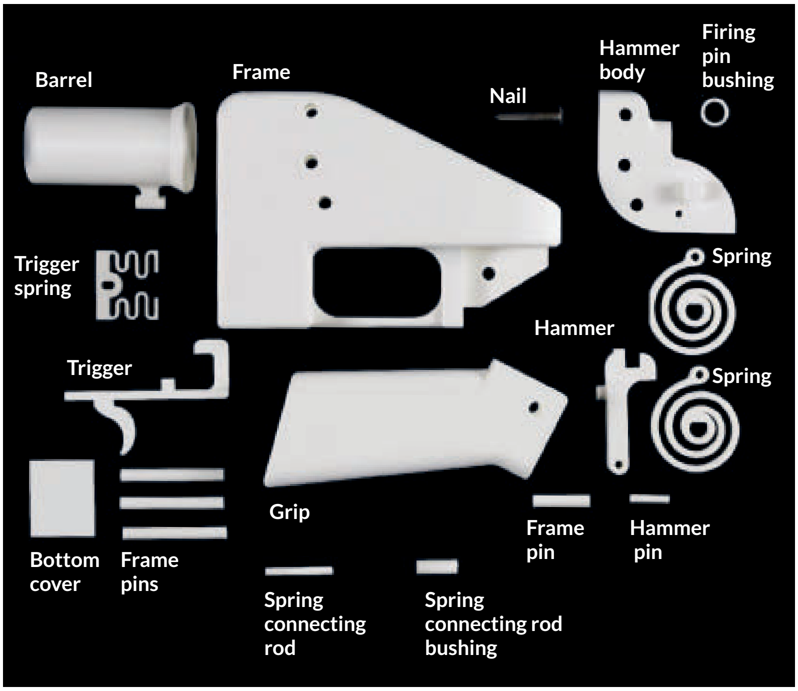
Knowing how to analyze the evidence 3-D printed guns leave at a crime scene may one day become an important skill.

A poor substitute

To see what kind of clues plastic guns do leave, forensic scientist Olivier Delémont and graduate student Hanna Honsberger of the University of Lausanne in Switzerland and colleagues began printing and testing a weapon known as the Liberator.

The Liberator made a splash in 2013 when Defense Distributed, a 3-D printing and firearms company, released blueprints for the gun, the first made entirely with printable parts except for a metal nail used as the firing pin. Within a couple days of its release, the blueprint was downloaded about 100,000 times. Defense Distributed has since been ensnared in lawsuits with U.S. states trying to keep the group from sharing the blueprints.

The Swiss researchers printed and assembled six Liberators with a plastic called acrylonitrile butadiene styrene and fired them in a test chamber. Radar clocked the speed of the bullet as it exited the gun at between 138 and 172 meters per second, the researchers reported in 2018 in *Forensic*



Parts list The Liberator handgun is built from mostly plastic parts made with a 3-D printer. A metal nail works as a firing pin to set off the internal explosion when the trigger is pulled. Blueprints for the gun were downloaded about 100,000 times within days of their 2013 release.

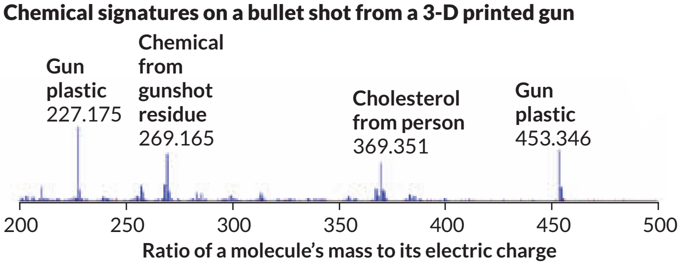
Science International. The same type of bullet launched from a typical handgun exited at about twice that speed.

The scientists fired a couple of bullets from plastic guns into a block of ballistics soap, the kind used to test a projectile's potential to wound. The faster of the two bullets lodged 21 centimeters into the block, suggesting that the gun could cause damage similar to a typical handgun of the same caliber.

Most of the plastic guns broke upon firing; the frame cracked or the barrel fell out. On occasion, the weapons also ejected the nail, and bullets often deviated from their intended path. Good thing the

Leaving a mark A special type of mass spectrometry reveals the chemical fingerprint of a nylon plastic scraped from a bullet, as well as gunshot residue and cholesterol left by a person who handled the bullet.

Chemical signatures on a bullet shot from a 3-D printed gun



scientists used a machine to fire the gun while they watched safely behind bulletproof glass.

Delémont doesn't think such a gun would tempt anyone who already has access to a regular firearm. Based on the guns his group tested, "it would be more dangerous to be the shooter than to be the target," he says.

Nevertheless, the Liberators left clues that could help crime scene investigators. Large pieces of plastic, like the barrels that broke away, could reveal the type of printer used, since various printer models produce printed plastics with visibly different textures, Delémont says.

Even if a shooter managed to avoid leaving a chunk of the gun behind, little bits of plastic might give the gun away. After firing, small fragments of plastic peppered the ground below the bullet's path, the swiss researchers reported in the February *Forensic Science International*. The metal bullets and cartridges also picked up near-microscopic bits of plastic. Under a blue forensic light, plastic residues on the spent ammunition popped into view.

Chemical traces

Back at the University of Mississippi, the plastic guns Black printed held up better than the Liberators. One weapon even fired several dozen times without any visible wear and tear, he says.

Black and Cizdziel first got into 3-D printing to replicate parts of lab equipment. The two used the knock-offs to show chemists-in-training how expensive equipment worked without having to pull apart a real instrument's guts.

When 3-D printed guns began making headlines, Black, who learned how to shoot from his father as a kid in Texas, pondered how one would trace a phantom firearm. In 2016, Black and Cizdziel took up the chemistry challenge, which became Black's doctoral project.

Black has printed and tested several copies of two models — a pistol called the Songbird and a revolver called the Washbear — using several different types of plastic. Though each gun took him dozens of hours of printer time, making the guns was surprisingly easy, Black says.

"That Washbear revolver is a fully functional five-shot revolver," he says. The blueprints, which he downloaded from a website, weren't difficult to find, though they tend to be taken down just a few days after posting.

Like Delémont's group, Black and Cizdziel found plastic on bullets and cartridges after the guns were fired.

FROM TOP: H. HONSBERGER *ET AL*/*FORENSIC SCIENCE INTERNATIONAL* 2018; O. BLACK *ET AL*/*FORENSIC CHEMISTRY* 2017

The University of Mississippi team sometimes used a machine to pull the trigger on 3-D printed guns, then looked for clues on bullets, cartridge cases and the target.

O. BLACK ET AL/*FORENSIC CHEMISTRY* 2017

To see if the shreds of plastic could be matched to their starting material, Black and Cizdziel turned to a technique called direct analysis in real-time mass spectrometry, or DART-MS for short. In forensics, DART-MS has helped investigators analyze seized drugs and explosive residues left on fingerprints.

The DART-MS spews a hot stream of gas molecules into a sample, in this case, a bit of plastic scraped from a bullet. The stream heats up chemicals in the plastic, which react with the gas and get sucked into a mass spectrometer. The instrument sorts the sample's molecules by mass. The process takes only seconds to yield a chemical fingerprint for all compounds that the instrument finds.

Black and Cizdziel were able to match the plastic on the bullets and on the T-shirt they used as a target to the original plastic used in the printer. The process worked even with the barrel-scraping friction and heat of being fired. The pair described the work in 2017 in *Forensic Chemistry* and has started more tests on a wider variety of plastics.

Plastics for 3-D printing can contain dozens of additives, such as dyes, that give them different properties. This provides chemists with an opportunity to nail down the specific source of the plastic used to make a gun.

Black and Cizdziel are building a database to catalog potential sources of plastics. So far, the pair has analyzed 84 of the hundreds of plastics that Black estimates are available for gunmaking. The idea is that if law enforcement needs to trace a plastic, investigators might find the plastic's match in the database and possibly track it down to a handful of stores.

The pair is also studying whether traditional crime scene investigation tactics can be applied to plastic guns: Can fingerprints be lifted from the textured plastic? How well do the guns hang onto DNA from the shooter?

At the scene of the crime

Conventional metal guns and 3-D printed plastic firearms differ in their makeup and the clues they leave behind.

	Conventional metal gun	3-D printed plastic gun
Evidence from the gun	If a gun is left at a crime scene, its serial number can be used to find its owner. Metal guns typically don't leave fragments or shavings when fired.	Plastic guns have no serial number. When bullets are fired, plastic gun flakes can be found on bullets and on the ground below a bullet's trajectory.
Marks on bullets and cartridges	Spiral ridges in the barrel leave distinctive marks on bullets. The firing pin also leaves a mark on the ammunition cartridge case.	The barrel leaves no marks on bullets, though the metal firing pin can leave marks on the cartridge.
Gunshot residue	Chemical residue from the barrel can give clues about the shooting distance.	Chemical residue is sprayed from the gun, but its relevance has not been tested.
Fingerprints	Prints can be lifted from a metal gun.	The texture of gun plastic may obscure prints. Chemicals used in traditional fingerprint-lifting methods might react with a gun's plastic, making fingerprints unrecoverable.
DNA recovery	Swabbing the gun may yield DNA, especially if skin cells, blood or sweat is left on the gun.	Textured plastic may make it easier to recover DNA from skin cells, blood or sweat left on the gun.

SOURCES: O. BLACK; O. DELÉMONT; DEREK PROCTOR/TENNESSEE BUREAU OF INVESTIGATION

Doing this work now makes sense to retired police chief Fernandez, who expects forensics investigators will eventually be contending with 3-D printed guns. "With technology today," he says, "it's just a matter of time before [people] figure out how to make a functioning multishot handgun work consistently."

Explore more

- James Cizdziel and Oscar Black. *Forensic Analysis of Gunshot Residue, 3D-printed Firearms and Gunshot Injuries.* Nova Science Publishers, 2019.

Astrophysicist Julián Alvarado Gómez has spent his career chasing a star that could reveal the secrets of the young sun.

Star Seeker

He's on a quest to study the sun's distant look-alikes

By Lisa Grossman

The Soell system was the site of a galactic disaster. The ancient Forerunners fought a long war against intelligent parasites called the Flood. As a last resort, the Forerunners built a ring-shaped superweapon orbiting the moon of Soell's largest planet. Triggering the weapon, the Halo Array, wiped out the Flood, the Forerunners and all other intelligent life in the galaxy. For millennia, the star Soell was forgotten — until humans found the Halo.

The popular video game Halo and its fictional stars were Julián Alvarado Gómez's obsession 15 years ago. As a young man in Bogotá, Colombia, he played Halo and its offshoots competitively. Today, at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass., he's studying an actual star, Iota Horologii.

His goal is to map the star's magnetic field over time along with its gusting stellar wind, the stream of energetic particles that defines a star's territory and batters its planets. This work will help him understand what our star was like in its youth and how it influenced the start of life on Earth.

"One of the big difficulties we have in our understanding of the sun is that we only have one sun," says the 35-year-old astrophysicist. Getting to know another star that has a similar mass and temperature as the sun, referred to as a "sunlike" star, would shore up astronomers' grasp of the sun. And it would offer details on how sunlike stars may affect potential life on their orbiting planets.

Alvarado Gómez's road to this stellar career was rocky. In 2003, he was about a third of the way through an undergraduate physics degree at the National University of Colombia in Bogotá when financial trouble put his studies on hold. He filled his time with friends and Halo. "We were practicing a lot," he jokes.

The game offered a solution to his money woes when he came in third place in a Halo tournament. His friend Julián Hernández took first. The two caught the attention of Microsoft representatives looking for skilled players to help advertise the game by playing in public.

The fictional planet called Threshold almost eclipses its star, Soell, in this image from the Halo series of video games. The ring in the foreground is the Halo Array weapon.

From there, he and Hernández earned a salary for playing at events, plus the occasional bonus for winning a tournament. It was fun, Alvarado Gómez says, and it paid the bills.

After two years, he returned to school to study physics again. "That was a very hard semester," he says. After an early focus on the sun, he shifted toward the stars for his Ph.D. at the European Southern Observatory in Garching, Germany.

That shift has brought Alvarado Gómez to some surprising differences between the sun and other sunlike stars. His research has also revealed how a star might protect its planets from its own energetic outbursts. Yet the work didn't take him as far from Soell as he'd thought.

OPPOSITE PAGE: PORTER GIFFORD; THIS PAGE: BUNGIE, LLC

Our star's younger self

The sun and Iota Horologii (shown above) have enough in common to make the distant star a good stand-in for a young sun.

	Sun	Iota Horologii
Surface temperature	5,500° Celsius	5,800° Celsius
Radius	695,500 km	806,780 km (1.16 solar radii)
Mass	2 x 10^{30} kg	2.46 x 10^{30} kg (1.23 solar masses)
Rotation period	24 days	8.2 days
Magnetic activity cycle	11 years	1.6 years
Age	4.6 billion years	625 million years
Distance from Earth	150 million km	530 trillion km
Planet at Earth orbit	Earth	A gas giant 2.5 times Jupiter's mass

The best way to get to know a star is through its magnetic field, Alvarado Gómez says. The sun is the most familiar example: Our star's temperamental behavior and periodic mood swings are thought to exist thanks to changes in magnetism.

Magnetic fields help heat the sun's wispy outer atmosphere, the corona, to millions of degrees Celsius. Those magnetic fields also help drive a stream of charged particles out into space (*SN Online: 8/11/17*). That solar wind blows a bubble that defines the boundary of the solar system (*SN Online: 12/10/18*). It can also batter unprotected planets; scientists think the solar wind stripped away much of Mars' atmosphere.

When tangled magnetic field lines on the solar surface suddenly snap, powerful eruptions of plasma called coronal mass ejections break free (*SN: 4/13/19, p. 15*). When strong CMEs hit Earth, they can fry satellites, shut down power grids and damage living cells.

Fickle fields

The sun's magnetic activity waxes and wanes in about an 11-year cycle. The peak, or maximum, rages with sunspots, CMEs and bright radiation flashes called flares, while the minimum is relatively quiet.

In another magnetic quirk, the direction of the sun's dominant magnetic field flips at the peak of each cycle (*SN: 3/3/01, p. 139*). As the sun's inner engine reorganizes itself, the south magnetic pole switches to the north, and vice versa. This polarity reversal has ripple effects on the solar wind that extend to the edges of the solar system.

Other stars share much of this magnetic fickleness. About 60 percent of sunlike stars show signs of magnetic cycles of varying lengths depending on the stars' ages. Young sunlike stars of a few hundred million years have shorter cycles and emit more flares than the 4.6-billion-year-old sun.

"You can use other stars to show snapshots of the sun at earlier and later periods in its evolution," says stellar physicist Travis Metcalfe of the Space Science Institute in Boulder, Colo. "What was the sun like in the past? What will it be like in the future?"

From what we can tell, stars seem to tame their magnetic frenzies as they age. They calm down by losing mass through their stellar winds and CMEs (*SN: 8/31/19, p. 11*).

But young stars can be rough on their planets. Stinging winds and violent outbursts could wipe out life as efficiently as the Halo Array, unless

DIGITAL SKY SURVEY/VIRGO

something stopped or blocked them (*SN Online: 3/5/18*).

The perfect star

To find out when a star's planets face the most danger, Alvarado Gómez needed a magnetic view of a young sun, from the field on its surface to the edges of its stellar wind.

Finding one turned out to be a massive undertaking. The perfect star had to be similar to the sun in mass and temperature, two features that determine a star's life span. And it needed an observable magnetic cycle in its corona. "If [stars] have corona, they have stellar winds," Alvarado Gómez says.

That final requirement was the trickiest. Astrophysicists have measured the cycles of fewer than 100 stars, based on variations in a particular wavelength of near-ultraviolet light that can be seen from ground-based telescopes. Tracking these cycles takes time, but is relatively easy.

The coronas of stars other than the sun, however, are best observed through the high-energy X-rays they emit. "I wanted a star in which I could be confident that I know what the activity cycle looks like," Alvarado Gómez says. "The best proxy for that — the best of all — is the X-rays." But the only way to see these X-rays is from space, a much more difficult and expensive prospect.

Very few stars have had their magnetic cycles recorded in X-rays. When Alvarado Gómez was searching for his target star in 2014, there were only four solar mass stars that would work, and three of them were in orbits with another star. Alvarado Gómez ruled those out, fearing the companion stars could mess things up. "There was only one star left," he says. "Iota Horologii."

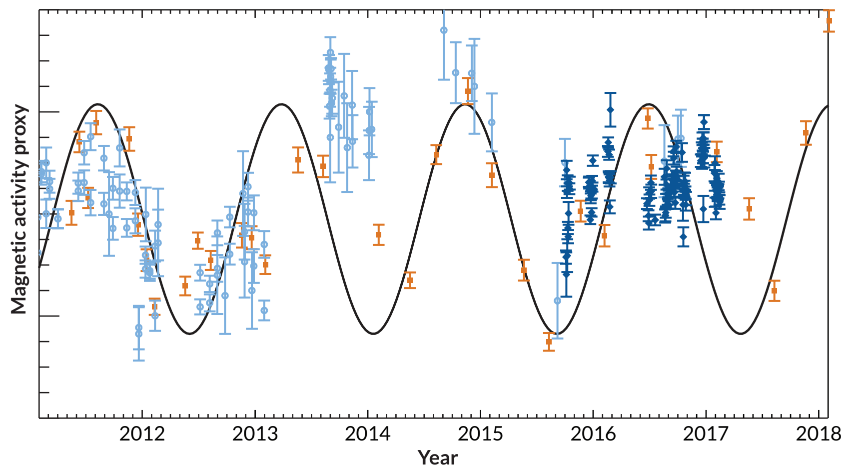
"This is a way to observe how the sun was at the moment when life appeared."
JORGE SANZ-FORCADA

Back to the Halo

Iota Horologii, located about 56 light-years (530 trillion kilometers) from Earth, is similar to the sun in temperature, size and mass (see Page 22). At about 625 million years old, it's the youngest star with a detected magnetic activity cycle.

Its age is more or less the age of the sun when life appeared on Earth, says astrophysicist Jorge Sanz-Forcada of the Center for Astrobiology in Madrid. "This is a way to observe how the sun was at the moment when life appeared." The star has a planet, too. Unfortunately, it's an uninhabitable gas giant, but its orbit lasts almost a full Earth year: 307 days.

Even better for observers, Iota Horologii has the shortest magnetic activity cycle observed to



Wicked waves Astronomers have watched Iota Horologii's 1.6-year magnetic cycle repeat several times. Observations span more than six years in near-ultraviolet light, polarized ultraviolet light and X -rays, all ways to measure magnetic activity. The orange square at the top right might be a stellar flare.

date. It peaks and falls over just 1.6 years, Sanz-Forcada, Metcalfe and astrophysicist Beate Stelzer of Eberhard Karls University in Tübingen, Germany, reported in 2013 in *Astronomy & Astrophysics*. Researchers could observe the star's full cycle almost seven times in the time it takes the sun to cycle once.

To go after Iota Horologii, Alvarado Gómez got access to every telescope he could, stockpiling more data than astronomers usually get for a single star. "This became a much bigger project than what was envisioned," he says. "We wanted to map the magnetic cycle. But then we realized that there's much more that you can do."

Between October 2015 and September 2018, he and colleagues observed the star using the High Accuracy Radial velocity Planet Searcher, or HARPS, spectrograph at La Silla Observatory in Chile. Then he teamed up with Sanz-Forcada's group to watch the star in X-rays, ultraviolet and visible light using a trio of space telescopes.

He also gathered another 13 years of data from previous observations of Iota Horologii in a wavelength of light that tracks magnetism on stars' surfaces. "We were able to trace it back all the way to 2002 — when I was playing Halo," Alvarado Gómez says. He now has data on more cycles for Iota Horologii than astronomers have for the sun in certain wavelengths.

"These types of observations are rare, especially

J. ALVARADO GÓMEZ ET AL

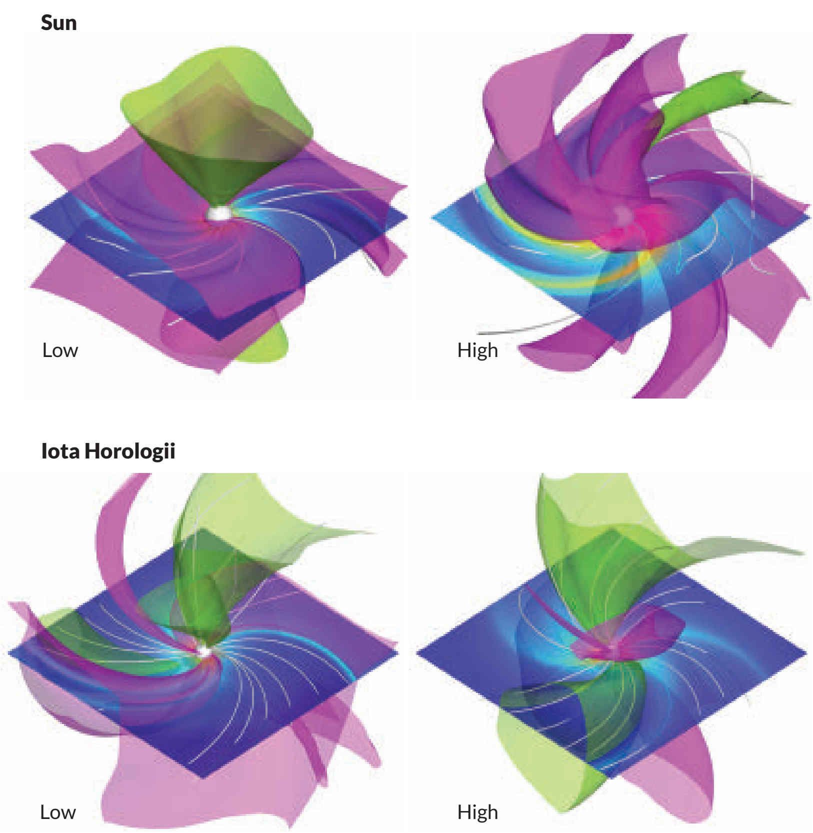
for new stars that haven't been observed a lot in the past," Metcalfe says. "It's enormously helpful to our understanding of where cycles come from and where they're going."

In late 2017, when Alvarado Gómez was writing the first paper on the HARPS observations, he learned Iota Horologii had a potential Halo connection that blew him away.

While searching for information about the star, he stumbled on a fan site laying out the case that the Halo star Soell is supposed to be Iota Horologii. The two have matching planets and similar properties and positions in the sky. It's possible, says Frank O'Connor, Halo franchise creative director at 343 Industries in Redmond, Wash. "Our normal process includes referencing our sci-fi against current scientific consensus, understanding and data. So it almost certainly got checked against real star systems ... and may indeed be the same one," he says.

"I just find it amazing," Alvarado Gómez says. He recalled his graduate adviser, astronomer Gaitee Hussain at ESO, telling him that stellar

Dancing winds The structure of the sun's winds (top row) changes with magnetic activity, as shown in these simulations. At low activity, the faster wind (green) swirls at the sun's poles, as slower wind (magenta) centers around the equator. At high activity, the wind grows more complex. Iota Horologii's winds are more variable throughout its magnetic cycle, data and simulations show.



physicists fall a little bit in love with the objects they study. "I was already in that process with Iota Horologii," he says. He took the potential connection to the game that helped get him back to school as "a sign that I should keep working on it."

Far beyond the sun

For all that Iota Horologii resembles the sun, its magnetic life looks subtly different in important ways, Alvarado Gómez and colleagues found. Those differences could hold clues to how sunlike stars change over time, and whether those changes influence their planets.

For one thing, Iota Horologii's magnetic field flips like the sun's — but faster. The sun flips once every cycle, so it takes two cycles to return to its original configuration. Iota Horologii's cycle is 1.6 years, but its polarity flips every 1.2 years. That speedy somersault could suggest that the internal engine that drives a star's magnetic field is different in young stars than in older ones.

Iota Horologii's magnetic activity cycle is also surprisingly stable, according to a paper the team posted September 3 at arXiv.org that will also appear in *Astronomy & Astrophysics*. Four cycles in a row lasted the same amount of time and reached the same activity levels.

"We never expected so much regularity," Sanz-Forcada says. "In the sun, [the cycle] is not so regular."

The sun's highest activity level varies from one cycle to the next; the most recent solar cycle had one of the wimpiest peaks ever recorded (*SN: 11/2/13, p. 22*). No one is sure why. But if Iota Horologii represents the sun in its youth, then the sun's cycles may have been more consistent a few billion years ago.

Alvarado Gómez is working on figuring out what all the data mean for Iota Horologii's stellar wind — and by extension, what winds could do to planets. He's making the first maps of the strength and direction of Iota Horologii's entire magnetic field at every point of the star's surface. He'll then use the maps to build computer simulations of the shape and strength of Iota Horologii's stellar wind.

He's also trying to observe the edge of Iota Horologii's stellar wind directly by looking for the star's hydrogen wall, a sheet of ultraviolet light produced when a star's wind slams into atoms from the surrounding interstellar environment (*SN: 9/15/18, p. 10*).

The hydrogen wall marks the edge of the star's sphere of influence. Measuring the wall's properties could reveal how much of Iota Horologii's mass

J. ALVARADO GÓMEZ ET AL/ARXIV.ORG 2019

is being carried away by the winds, and whether that mass loss changes with the stellar cycle.

Unfortunately, Iota Horologii showed no sign of a wall when Alvarado Gómez searched for one with the Hubble Space Telescope in September 2018. But he thinks he saw a wall for an even younger sunlike star called HD 147513, located about 42 light-years from Earth. If that's confirmed, the finding will be a major step toward learning how young stars lose mass, calm down and stop pummeling their planets.

Caged energy

Coronal mass ejections can also fling mass from stars and fry nearby planets. "If we know very little about winds, we know even less about CMEs," Alvarado Gómez says. Cracking the CME code could solve another stellar mystery: How do these violent young stars, which emit flares much more often than the sun, avoid quickly burning themselves out? And are their planets safe?

On the sun, the rare solar flares, sudden bright flashes of high-energy light, are almost always accompanied by CMEs. The brighter the flare, the bigger and faster the CME. Not so for young sunlike stars.

Some young stars emit bright flares nonstop — but without monstrous CMEs. Only one confirmed CME has been caught fleeing a star other than the sun in real time (*SN Online: 8/7/18*). Alvarado Gómez's collaborator Sofia-Paraskevi Moschou, an astrophysicist at the Harvard-Smithsonian Center for Astrophysics, identified only 12 more possible CMEs in a historical review in the May *Astrophysical Journal*.

That may be just as well. If those stars really were burping out enormous CMEs as often as they emit huge flares, Moschou says, "it would strip away all the energy of the star after a few events."

Alvarado Gómez thinks he knows what keeps the CMEs contained: a magnetic cage. This effect has been seen on the sun. The largest sunspot observed in the past 30 years, called AR 2192, sprouted in 2014. This spot generated hundreds of flares, some of which were in the strongest category ever observed. But none of those flares included a CME. The strong magnetic fields in that sunspot may have arced across the region and acted as a magnetic cage, preventing any CMEs from escaping.

Alvarado Gómez and colleagues think that in younger stars, the cage envelops the entire star, not just one star spot, the team reported in 2018 in the *Astrophysical Journal*.

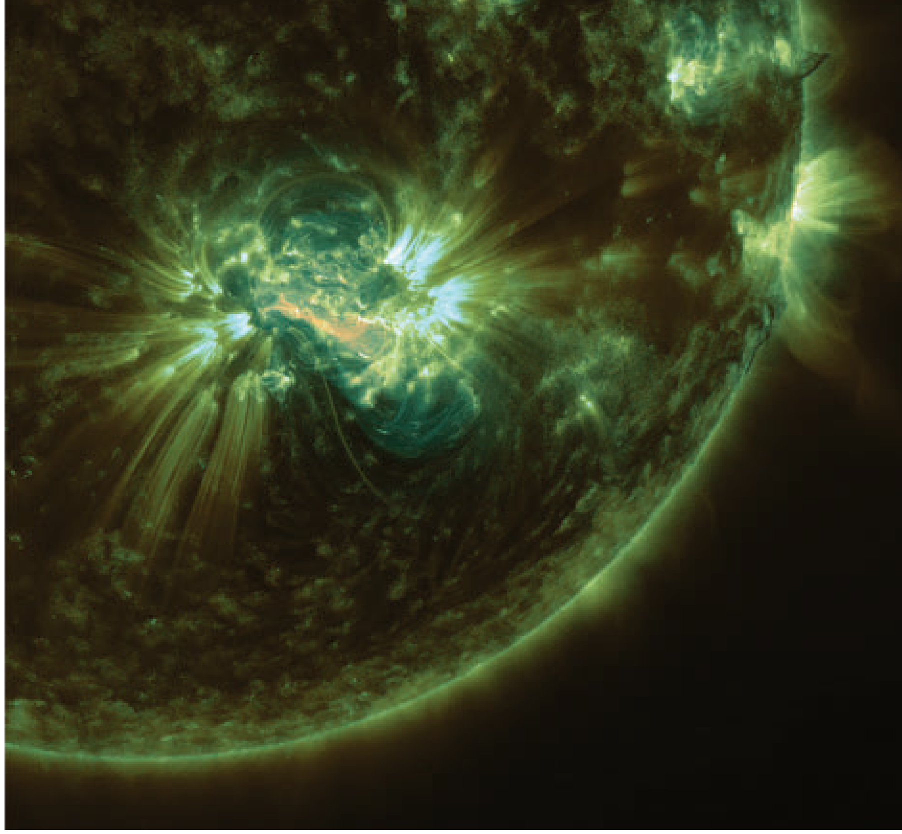
With a cage like that, "you could stop almost all the CMEs we have ever observed in the sun," he says. Even the CMEs that manage to escape would be slower and less energetic than expected from observed flares.

That's exactly what Moschou found: Bright flares give off slower CMEs than expected. That could be good news for the habitability of planets near these stars, although Alvarado Gómez thinks the case may be more mixed.

"The bad news is that this energy has to go somewhere," he says. It could go back into the star to power more flares, which also could be bad for life on orbiting planets (*SN Online: 3/5/18*).

Like young stars that slow their cycles over time, Alvarado Gómez has slowed his gaming. "I still play, but not on the same kind of level," says Alvarado Gómez, who will move to the Leibniz Institute for Astrophysics Potsdam in Germany this fall.

But he's reminded of his youthful obsession each time he opens his laptop to work on a stellar simulation. Halo's main character, Master Chief, is the image staring out from his screen. ■

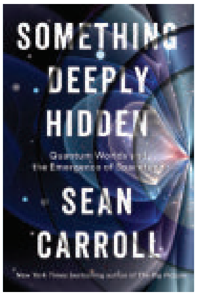


This monster sunspot, AR 2192 (orange in the center of this image from NASA's Solar Dynamics Observatory), emitted lots of bright flares in 2014, but no coronal mass ejections. A magnetic cage may have restrained the CMEs.

TAHAR AMARI *ET AL*/CENTER FOR THEORETICAL PHYSICS, ÉCOLE POLYTECHNIQUE, JOY NG/NASA GODDARD

Explore more

- Jorge Sanz-Forcada *et al*. "Multi-wavelength variability of the young solar-analog ιHor. X-ray cycle, star spots, flares and UV emission." Posted online at arXiv.org September 3, 2019.
- Julián D. Alvarado Gómez *et al*. "Far beyond the sun — I. The beating magnetic heart in Horologium." *Monthly Notices of the Royal Astronomical Society*. February 2018.



Something Deeply Hidden
Sean Carroll
DUTTON, $29

BOOKSHELF

Quantum physics may lead to many worlds

Quantum physics is about multiplicity.

Its equations describe multiple possible outcomes for a measurement in the subatomic realm. Physicists have devised a dozen or two different interpretations of what that really means. And in turn, dozens and dozens of books have been written to explain, defend or deny the validity of those various interpretations.

Caltech physicist Sean Carroll's *Something Deeply Hidden* defends one of the most provocative of those interpretations: that multiple possible measurement outcomes imply a multiplicity of universes. Known as the Many-Worlds Interpretation, that view contends that all the possible outcomes of quantum experiments actually come true.

Measuring the spin of an electron, for instance, might yield the result that the spin axis points either up or down. When the measurement is made, the universe splits, branching into two copies, one with the spin up, the other with the spin down. As each measurement is made, this view of quantum theory insists, additional universes are instantly created.

"The theory describes many copies of what we think of as 'the universe,'" Carroll writes, "each slightly different, but each truly real in some sense." If you want to know where these branches are, he says, "There is no 'place' where those branches are hiding; they simply exist simultaneously, along with our own, effectively out of contact with it."

Many Worlds is a well-known quantum interpretation, originated in the 1950s by American physicist Hugh Everett III. It was mostly ignored for a long time. But in recent decades, many physicists have found it (or variants of it) preferable to the traditional view of quantum mechanics associated with Danish physicist Niels Bohr.

That standard approach is often glibly derided as "shut up and calculate," since all the quantum math does is provide a recipe for calculating the likelihood of different experimental results. It doesn't have anything to say about what unseen, or deeply hidden, mechanisms might be responsible for the recipe. And all competing interpretations, it seemed, predicted the same observable results.

But maybe not. Carroll argues that the various interpretations are actually "well-constructed scientific theories, with potentially different experimental ramifications."

Carroll echoes Everett in contending that the key mathematical expression in quantum physics, known as the wave function, should be taken seriously. If the wave function contains multiple possible realities, then all those possibilities must actually exist. As Carroll argues, the wave function is "ontic" — a direct representation of reality — rather than "epistemic," a merely useful measure of our knowledge about reality for use in calculating experimental expectations. In epistemic interpretations, "the wave function isn't a physical thing at all, but simply a way of characterizing what we know about reality."

In the ontic view, favored by Carroll, reality as a whole is one comprehensive universal wave function. We split up into copies of ourselves as we travel along the branching paths of events that the wave function encompasses. Or, as Carroll suggests, you can think of the process "as dividing the existing universe into almost identical slices."

As quantum books go, Carroll's is exceptionally clear, conversational and enjoyable. He has a knack for linguistic lubrication that helps make some highly technical concepts reasonably smooth to swallow. His is by far the most articulate and cogent defense of the Many-Worlds view in book-length depth with a close connection to the latest ongoing research (in the arena known as quantum foundations).

There are some minor shortcomings. Carroll's historical passages are sketchy and sometimes misleading. The atoms proposed by Greek philosophers were not pointlike, as Carroll writes — they had size and shape and possibly even parts. And the last major salvo of Bohr's quantum debate with Albert Einstein was not papers on quantum entanglement in 1935, but Bohr's 1949 essay on the debate in a collection of papers about Einstein, and Einstein's reply.

Toward the end of the book, the clarity of Carroll's narrative diminishes somewhat — no doubt, as he acknowledges, because he has passed from the realm of established physics to the current unsettled search for the correct theory combining quantum physics with gravity. From that search, recent work indicates, an understanding of the quantum origins of space and time might emerge.

As for the many quantum worlds, Carroll's case is strong but not conclusive. As he notes, a process known as quantum decoherence is "absolutely crucial to making sense" of the Many-Worlds view, explaining what happens when measurements select one possibility out of the wave function. In essence, decoherence occurs when microscopic quantum objects get entangled with the macroscopic environment, ensuring that only one result is observed by an experimenter on one branch. The other outcome occurs in another branch.

But other quantum experts use decoherence to explain quantum phenomena without invoking multiple universes. And as Carroll admits, the decoherence process does not require belief in the reality of the other branches. It just seems to him (and many others) to be the most elegant explanation for quantum mysteries.

So it remains the case that the ultimate definitive account of how to properly explain quantum mechanics remains unwritten. That secret remains hidden, if perhaps not quite as deeply as it once was. — *Tom Siegfried*

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AUGUST 17, 2019

Not just neurons

Scientists at the Allen Institute for Brain Science in Seattle are probing neurons to understand how those cells let us think and act in ways that other animals can't, ***Laura Sanders*** *reported in "A menagerie of neurons"* (SN: 8/17/19, p. 22).

"The excellent article on neurons ... mentions that the answer to humanity's difference may not lie in the neurons at all, but in other cells, such as the glial cells," reader **Devin J. Starlanyl** wrote. "I have contacted quite a few people doing neuron research over the years," she wrote. "When I ask them why they are working with neurons, their reply has always been the same. The answers might be with the glial cells, but the money goes to the neuron research."

Neurons have long been considered the stars of the brain, likely responsible for really important jobs, such as memory, emotions and consciousness itself, **Sanders** says. "But it's true that glial cells, which are often described as supporting cast members that help neurons operate, are having a moment." Scientists are finding more unexpected and complex jobs for these brain cells: Glia have the power to change conversations between neurons by releasing chemical signals, regulating blood flow and even gobbling up neural connections (*SN: 8/22/15, p. 18*). Though there's never enough research money to go around, **Sanders** says, "with so many basic facts about the brain unknown, studying any cells in the human brain, neurons or glial cells, will undoubtedly lead to insights."

Carbon solutions

Planting roughly 1 billion hectares–worth of trees could trap about two-thirds of the carbon released by human activities since the Industrial Revolution began, ***Susan Milius*** *reported in "Planting forests can buy time to fight climate change"* (SN: 8/17/19, p. 4).

The story reminded reader **Ron Blachman** of the IronEx experiments, in which fertilizing the ocean with iron boosted carbon-absorbing algal blooms (*SN: 9/30/95, p. 220*). When those algae die, they sink to the ocean floor, taking carbon with them. In theory, more blooms could mean more carbon gets stored in the deep ocean. **Blachman** suggested scientists might also take an approach similar to IronEx.

Concern over climate change is resurrecting geoengineering ideas such as **Blachman's**, says *Science News* earth and climate writer **Carolyn Gramling**. "But there's a lot we don't know about consequences." Some experiments hint that iron fertilization of the ocean could boost levels of nitrous oxide or methane in the atmosphere. And fertilizing one patch of ocean might not trigger an overall bloom bonanza. What's more, big blooms in one locale could take additional nutrients away from other areas, she says.

Correction

"Threads of time" (*SN: 8/31/19, p. 16*) incorrectly reported that people started spinning thread around the fourth century B.C. People probably started in the fourth millennium B.C.

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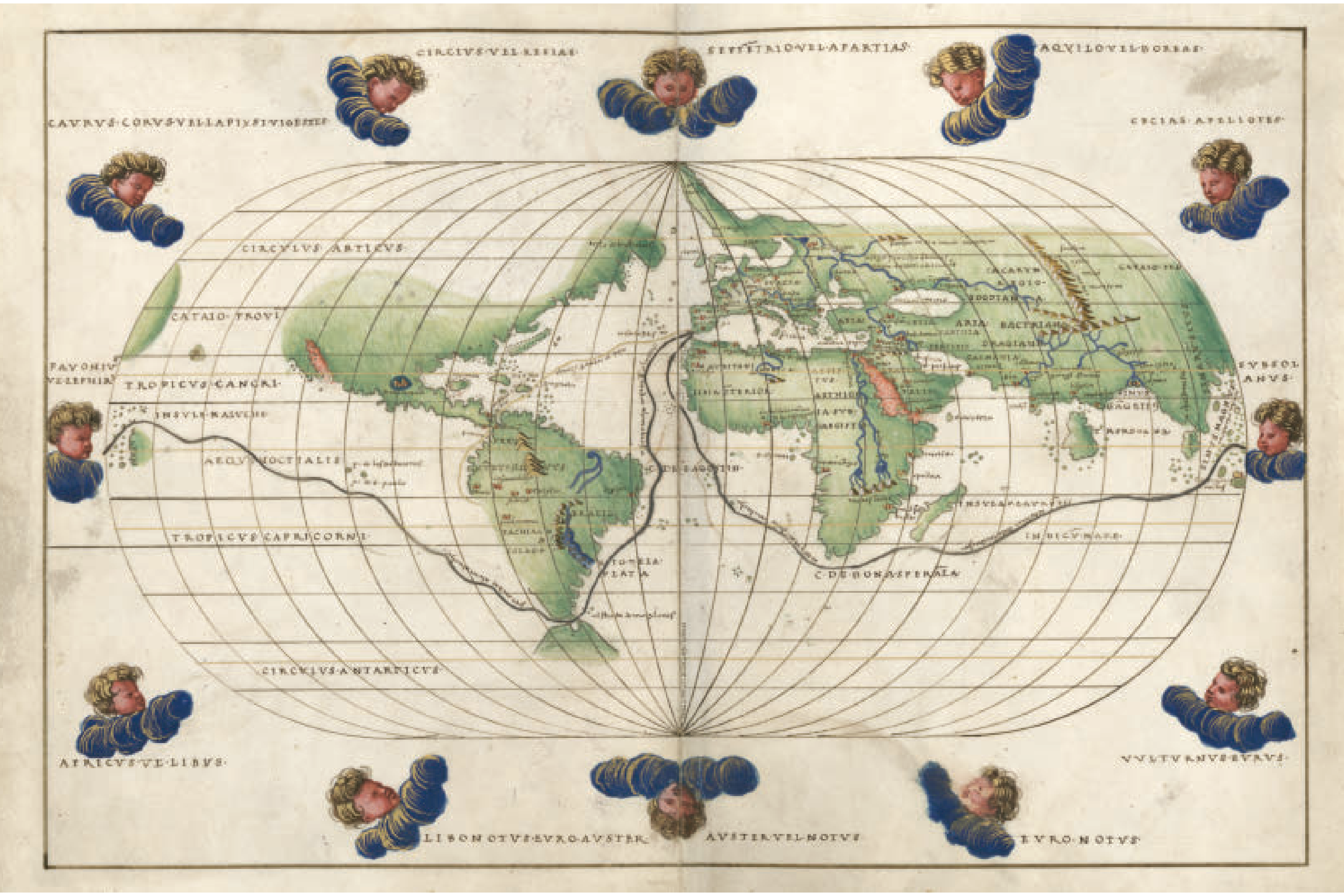
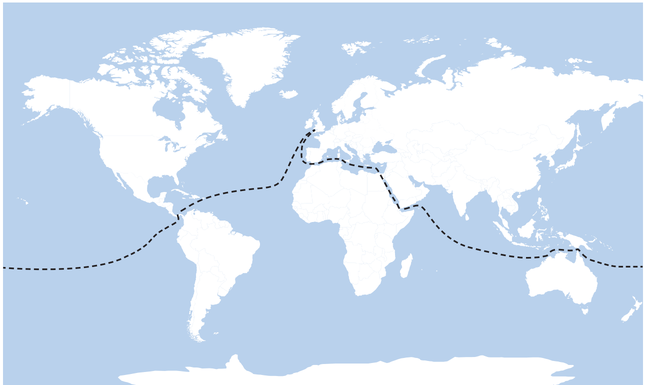


500 years after Magellan, circumnavigation is a shorter route

Half of a millennium ago, Portuguese explorer Ferdinand Magellan and his crew embarked on the first voyage to successfully sail around the world. A map (above) created by Genoese cartographer Battista Agnese ca. 1544 shows the approximate route: On September 20, 1519, Magellan's five-ship fleet set sail from Spain and traveled south, crossing the Atlantic to South America. There, the sailors happened upon a channel, later dubbed the Strait of Magellan, to the Pacific Ocean, and the ships continued west.

The journey was anything but smooth sailing. Magellan dealt with shipwrecks, mutiny and conflicts with indigenous people. He was killed during such a conflict in the Philippines in 1521. But his crew carried on, traversing the Indian Ocean and hooking around Africa's southern tip to sail north back to Spain. A lone ship docked in Seville in 1522.

Magellan's fleet barely managed to circumnavigate the globe in three years. Subsequent sailing voyages took roughly as long until engineering feats in the 19th and 20th centuries



shortened the trip by thousands of kilometers (a typical modern route shown with dotted line). In 1869, the Suez Canal opened a corridor by way of Egypt that allowed quicker passage between the Atlantic and Indian oceans. And the Panama Canal, completed in 1914, meant ships could cross between the Atlantic and Pacific without having to sail most of the way around South America. Together, those shortcuts shave off roughly a year of travel. — *Cassie Martin*

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