Humans' Heat Limit | A Recipe for Green Jet Fuel

# Science News

MAGAZINE OF THE SOCIETY FOR SCIENCE ■ AUGUST 27, 2022

## Pluto's Icy Kingdom

The distant Kuiper Belt helps explain solar system evolution

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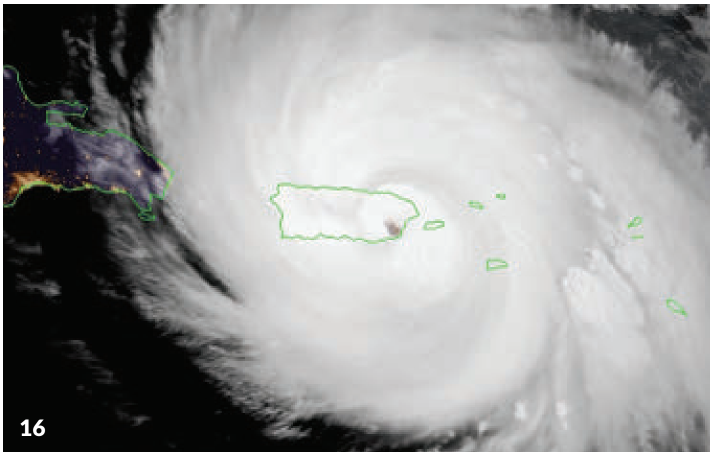
# ScienceNews

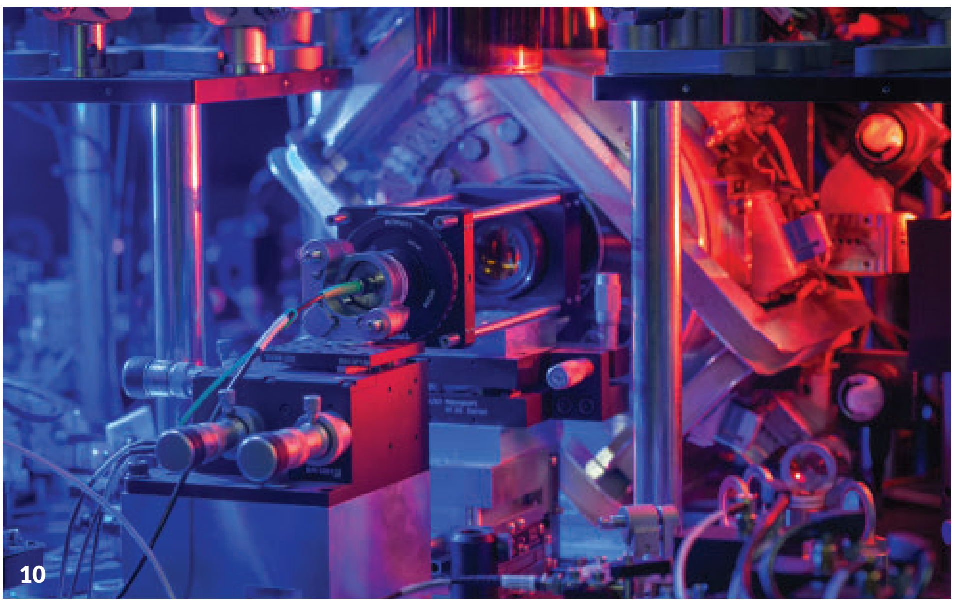


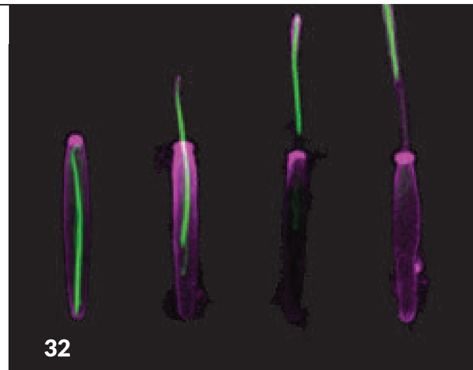

## Features



## News






## Departments



**COVER** The solar system's Kuiper Belt is beyond Neptune's orbit and home to Pluto and a slew of other icy bodies. *Nicolle R. Fuller/SayoStudio*

FROM TOP: CIRA/NOAA; THE GIBSON LAB/STOWERS INSTITUTE FOR MEDICAL RESEARCH; DAVID NADLINGER/UNIV. OF OXFORD

# Summer nights may never be the same again

The summers of my Midwestern childhood were sticky hot. During the day, backyard sprinklers, Popsicles and squirt gun battles helped us cool off. At night, we ran window fans and hoped for cooler air.

But those summer nights seem idyllic compared with the extraordinary heat waves that people around the world are suffering through now. This summer, thousands of new records have been set not just for daily high temperatures, but also for warmest overnight lows. Hot nights are dangerous because they rob people of the chance to cool down before the next sweltering day.

Scientists have long known that prolonged heat waves are more deadly than a short blast. New research suggests that people may not be able to endure as much heat as once thought, earth and climate writer Carolyn Gramling reports in this issue (Page 6). And those data come from young, healthy adults who were subjected to high heat for 1.5 to two hours in laboratory conditions. Older people, children and people with medical conditions most likely face higher risks.

A lot of factors go into figuring out how dangerous heat is to humans, Gramling reports, including humidity, whether high heat is unusual for that location, as in the Pacific Northwest, and if the heat wave comes earlier in summer, before people have time to acclimate. These days, weather reports saying "It's gonna be hot out there" often aren't enough to help people understand the risk and protect themselves.

There's no standard definition for when a heat wave becomes life-threatening. Scientists around the world are working on ways to standardize warnings — and name heat waves like we do hurricanes (SN: 9/12/20, *p.* 4). Those efforts, experts hope, will make it easier for people to know what they're up against, and prepare.

In this issue, we also explore how gathering data in one field of science can unexpectedly deliver insights about a completely different question. In this case, researchers studying how pollution affects coral reefs off Puerto Rico installed underwater sensors a few months before Hurricane Maria roared through in September 2017 (Page 16). The team figured the equipment was destroyed, freelance writer Martin J. Kernan reports. But not only did the instruments survive, they also revealed unexpected shifts in water flow and temperature that fueled the intensity of the storm.

And last month, a group of journalists from Latin America visited *Science News* as part of an exchange program. They were intensely interested in how we cover climate change, including how we get readers engaged in a subject that can seem both overwhelming and dauntingly technical. Gramling's and Kernan's articles are great examples of how we do it. Climate change now touches just about every beat our journalists cover, just as it touches all of our lives. If you're not intrigued by how ocean currents influence hurricanes, you may enjoy learning about six foods that may become more popular as the planet warms (SN: 5/7/22 & 5/21/22, *p.* 34).

We also cover climate change and potential solutions through our *Science News Explores* website and new print magazine for readers ages 9 and up. We'll keep them — and us more seasoned readers — up to speed on the latest innovative ideas that aim to ensure a brighter future for us all. — *Nancy Shute, Editor in Chief*

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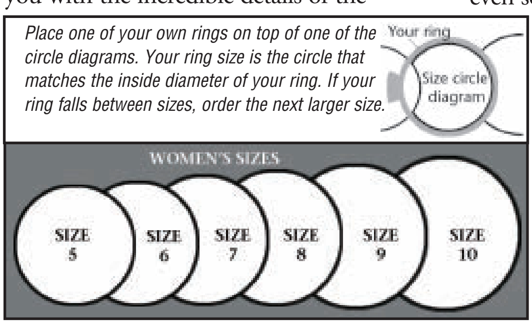


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Excerpt from the September 2, 1972 issue of *Science News*

50 YEARS AGO

## Visualizing genes

Molecular biologists can now visualize the larger structures of the cell, such as the nucleus and chromosomes, under the powerful electron microscope. But they have not been able to obtain images of genes (DNA) on the chromosomes. Nor have they been able to see RNA … or the intricate details of cell membranes, enzymes and viruses.

**UPDATE:** Electron microscopes have become much more powerful over the last 50 years. For instance, in 1981, biophysicist Jacques Dubochet discovered that tiny biological structures supercooled with ethane could be observed in their natural state under an electron microscope. That finding paved the way for cryo-electron microscopy, which scientists use to visualize proteins, viruses and bacteria at the molecular level (*SN: 10/28/17, p. 6*).

Capturing detailed images of genes remains elusive, but scientists are inching closer. In 2021, researchers reported using an electron microscope and the molecular scissors CRISPR/Cas9 to visualize proteins transcribing DNA instructions for two genes into RNA.

THE SCIENCE LIFE

# Amateur astronomers help unravel a mysterious aurora's birth

Snapshots of two types of auroras together (the red and green bands) suggest that the mysterious red glow is caused by electron rain.

When two different kinds of auroras get together, one spills the other's secrets.

Amateur astronomers have captured a strange union of red and green auroras on camera. And physicists have now used the images to learn what may trigger the red, more mysterious part of the light show.

Photographer Alan Dyer was in his backyard in Strathmore, Canada, in 2021 when he saw the lights dancing overhead and started filming. "I knew I had something interesting," Dyer says. What he didn't know was that he had just made the most complete recording of this rarely seen phenomenon.

At a glance, the video looks like it shows a celestial watermelon. The rind, a rippling green aurora, is well understood: It appears when the solar wind energizes protons trapped within Earth's magnetic field, which then rain down and knock electrons and atoms around (SN: 12/13/03, p. 372). That action is what gives this green glow — called a proton aurora — its name.

The swath of fruity magenta is more mysterious. Though scientists have known about these stable auroral red arcs for decades, there's no widely accepted proof of how they form. One popular theory is that Earth's magnetic field heats up the atmosphere and, like proton rain, jostles particles.

Researchers had seen both types of aurora before, but the combination was odd, says space physicist Toshi Nishimura of Boston University. "Scientists didn't have a good idea of why they could be together."

Along with satellite observations, Dyer's images and similar ones captured by other amateur astronomers in Finland show how the two phenomena may be related, Nishimura's team reports in the July *JGR: Space Physics*.

The auroras appearing together hint that they form in a similar way. And thin rays in the red aurora, never before seen at the same time as a green proton aurora, provide strong evidence for that idea, the scientists report.

The lines trace the paths of electrons as they fall along the Earth's magnetic field. Since electrons carry less energy than protons, the negatively charged particles make for a more reddish color.

So just as proton rain triggers the green aurora, electron rain may trigger the red one, with the solar wind powering both at the same time, the team says.

Electron rain may not be the only way to produce stable auroral red arcs, says space physicist Brian Harding of the University of California, Berkeley. Still, the results are exciting because they show what's going on is more complicated than researchers thought, he says.

The findings would not have been possible without amateur astronomers, Nishimura says. "When they take more and more cool images, they find more and more things that we don't know about." — *Asa Stahl*

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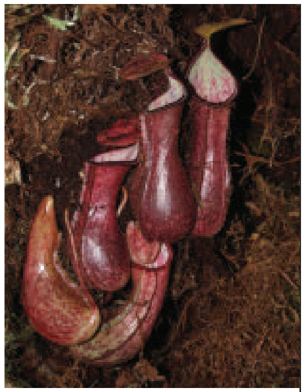
Watch a video of the rare light show at **bit.ly/SN_AuroraSecrets**

INTRODUCING

## This pitcher plant hides its deathtraps



A newfound meat-eating pitcher plant species sets traps in an unusual location: underground.

On a hike through a rainforest in Borneo, biologist Martin Dančák and colleagues stumbled upon a subterranean surprise.

Hidden within dark, mossy pockets below tree roots, carnivorous pitcher plants dangled their deathtraps underground. The pitchers look like hollow eggplants and probably lure prey into their sewer hole–like traps. Once an ant or a beetle steps in, the insect falls to its death, drowning in a stew of digestive juices (SN: 1/21/17, *p.* 4). Until now, scientists had never observed pitcher plants with traps almost exclusively entombed in earth.

"We were, of course, astonished as nobody would expect that a pitcher plant with underground traps could exist," says Dančák, of Palacký University Olomouc in Czech Republic.

That's because pitchers tend to be fragile. But the new species, described June 23 in *PhytoKeys*, has traps with fleshy walls, which may help the plant push against soil as it grows. Since the pitchers stay hidden, the team named the species *Nepenthes pudica*, a nod to the Latin word for bashful. —*Meghan Rosen*

TEASER

## Tears fuel a new diagnostic tool

Human tears could carry a flood of useful information. With just a few drops, a new technique can spot eye disease and even signs of diabetes, biomedical engineer Fei Liu and colleagues report July 20 in *ACS Nano*.

The method could open a window for scientists to peer into the entire body and perhaps even let people test their tears at home, says Liu, of Wenzhou Medical University in China.

Tears contain tiny sacs stuffed with cellular messages. Intercepting these microscopic mailbags, called exosomes, could offer intel on what's happening inside the body. But separating enough of them from tiny volumes of tears is tricky. The researchers' method filters a solution containing human tears through two vibrating nanoporous membranes, isolating the sacs within minutes.

Analysis of the sacs gave scientists an eyeful. Different types of dry eye disease and stages of diabetes shed their own molecular fingerprints in people's tears, the team reports. The latter finding suggests tears could help doctors monitor how a patient's diabetes is progressing. Now, the scientists want to tap tears for evidence of other diseases, as well as depression and emotional stress, says study coauthor Luke Lee, a bioengineer at Harvard Medical School. "This is just the beginning," he says. "Tears express something that we haven't really explored." —*Meghan Rosen*

FOR DAILY USE

## Math hints at the quickest way to grill burgers

If you have a hankering for a hamburger, math may have some timesaving cooking tips for you.

Continually flipping a burger reduces its cook time by up to nearly a third compared with the single-flip method, theoretical calculations suggest. But cooks at home probably won't see much benefit out of more than three to four flips, mathematician Jean-Luc Thiffeault of the University of Wisconsin–Madison reports June 25 in *Physica D: Nonlinear Phenomena*.

Thiffeault used math to model how heat moves through a theoretical slab of meat that cooks continuously on the bottom side and cools on the top until the meat is flipped. Flipping heated the meat evenly, speeding up cooking, the analysis showed. And more flips led to a faster cook. For example, flipping this 1-centimeter-thick patty just once cooked it in about 80 seconds, while flipping it 10 times at intervals ranging from six to 11 seconds cooked the slab in 69 seconds.

For the fastest way to cook a burger, flip the patty three or four times, a mathematician says.

Flipping the burger multiple times decreased cooking time by up to 29 percent compared with flipping it once. But the timesaving benefit diminished as the number of flips increased beyond a certain threshold, Thiffeault says. "After three or four flips, the gain in time is negligible."

Thiffeault's findings align with what chef and food writer J. Kenji López-Alt has observed in the kitchen. In a 2019 article for the food and drink website Serious Eats, López-Alt compared how long it took for a burger's internal temperature to reach about 52° Celsius based on cooking method. Flipping a burger every 15 seconds, as opposed to flipping the patty just once, shortened cooking time by nearly a third.

But there isn't a one-size-fits-all way to cook a burger, López-Alt notes. "It's all based on what you want," he says. Thiffeault's model accounts for only how cooked the meat is and doesn't consider factors such as sear or juiciness.

His friends probably wouldn't want his theoretical hamburger, Thiffeault jokes. At 70° C when cooked, "it's quite a well-done burger." —*Anil Oza*

CLOCKWISE FROM TOP LEFT: M. DANČÁK *ET AL*/*PHYTOKEYS* 2022; SPICYTRUFFEL/ISTOCK/GETTY IMAGES PLUS; BIGACIS/ISTOCK/GETTY IMAGES PLUS

# News

EARTH & ENVIRONMENT

## How much heat can we handle?

### The human body's tolerance may be lower than thought

On July 20, misting fans offer some relief from an intense heat wave in Baghdad.

AHMAD AL-RUBAYE/AFP VIA GETTY IMAGES

**BY CAROLYN GRAMLING**

More than 2,000 people dead from extreme heat and wildfires raging in Portugal and Spain. High temperature records shattered from England to Japan.

Brutal heat waves quickly became the hallmark of the summer of 2022.

Recent research suggests that people's tolerance to heat stress may be lower than previously thought. If true, millions more people could be at risk of succumbing to dangerous temperatures sooner than expected. That's bad news as climate change cranks up the temperature.

"Bodies are capable of acclimating over a period of time" to temperature changes, says Vivek Shandas, an environmental planning and climate adaptation researcher at Portland State University in Oregon. Over geologic time, there have been many climate shifts that humans have weathered, Shandas says. But "we're in a time when these shifts are happening much more quickly."

Heat waves ravaged many countries this year. In April, Wardha, India, saw a high of 45° Celsius (113° Fahrenheit); in May in Nawabshah, Pakistan, temperatures rose to 49.5° C (121.1° F). And extreme heat alerts have blared across Europe. The United Kingdom shattered its hottest-ever record July 19 when temperatures reached 40.3° C in the English village of Coningsby.

The litany goes on: June brought Japan's highest recorded June temperature of 40.2° C. And a series of heat waves gripped parts of the United States in June and July. Temperatures soared to 42° C in North Platte, Neb., and to 45.6° C in Phoenix.

The heat already is taking an increasing toll on human health. It can cause heat cramps, heat exhaustion and heat stroke, which is often fatal. Dehydration can lead to kidney and heart disease. Extreme heat can even change how we behave, increasing aggression and decreasing our ability to focus (*SN: 9/11/21, p. 14*).

### Staying cool

The human body has various ways to shed excess heat and keep the core of the body at an optimal temperature of about 37° C. The heart pumps faster, speeding up blood flow that carries heat to the skin (*SN: 4/14/18, p. 18*). Air passing over the skin can wick away some of that heat. Evaporative cooling — sweating — also helps.

But there's a limit to how much heat humans can endure. In 2010, scientists estimated that theoretical heat stress limit to be at a "wet bulb" temperature of 35° C. Wet bulb temperatures depend on a combination of humidity and "dry bulb" air temperature measured by a thermometer. Those variables mean a place could hit a wet bulb temperature of 35° C in different ways — for instance, if the air is that temperature and there's 100 percent humidity, or if the air temperature is 45° C and there's 50 percent humidity. The difference is due to evaporative cooling.

When water evaporates from the skin, it steals away energy in the form of heat, briefly cooling the skin. That means that in drier regions, the wet bulb temperature will be lower than the actual air temperature because that ephemeral cooling effect happens readily. In humid regions, however, wet and dry bulb temperatures are similar, because the air is so moist it's difficult for sweat to evaporate quickly.

So when thinking about heat stress on the body, scientists use wet bulb temperatures because they are a measure of how much cooling through evaporation is possible in a given climate, says Daniel Vecellio, a climate scientist at Penn State.

"Both hot/dry and warm/humid environments can be equally dangerous," Vecellio says — and this is where the body's different cooling strategies come into play. In hot, dry areas, where the outside temperature may be much hotter than skin temperature, human bodies rely entirely on sweating to cool down, he says. In warm, humid areas, where the air temperature may be cooler than skin temperatures (but the humidity makes it feel warmer than it is), the body can't sweat as efficiently. Instead, the cooler air passing over the skin can draw away the heat.

### How hot is too hot?

Given the complexity of the body's cooling system, and the diversity of human bodies, there isn't really a one-size-fits-all threshold temperature for heat stress for everybody. "No one's body runs at 100 percent efficiency," Vecellio says.

Still, for the last decade, that theoretical wet bulb 35° C number has been considered to be the point beyond which humans can no longer regulate their body temperature. But recent laboratory-based research by Vecellio and colleagues suggests that a general, real-world threshold for human heat stress is much lower, even for young and healthy adults.

The researchers tracked heat stress in two dozen subjects ages 18 to 34, under a variety of controlled climates. In the series of experiments, the team varied humidity and temperature conditions within an environmental chamber, sometimes holding temperature constant while varying the humidity, and sometimes vice versa.

Participants exerted themselves within the chamber just enough to simulate minimal outdoor activity, walking on a treadmill or pedaling slowly on a bike with no resistance. During these 1.5- to two-hour sessions, the researchers measured the subjects' skin temperatures and assessed their core temperatures using a small telemetry pill that the subjects swallowed.

In warm and humid conditions, study participants were unable to tolerate heat stress at wet bulb temperatures of about 30° or 31° C, the team estimates. In hot and dry conditions, that wet bulb temperature was even lower, ranging from 25° to 28° C, the researchers reported in the February *Journal of Applied Physiology*. For context, in a very dry environment at about 10 percent humidity, a wet bulb temperature of 25° C would correspond to an air temperature of about 50° C (122° F).

These results suggest that there is much more work to be done to understand what humans can endure under real-world heat and humidity conditions, but that the threshold may be much lower than thought, Vecellio says. The 2010 study's theoretical finding of 35° C may still be "the upper limit," he adds. "We're showing the floor."

And that's for young, healthy adults doing minimal activity. Thresholds for heat stress are expected to be lower for outdoor workers required to exert themselves, or for children or older adults. Vecellio and colleagues are assessing laboratory limits for more at-risk people.

If the human body's tolerance for heat stress is generally lower than scientists have realized, that could mean millions more people will be at risk from the deadliest heat in the near term than scientists had thought. As of 2020, there were few reports of wet bulb temperatures around the world reaching 35° C, but climate simulations project that limit could be regularly exceeded in parts of South Asia and the Middle East by the middle of this century.

Some of the deadliest heat waves in the last two decades were at lower wet bulb temperatures: Neither the 2003 European heat wave, which caused an estimated 30,000 deaths, nor the 2010 Russian heat wave, which killed over 55,000 people, exceeded wet bulb temperatures of 28° C.

## Protecting people

How best to inform the public about heat risk is "the part that I find to be tricky," says Shandas, who wasn't involved in Vecellio's research. Shandas developed the scientific protocol for the National Integrated Heat Health Information System's urban heat island campaign to map neighborhood hot spots in U.S. cities.

Physiological and environmental variability still make it difficult to know how best to apply Vecellio's findings to extreme heat warnings for the public, he says. "There are so many microconsiderations that show up when we're talking about a body's ability to manage [its] internal temperature."

One of those considerations is the body's ability to quickly acclimate to a temperature extreme. Regions that aren't used to extreme heat may experience greater mortality, even at lower temperatures, simply because people there aren't used to the heat. The 2021 heat wave in the Pacific Northwest wasn't just extremely hot—it was extremely hot for that part of the world at that time of year, which makes it more difficult for the body to adapt, Shandas says.

Heat that arrives unusually early can also be more deadly, says Larry Kalkstein, a climatologist at the University of Miami and the chief heat science adviser for the Washington, D.C.–based nonprofit Adrienne Arsht-Rockefeller Foundation Resilience Center. "Often early season heat waves in May and June are more dangerous than those in August and September."

Treating heat waves like other natural disasters, including giving them names and severity rankings, may help. Rankings developed by an international coalition known as the Extreme Heat Resilience Alliance form the basis of a new type of heat wave warning that considers the factors that impact heat stress, such as wet bulb temperature and acclimation.

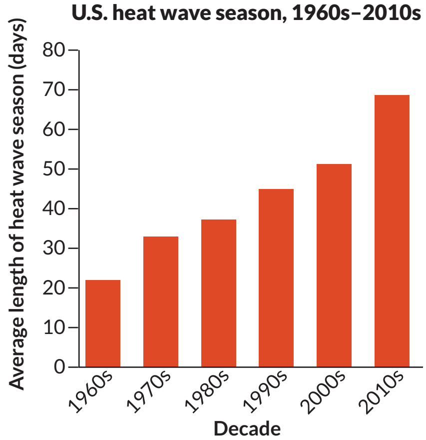
The rankings also consider factors such as cloud cover, wind and overnight temperatures. "If it's relatively cool overnight, there's not as much negative health outcome," says Kalkstein, who created the system. But in many places, overnight temperatures aren't getting as low as they used to. In the United States, for example, the average minimum temperatures at night are now about 0.8 degrees C warmer than during the first half of the 20th century.

By naming and ranking heat waves, officials hope to increase citizens' awareness of the dangers of extreme heat and help cities tailor their interventions to the severity of the event. Six metro areas are testing the system's effectiveness: four in the United States and Athens, Greece, and Seville, Spain. On July 24, with temperatures heading toward 42° C, Seville became the first city in the world to officially name a heat wave, sounding the alarm for Heat Wave Zoe.

As 2022 continues to smash temperature records, such warnings may come not a moment too soon. ■

**Rising heat** In the United States in the 1960s, the average time between the beginning of the first heat wave and the end of the last heat wave in a year was about 24 days. By the 2010s, the average heat wave season had lengthened to almost 70 days. SOURCE: NOAA, EPA

**Change in the duration of annual U.S. heat wave season, 1960s–2010s**




E. OTWELL

HUMANS & SOCIETY

# Friendships can lift kids out of poverty

## Connections to richer peers lead to greater earnings later

**BY SUJATA GUPTA**

Relationships can have a profound influence on a life, from the schools that people attend to the jobs they land. But teasing out how those connections impact a person's economic status is tricky. Now, an analysis of billions of Facebook connections suggests that childhood friendships between wealthier and poorer individuals are linked to increased earnings later in life for children from low-income families, researchers report in the Aug. 4 *Nature*.

The study uses big data to explain long-standing research showing that a child's loose social connections, such as to mentors or wealthier friends' parents, can help lift that child out of poverty, says sociologist Xi Song of the University of Pennsylvania, who was not involved with the research.

"For people you know very well, with whom you have strong ties, you have very similar resources or social statuses," Song says. "But what will really help you find a job, say…are those with a weak tie to you." People outside a child's immediate orbit can show them options for the future they may otherwise never consider, such as certain career tracks.

Economist Raj Chetty of Harvard University and colleagues used data on roughly 72 million U.S. Facebook users ages 25 to 44. If a child from a relatively low-income home were to live where they can make roughly the same number of wealthy friends as the average wealthy child, the adult income of the child with little means would be 20 percent higher on average than would be expected without that network, the team found.

Those friendships across class—what the team calls economic connectedness—are "one of the strongest predictors of economic mobility that anyone has identified to date," Chetty said in a July 28 news conference.

Other studied measures of social capital, or the value of one's relationships, such as civic engagement or how tight-knit a friendship network is, showed no link to higher-than-expected earnings.

The team gauged socioeconomic status by looking at the average income in a Facebook user's residential neighborhood and self-reported educational attainment. Individuals were then divided into below-median and above-median income groups.

The team also identified the drivers of economic connectedness, dubbed "exposure" and "friending bias," in a second study in the same issue of *Nature*. Exposure refers to the average number of high-income people that a low-income person comes into contact with in daily life, such as at school, work or a religious organization. Friending bias refers to the rate at which low-income people befriend higher-income individuals within those social spheres. High friending bias can arise from both people's desire to hang out with others like themselves and structural barriers, such as sorting kids into different academic tracks, Chetty said.

> Friendships across class "are one of the strongest predictors of economic mobility that anyone has identified to date."
> RAJ CHETTY

Surprisingly, only about half of the social disconnect in the United States arises from a lack of exposure, or segregation, the researchers found. The other half arises from friending bias. So policies aimed at increasing exposure alone, such as busing children to certain schools, are insufficient to facilitate economic connectedness, the team says.

So much effort has gone toward intensive efforts to integrate groups, says economist Bruce Sacerdote of Dartmouth College, who cowrote a perspective in *Nature* on the studies. This work suggests "there may be simpler, lower cost things you can do to increase connectedness without, say, moving your entire family."

For instance, Lake Highlands High School in Texas has roughly the same percentage of students from high and low socioeconomic backgrounds but high friending bias. Administrators and students recently identified the school's architecture as a culprit. The school had three cafeterias, which caused students to sort themselves into lunchrooms based on social class. So architects created a single lunchroom for everyone to mix together and more spaces for interaction.

Chetty's team has released a public dataset that allows users to gauge the level of connections between high-income and low-income people for every county, ZIP code, high school and college in the United States. The team hopes that policy makers and school administrators can use this data to identify class integration policies that will work best given local conditions.

Building connections—even after childhood ends—is key to reducing friendship bias and improving economic outcomes, the researchers emphasize. As an example of the type of program that's needed, they point to Inner City Weightlifting, headquartered in Dorchester, Mass., whose mission is connecting people from different social worlds. The nonprofit trains people from impoverished backgrounds as personal gym trainers and then connects them to more well-heeled clients.

"Generally, trainers and clients become friends," says founder and CEO Jon Feinman. He has seen clients vouch for their trainers in court or pay for their kids to attend expensive summer camps.

Bobby Fullard, 30, is one of those trainers. He remembers a couple years ago when a white client at the gym invited him to run with her. Fullard, who is Black, agreed reluctantly. "The most uncomfortable thing to me is talking to a white woman. I just don't think they are ever going to understand my world," Fullard says. When he showed up, the woman had brought a friend, another white woman. He was doubly anxious. "I'm saying two words every time I speak," he recalls. But he got more comfortable over time, and the trio have been running together ever since. More recently, Fullard launched his own carpentry business. Among his first clients? Those two running partners. ■



Explore U.S. data on economic connectedness at **bit.ly/SocialCapitalData**

# Warm-bloodedness tracked to Triassic

## Inner ears may record rise in mammal body temperatures

**BY CAROLYN GRAMLING**

Hot or not? Peeking inside an animal's ear — even a fossilized one — may tell you whether it was warm- or cold-blooded. An analysis of the size and shape of inner ear canals suggests that mammal ancestors abruptly became warm-blooded about 233 million years ago, researchers report in the July 28 *Nature*.

Warm-bloodedness, or endothermy, is one of mammals' key features, allowing the animals to regulate their internal body temperatures by controlling their metabolic rates. This feature allowed mammals to occupy environmental niches from pole to equator, and to weather the instability of ancient climates.

When endothermy evolved, however, has been a mystery. Analyses of growth rates and oxygen isotopes in ancient bones have suggested an emergence date as early as 300 million years ago.

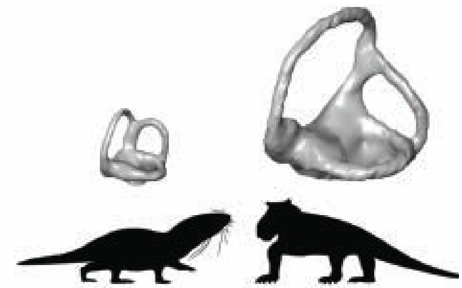
The inner ear holds the key to solving that mystery, suggests vertebrate paleontologist Ricardo Araújo of the University of Lisbon in Portugal. In vertebrates, the labyrinth of semicircular canals in the inner ear contains a fluid that responds to head movements, brushing against hair cells in the ear and helping to maintain a sense of balance. That fluid can become thicker or thinner depending on body temperature.

"Mammals have very unique inner ears," Araújo says. Compared with cold-blooded vertebrates of similar size, the dimensions of mammals' semicircular canals are particularly small, he says. "The ducts are very thin and tend to be very circular compared with other animals."

What if, Araújo and colleagues hypothesized, the size and shape of the ear canals relate to body temperature? In warm-blooded animals, the ear fluid becomes less viscous, and the canals may have shrunk to compensate. If so, it may be possible to trace how the shape of fossilized inner ear canals changed over time to discover when warm-bloodedness emerged.

To test that hypothesis, the researchers studied 341 different vertebrates and created a tool they call the "thermo-motility index" that links inner ear dimensions to an animal's ability to regulate its body temperature. Accounting for size differences, the value of the index turned out to closely track body temperature across fish, reptiles and mammals. Reptiles had low index values; mammals had high ones.

The team applied this index to the fossilized ear canals of 56 mammal ancestor species. The data showed a sharp change in inner ear morphology about 233 million years ago corresponding to an increase in body temperature of between 5 and 9 degrees Celsius — suggesting that endothermy evolved abruptly around that time. "The fact that it is a sharp break in the data [suggests] the transition happened rapidly, within about a million years," says coauthor Kenneth Angielczyk, a paleontologist at the Field Museum in Chicago.



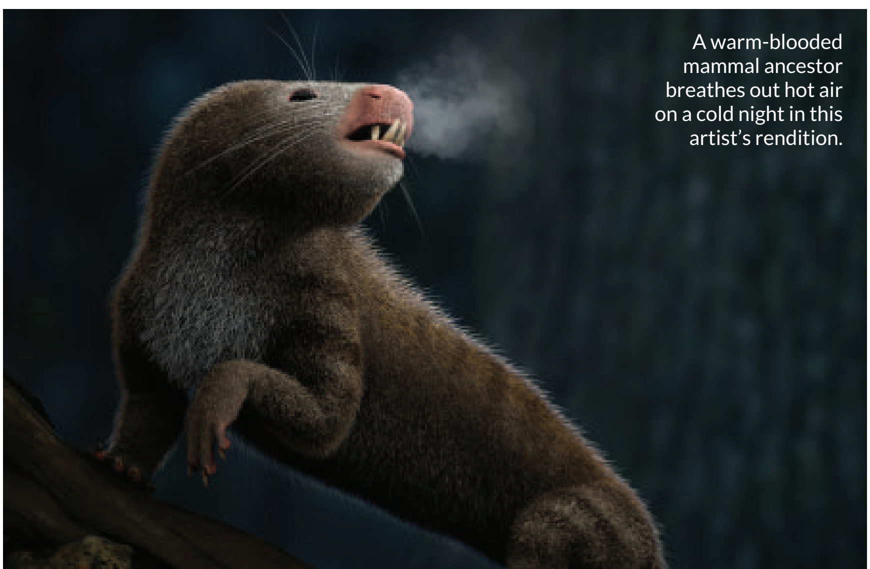
Warm-blooded mammal ancestors had smaller, more tightly curved inner ear canals (left) than earlier cold-blooded animals called synapsids (right) of a similar body size.

It's a clever study, says Stephen Brusatte, a paleontologist at the University of Edinburgh. "I've been using [computed tomography] data to study the shapes of inner ears for years to try to infer how extinct species moved and how they could hear, and it never occurred to me that inner ear shape is related to metabolism and could be used to predict body temperatures of fossil species."

However, Brusatte notes, there's a limit to what scientists can glean from fossilized ear canals alone. They don't reveal what soft tissues may have been present, such as the hair cells, or the actual viscosity of the ear fluid. "Shape alone may not always be sufficient to predict something as complex as body temperature or metabolic style," he says.

The timing of the purported shift corresponds to a geologically brief interlude of highly unstable climate known as the Carnian Pluvial Episode. "It was a time when global temperatures were changing a lot, and it was also a very wet, humid time," Angielczyk says. "One of the benefits of endothermy is that it stabilizes the internal body environment, lets you operate independent of environmental conditions."

The finding highlights how "the whole Triassic was a bit insane," Araújo says. The start of the Triassic Period, on the heels of the mass extinction at the end of the Permian Period, was epically hot. Vertebrates had just begun to recover from the extinction when the Carnian Pluvial Episode hit. The Triassic also saw the dawn of mammals and dinosaurs. All of the instability may have armed both groups with the evolutionary tools needed to weather yet another mass extinction, at the end of the Triassic 201 million years ago. ■



A warm-blooded mammal ancestor breathes out hot air on a cold night in this artist's rendition.

FROM TOP: ROMAIN DAVID, R. ARAÚJO; LUZIA SOARES

MATTER & ENERGY

# Quantum missives that can't be hacked

## Entanglement confirms the security of quantum encryption

**BY EMILY CONOVER**

Stealthy communication just got more secure, thanks to quantum entanglement.

Quantum physics allows for the sharing of secret information in a way that's mathematically proven to be safe from the prying eyes of spies. But demonstrations of the technique, called quantum key distribution, have rested on an assumption: The devices used to create and measure quantum particles have to be known to be flawless. Hidden defects could allow a snoop to penetrate the security unnoticed.

Now, three research teams have demonstrated the ability to perform secure quantum communication without prior confirmation that the devices are foolproof. Called device-independent quantum key distribution, the method is based on quantum entanglement, a mysterious relationship between particles that links their properties even over long distances.

In everyday communication, such as the transmission of credit card numbers over the internet, a message is garbled so that it can be read only by someone who possesses a secret code, or key.

Quantum physics provides a way for a sender and receiver to share keys while ensuring that no one intercepts them, by transmitting a series of quantum particles, such as particles of light called photons, and performing measurements on them. By comparing notes, the users can be sure that no one else has intercepted the key. Those secret keys, once established, can then be used to encrypt sensitive intel. By comparison, standard internet security rests on a relatively shaky foundation of math problems that, though practically impossible for today's computers to solve, could be vulnerable to new technology, namely quantum computers.

But quantum communication has a catch. "There cannot be any glitch that is unforeseen," says quantum physicist Valerio Scarani of the National University of Singapore. For example, he says, imagine that your device is supposed to emit one photon but unknown to you, it emits two. Any such flaws would mean that the mathematical proof of security no longer holds. A hacker could sniff out your key, even though the transmission seems secure.

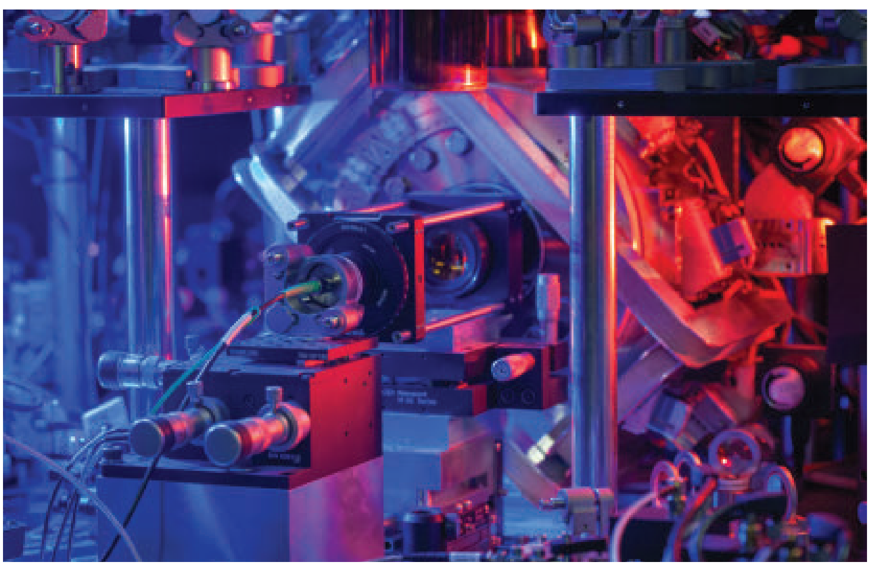
Device-independent quantum key distribution can rule out such flaws. The method builds off a quantum technique known as a Bell test, which involves measurements of entangled particles. Such tests can prove that quantum mechanics really does have "spooky" properties, namely nonlocality, the idea that measurements of one particle can be correlated with those of a distant particle. In 2015, researchers performed the first "loophole-free" Bell tests, which certified beyond a doubt that quantum physics' counterintuitive nature is real (SN: *12/26/15, p. 24*).

"The Bell test basically acts as a guarantee," says Jean-Daniel Bancal of CEA Paris-Saclay. A faulty device would fail the test, so "we can infer that the device is working properly." In a study in the July 28 *Nature*, Bancal and colleagues used entangled, electrically charged strontium atoms separated by about two meters. Measurements of those ions certified that their devices were behaving properly, and the researchers generated a secret key.

Typically, quantum communication is meant for long-distance dispatches. So Scarani and colleagues studied entangled rubidium atoms 400 meters apart. The setup had what it took to produce a secret key, the researchers report in the same issue of *Nature*. But the team didn't follow the process all the way through: The extra distance meant that producing a key would have taken months.

In the third study, published in the July 29 *Physical Review Letters*, scientists wrangled entangled photons. Wen-Zhao Liu, a physicist at the University of Science and Technology of China in Hefei, and colleagues also demonstrated the capability to generate keys at distances of up to 220 meters. This is particularly challenging to do with photons, Liu says, because photons are often lost in the process of transmission and detection.

Loophole-free Bell tests are no easy feat, so the technique won't see practical use anytime soon, says physicist Nicolas Gisin of the University of Geneva. Still, device-independent quantum key distribution is "a totally fascinating idea," he says. Bell tests were designed to answer a philosophical question about the nature of reality—whether quantum physics really is as weird as it seems. "To see that this now becomes a tool that enables something else," he says, "this is the beauty." ■



Three new experiments, including the one shown, demonstrate that quantum entanglement, a type of ethereal link between particles, can improve the security of quantum communication.

DAVID NADLINGER/UNIV. OF OXFORD

EARTH & ENVIRONMENT

# How to make a green jet fuel

## Sunlight, $CO_2$ and water vapor form carbon-neutral kerosene

**BY NIKK OGASA**

Jet fuel can now be siphoned from the air. Or at least that's the case in Móstoles, Spain, where an outdoor system produced kerosene with a few simple ingredients: sunlight, carbon dioxide and water vapor. If the system can be scaled up, solar kerosene could replace petroleum-derived jet fuel in aviation and help stabilize greenhouse gas emissions, researchers report in the July 20 *Joule*.

Burning solar-derived kerosene releases $CO_2$, but only as much as is used to make it, says Aldo Steinfeld, an engineer at ETH Zurich. "That makes the fuel carbon neutral, especially if we use carbon dioxide captured directly from the air."

Kerosene is the fuel of choice for aviation, which accounts for about 5 percent of annual human-caused greenhouse gas emissions. Finding sustainable alternatives is difficult because kerosene packs so much energy, says chemical physicist Ellen Stechel of Arizona State University in Tempe, who was not involved in the study.

In 2015, Steinfeld and colleagues synthesized solar kerosene in the lab. No one had produced the fuel entirely in a single system in the field, so the team positioned 169 sun-tracking mirrors to reflect and focus radiation equivalent to about 2,500 suns into a solar reactor atop a 15-meter-tall tower. The reactor has a window to let the light in, ports that supply $CO_2$ and water vapor, and a material called porous ceria that's used to catalyze chemical reactions.

When heated with sunlight, the ceria reacts with $CO_2$ and water vapor to make syngas — a mixture of hydrogen gas and carbon monoxide. The syngas is piped to the tower's base where a machine converts it into kerosene and other hydrocarbons.

Over nine days of operation, the tower converted about 4 percent of the solar energy used to heat the ceria into roughly 5,200 liters of syngas. From the syngas, this proof-of-principle setup made about a liter of kerosene a day, Steinfeld says.

IMDEA ENERGY

Reflectors focus sunlight on a solar reactor at the top of this tower. The light reacts with carbon dioxide and water vapor, forming a mixture that can be turned into jet fuel.

"It's a major milestone," Stechel says, though the efficiency needs to be improved to be useful to industry. For context, a Boeing 747 passenger jet burns about 19,000 liters of fuel during takeoff and the ascent to cruising altitude. Improving the ceria's heat absorption and recovering heat unused by the system could boost the tower's efficiency to more than 20 percent, making it economically practical, the researchers say. ■


LIFE & EVOLUTION

# Tiny crustaceans 'pollinate' seaweed

## Animal-driven fertilization may have first evolved in the ocean

**BY JAKE BUEHLER**

When it comes to reproduction, one type of red algae gets by with a little help from its friends: small sea crustaceans that transport sex cells between male and female algae, just like pollen-laden bees that buzz between flowers.

It's the first known example of animal-driven "pollination" in algae, researchers report in the July 29 *Science*. Both the red algae and crustaceans belong to far more ancient groups than land plants do, raising the possibility that a form of pollination first evolved in the ocean and hundreds of millions of years earlier than thought.

Pollination typically describes the transfer of male sex cells — pollen — to a female flower. In 2016, researchers determined that marine invertebrates "pollinate" seagrass flowers, which descended from land plants. But nothing similar had been documented in algae.

Like other red algae, *Gracilaria gracilis* doesn't have free-swimming male sex cells. Called spermatia, the cells were thought to be dispersed by the flow of water, much like how wind can spread pollen on land.

Myriam Valero, a population geneticist at the Roscoff Marine Station in France, and colleagues were studying the genetics and mating of *G. gracilis* when they noticed hundreds of small, oblong crustaceans among collected samples of the seaweed. The similarity of the algae's spermatia to pollen led the team to wonder if the crustaceans help "pollinate" the algae.

An isopod crustacean (*Idotea balthica*) climbs along a stalk of red algae (*Gracilaria gracilis*). The organisms' relationship is similar to that of a bee and flowering plant, a new study finds.

In the lab, the researchers placed male and female algae 15 centimeters apart in tanks with no water movement. Some tanks also included the centimeters-long *Idotea balthica*, an isopod crustacean, while others didn't. When a successful fertilization occurs on the body of a female red algae, it creates a bubblelike structure called a cystocarp. By counting cystocarps, the team quantified how many spermatia were reaching and fertilizing the female algae. When isopods were present, fertilization success was about 20 times as high as in their absence.

The team also set up tanks with just female algae and isopods exposed to male algae earlier. Some of the females then bore cystocarps, more evidence that the crustaceans shuttle sex cells between algal stalks. Under a microscope, the crustaceans resembled bumblebees dusted with pollen, covered in spermatia.

Today some primitive plants like mosses are fertilized by tiny arthropods, so animal-driven fertilization on land could go back to the origins of land plants, some 470 million years ago. But red algae are possibly more than 800 million years old, and complex animal life dates back more than half a billion years.

"Such a system [of pollination] could extend to the Precambrian when red algae were present," says paleobiologist Conrad Labandeira of the Smithsonian National Museum of Natural History in Washington, D.C. The pollinators wouldn't have been isopods, he says, but very early arthropods.

Water movement may still help *G. gracilis* to spread its spermatia. But much of the algae's fertilization occurs in rocky pools at low tide, when the water is calm, Valero says. "We think that the influence of the *Idotea* might be very important in those conditions." In return for their services, the isopods may gain shelter from the bushy algae and access to food stuck to the algae.

The team now wants to know if other red algae use "pollinators" and if other animals are involved in algal reproduction. ■

BODY & BRAIN

# Lab-made proteins can stop malaria

## Monoclonal antibodies may offer months of protection

**BY AIMEE CUNNINGHAM**

A single shot that could provide months-long protection against malaria has proved effective and safe in an early clinical trial.

The shot, which contains monoclonal antibodies, would primarily be intended for infants and children in countries with the most malaria transmission, the team who conducted the trial says. These young children have the highest risk of dying from severe malaria.

In the study, 15 of 17 adult participants who received the monoclonal antibodies did not become infected after being exposed to mosquitoes with malaria in the lab, the researchers report in the Aug. 4 *New England Journal of Medicine*. Six people who did not receive the medicine developed infections.

Based on a computer model of how the medicine is taken up, distributed and then cleared by the body, the researchers estimate that one shot may protect against malaria for six months.

"What we've always been looking for is some sort of intervention that will prevent infection reliably and for as long a time as possible," says Miriam Laufer, director of the Malaria Research Program at the University of Maryland School of Medicine in Baltimore.

Ideally, Laufer says, that would be a highly effective vaccine that provides years and years of protection. A new four-shot malaria vaccine that recently became available is only modestly protective, and that protection wanes rapidly (*SN: 12/18/21 & 1/1/22, p. 32*).

Monoclonal antibodies could provide an option that requires only one shot, once a year. But it will take more research to see how well the antibodies work against malaria outside of the laboratory and how cost-effective the shot is.

The monoclonal antibodies wouldn't exclude the need for other prevention

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strategies, says Laufer, who was not involved in the study. But it could be "one of the easier interventions in terms of minimal contact with the health care system, with good benefit."

What's appealing, she says, "is the possibility that you could give kids, even the youngest kids, an injection [of] premade antibodies that could last for six months or longer and protect them throughout the rainy season." That once-a-season shot would be helpful in West Africa, where malaria transmission occurs only during the rainy season.

Malaria sickened roughly 241 million people and killed 627,000 worldwide in 2020. Most of those deaths were in sub-Saharan Africa in children younger than 5. These littlest kids haven't had the chance to develop immunity to the disease and are more susceptible to dying.

Reducing the spread of malaria includes measures to control mosquitoes, such as using insecticide-treated nets over beds or spraying to kill mosquitoes indoors, as well as preventing infections, such as taking antimalarial drugs at regular intervals. In 2021, the World Health Organization also recommended the new vaccine, which in clinical trials reduced cases of malaria and severe malaria by 36 percent after four years of follow-up.

In Sierra Leone, a woman sleeps with her baby under a net to keep malaria-infected mosquitoes away. Monoclonal antibodies hold promise for protecting children from malaria for months.

Monoclonal antibodies are a lab-made version of antibodies, the proteins that the immune system produces in response to a vaccine or natural infection. Monoclonal means that it contains clones, or copies, of one particular antibody.

The antibody evaluated in the clinical trial attaches to a protein on the surface of sporozoites — the form of the malaria parasite that enters the body after an infected mosquito bites — and stops the parasites from infecting the liver.

Two clinical trials are planned to assess how well the medicine protects children in places where malaria is spreading. One trial in Mali, where malaria transmission is seasonal, will study the shot's efficacy over seven months. Another trial in Kenya, in East Africa where malaria spreads year-round, will assess how well the shot works while following the children for a year. ■

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ATOM & COSMOS

# New type of black hole merger found

## Two black holes met each other late in life before colliding

**BY JAMES R. RIORDON**

Signals buried deep in data from gravitational wave observatories imply a collision of two black holes that were clearly born in different places.

Almost all the spacetime ripples that experiments like LIGO see come from collisions between black holes that were once pairs of stars born at the same time and in the same place, eventually collapsing to form orbiting black holes in old age.

A newly noted marriage of black holes, found in existing data from U.S.-based LIGO and its sister observatory Virgo in Italy, seems to be of an unrelated pair. Evidence for this stems from how they were spinning as they merged, researchers report in a paper in press at *Physical Review D*. Black holes that are born in the same place tend to have their spins aligned, like a pair of toy tops spinning on a table, as they orbit each other. But the pair in this case have no correlation between their respective spins.

"This is telling us we've finally found a pair of black holes that must come from the non-grow-old-and-die-together channel," says Seth Olsen, a physicist at Princeton University.

Previous events that have turned up in gravitational wave observations show black holes merging that aren't perfectly aligned, but most are close enough to imply family connections. The new detection, which Olsen and colleagues found in data that the LIGO-Virgo collaboration released to the public, is different. One of the black holes is effectively spinning upside down relative to the other. That can't easily happen unless the two black holes come from separate places.

The team also identified nine other black hole mergers that had slipped through previous LIGO-Virgo studies. "This is actually the nice thing about this type of analysis," says LIGO spokesperson Patrick Brady, a physicist at the University of Wisconsin–Milwaukee who was not affiliated with the new study. "We deliver the data in a format that can be used by other people and then [they] will have access to try out new techniques."

To compile so many new signals in data that had already been gone over by other researchers, Olsen's group lowered the analytical bar a little. "Out of the 10 new ones," Olsen says, "there are about three of them, statistically, that probably come from noise" rather than being definitive black hole merger detections. Assuming that the merger of black hole strangers is not among the errant signals, it almost certainly tells a tale of black hole histories distinct from the others seen so far.

"It would be [extremely] unlikely for this to come from two black holes that have been together for their whole life span," Olsen says. "This must have been a capture. That's cool because we're finally able to start probing that region of the [black hole] population."

Brady notes that "we don't understand the theory [of black hole mergers] well enough to be able to confidently predict all of these types of things." But the study may point to new and interesting opportunities in gravitational wave astronomy. ■

PMI IMPACT MALARIA

HUMANS & SOCIETY

# On the origin of lactose tolerance

## Famine and disease may have driven milk digestion in Europe

**BY BRUCE BOWER**

Ancient Europeans may have evolved an ability to digest milk thanks to periodic famines and disease outbreaks.

Europeans tapped into milk-drinking about 9,000 years ago when dairying groups reached southeastern Europe, researchers report July 27 in *Nature*. Yet it took several thousand years before large numbers of Europeans evolved a gene for digesting lactose, the sugar in milk.

These discoveries undermine an influential idea that milk use dramatically increased as the product's nutritional and health benefits drove the evolution of lactose tolerance, say biogeochemist Richard Evershed of the University of Bristol in England and colleagues.

Milk drinkers who can't digest lactose experience diarrhea, gas, bloating and intestinal cramps. Those uncomfortable reactions were too mild to move the evolutionary needle toward lactose tolerance on their own, Evershed's group says. But during periodic famines and infectious disease outbreaks, lactose-induced diarrhea became fatal for severely malnourished individuals in farming communities, the scientists suggest. Those recurring threats hot-wired the evolution of lactose tolerance, the team contends.

The report "comprehensively rules out" widespread milk consumption as the evolutionary force behind lactose tolerance, says bioarchaeologist Oliver Craig of the University of York in England. Further studies need to clarify the scale and extent of famines or disease episodes, he says. Investigators must also keep in mind that cheese and other low-lactose dairy products date to as early as about 7,400 years ago in Europe. If these foods were available, it's unclear why lactose-intolerant Europeans would not have survived times of famine or disease, Craig says.

Evershed's team mapped estimated frequencies of milk use across Europe from 9,000 to 500 years ago by analyzing data from animal fat residues extracted from pottery at about 550 archaeological sites.

Migrating farmers introduced dairying to Europe's Balkan Peninsula, the team says. Milk use then fluctuated over time in different parts of the continent. After about 7,500 years ago, relatively heavy milk use characterized western France, northern Europe and the British Isles.

Using ancient DNA data from nearly 1,800 Europeans and Asians, the team also tracked the spread of lactose tolerance. The earliest European evidence of a gene variant in adults that boosts the activity of lactase, an enzyme that breaks down lactose, dates to about 6,650 years ago. But this lactase persistence did not become common until around 3,000 years ago.

Before then, increasing levels of lactase persistence tended to align with population busts linked to famines in particular regions, the researchers report. Between 8,000 and 4,000 years ago, excavated farming sites across Europe show signs of periodic population declines that were influenced by severe food shortages.

Settlement density, a measure of how close together people lived, also tended to decline at times of increasing lactase persistence. The spread of animal-borne infections such as salmonella lowered settlement densities as residents unable to digest lactose suffered an excess of deaths, the scientists suspect. In periods of malnourishment and illness, lactase persistence boosted access to badly needed nutrients in milk, the team speculates.

But archaeologist Ron Pinhasi of the University of Vienna is not convinced the famine and disease theory holds up. Diarrhea causes death more often in malnourished children, he says, so he questions whether it would have led to enough adult fatalities to trigger the evolution of milk tolerance. No current proposal explains how lactase persistence spread, he says. ■

HUMANS & SOCIETY

# Ancient DNA links an East Asian woman to early Americans

X. ZHANG ET AL/CURRENT BIOLOGY 2022

A previously undetected *Homo sapiens* population lived in what's now southwestern China around 14,000 years ago and contributed to the ancestry of ancient Americans.

This far-ranging Asian group's evolutionary identity has been revealed thanks to ancient DNA extracted from a skullcap (shown from three views) excavated in 1989 at Mengzi Ren, or MZR, a site in southwestern China's Red Deer Cave, researchers report in the July 25 *Current Biology*.

The work offers a rare opportunity to narrow down where in East Asia the ancestors of ancient Americans came from.

In some ways, hominid bones found at Red Deer Cave look like those of people today but in other ways resemble those of Neandertals and *Homo erectus*. Genetic analyses now peg the MZR individual's DNA as that of a female *H. sapiens* from southern East Asia. Much like East Asians today, the ancient female's ancestry included small contributions from Denisovans and Neandertals.

Geneticist Bing Su of China's Kunming Institute of Zoology and colleagues also found that the MZR woman carried genetic ties to people in the Americas who date to as early as about 12,000 years ago. The scientists suspect that some ancient southern East Asians traveled up China's eastern coast, possibly by way of Japan, and crossed a land bridge to North America. — *Bruce Bower*

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Yasmin Morales stands in what's left of her home in the eastern part of Puerto Rico in September 2017 after Hurricane Maria battered the island.

# What Fed Hurricane Maria's Fury?

## A coral pollution study helps explain the destruction in Puerto Rico

**By Martin J. Kernan**

HECTOR RETAMAL/AFP VIA GETTY IMAGES

Hurricane Maria struck the island of Puerto Rico early on September 20, 2017, with 250-kilometer-per-hour winds, torrential rains and a storm surge up to three meters high. In its wake: nearly 3,000 people dead, an almost yearlong power outage and over $90 billion in damages to homes, businesses and essential infrastructure, including roads and bridges.

Geologist and diver Milton Carlo took shelter at his house in Cabo Rojo on the southwest corner of the island with his wife, daughter and infant grandson. He watched the raging winds of the Category 4 hurricane lift his neighbor's SUV into the air, and remembers those hours as some of the worst of his life.

For weeks, the rest of the world was in the dark about the full extent of the devastation, because Maria had destroyed the island's main weather radar and almost all cell phone towers.

Far away on the U.S. West Coast, in Santa Cruz, Calif., oceanographer Olivia Cheriton watched satellite radar images of Maria passing over the instruments she and her U.S. Geological Survey team had anchored a few kilometers southwest of Puerto Rico. The instruments, placed offshore from the seaside town of La Parguera, were there to track pollution circulating around some of the island's endangered corals.

More than half a year went by before she learned the improbable fate of those instruments: They had survived *and* had captured data revealing hurricane-related ocean dynamics that no scientist had ever recorded.

The wind-driven coastal currents interacted with the seafloor in a way that prevented Maria from drawing cold water from the depths of the sea up to the surface. The sea surface stayed as warm as bathwater. Heat is a hurricane's fuel source, so a warmer sea surface leads to a more intense storm. As Cheriton figured out later, the phenomenon she stumbled upon likely played a role in maintaining Maria's Category 4 status as it raked Puerto Rico for eight hours.

"There was absolutely no plan to capture the impact of a storm like Maria," Cheriton says. "In fact, if we somehow could've known that a storm like that was going to occur, we wouldn't have put hundreds of thousands of dollars' worth of scientific instrumentation in the water."

A storm's path is guided by readily observable, large-scale atmospheric features such as trade winds and high-pressure zones. Its intensity, on the other hand, is driven by weather events inside the hurricane and wave action deep below the ocean's surface. The findings by Cheriton and colleagues, published May 2021 in *Science Advances*, help explain why hurricanes often get stronger before making landfall and can therefore help forecasters make more accurate predictions.

Elkhorn coral (left) and mountainous star coral (right) were once ubiquitous in the Caribbean. Their numbers have dropped greatly due to bleaching and disease. Pollution is partly to blame.

## Reef pollution

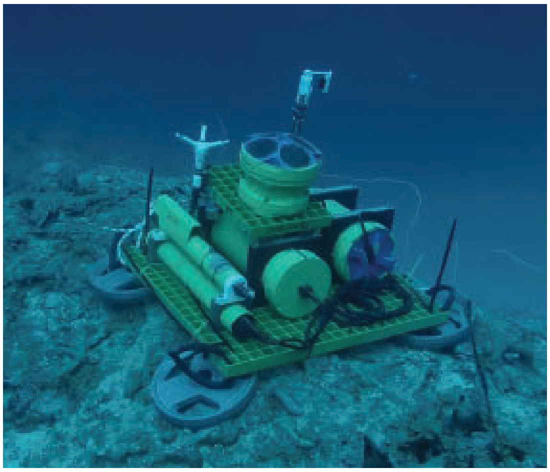
Cheriton's original research objective was to figure out how sea currents transport polluted sediments from Guánica Bay — where the Lajas Valley drains into the Caribbean Sea — to the pristine marine ecosystems 10 kilometers west in La Parguera Natural Reserve, famous for its bioluminescent waters.

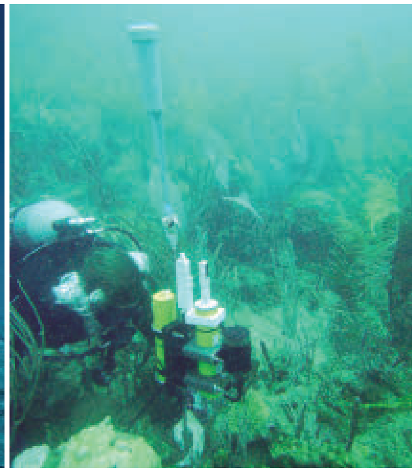
Endangered elkhorn and mountainous star corals, called "the poster children of Caribbean reef decline" by marine geologist Clark Sherman, live near shore in some of the world's highest recorded concentrations of now-banned industrial chemicals. Those polychlorinated biphenyls, or PCBs, hinder coral reproduction, growth, feeding and defensive responses, says Sherman, of the University of Puerto Rico–Mayagüez.

Marine geologist Clark Sherman dives amid colonies of healthy great star corals, black corals, a large sea fan and a variety of sponges along the steep island shelf of southwest Puerto Rico. Sherman helped investigate whether pollution was reaching these deepwater reefs.

CLOCKWISE FROM TOP LEFT: NICK HOBGOOD/WIKIMEDIA COMMONS (CC BY-SA 3.0); NOAA FISHERIES; E. TUOHY/UNIV. OF PUERTO RICO–MAYAGÜEZ

In June 2017, research geologist Curt Storlazzi (left) and physical scientist Joshua Logan (right) prepare to dive near Puerto Rico's Guánica Bay to install instruments for monitoring currents suspected of delivering pollution to coral reefs.





The instruments installed by Storlazzi, Logan and others collected unexpected underwater ocean observations during Hurricane Maria. An acoustic Doppler current profiler (left) used pulsating sound waves to measure the direction and speed of currents at the shelf break and slope site about 12 kilometers offshore of La Parguera. A Marotte current meter (right) measured wave height, current speed and temperature at six spots close to shore.

Half of corals in the Caribbean have died since monitoring began in the 1970s, and pollution is a major cause, according to an April 2020 study in *Science Advances*. Of particular interest to Cheriton, Sherman and their colleagues was whether the pollution had reached deepwater, or mesophotic, reefs farther offshore, which could be a refuge for coral species that were known to be dying in shallower areas.

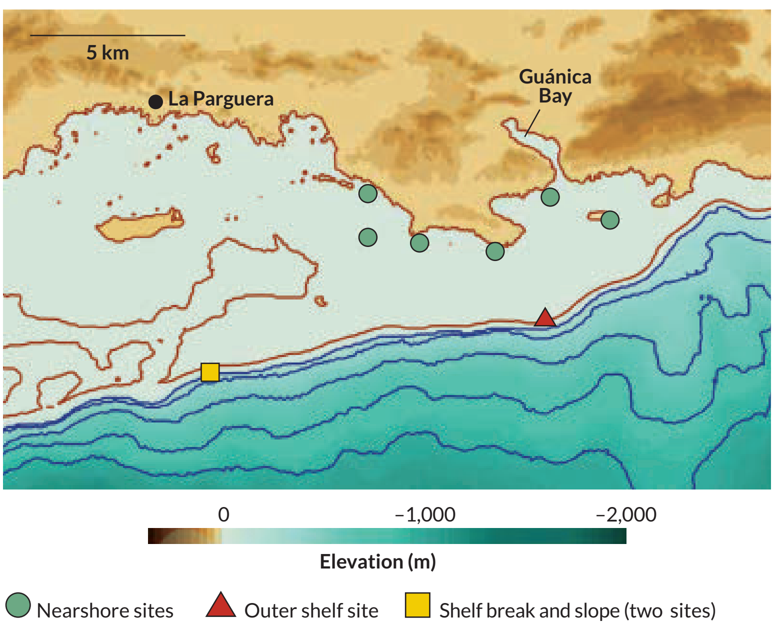
The main artery for this pollution is the Rio Loco — which translates to "Crazy River." It spews a toxic runoff of eroded sediments from the Lajas Valley's dirt roads and coffee plantations into Guánica Bay, which supports a vibrant fishing community. Other possible contributors to the pollution — oil spills, a fertilizer plant, sewage and now-defunct sugar mills — are the subject of investigations by public health researchers and the U.S. Environmental Protection Agency.

In June 2017, the team convened in La Parguera to install underwater sensors to measure and track the currents in this threatened marine environment. From Sherman's lab on a tiny islet overrun with iguanas the size of house cats, he and Cheriton, along with team leader and USGS research geologist Curt Storlazzi and USGS physical scientist Joshua Logan, launched a boat into choppy seas.

At six sites near shore, Storlazzi, Sherman and Logan dove to the seafloor and used epoxy to anchor pressure gauges and batonlike current meters. Together the instruments measured hourly temperature, wave height and current speed. The team then moved farther offshore where the steep island shelf drops off at a 45-degree angle to a depth of 60 meters, but the heavy ocean chop scuttled their efforts to install instruments there.

For help working in the difficult conditions, Sherman enlisted two expert divers for a second attempt: Carlo, the geologist and diving safety officer, and marine scientist Evan Tuohy, both of the University of Puerto Rico–Mayagüez. The two were able to install the most important and largest piece, a hydroacoustic instrument comprising several drums fastened to a metal grid, which tracked the direction and speed of currents every minute using pulsating sound waves. A canister containing temperature and salinity sensors took

**Study sites**
USGS instruments were placed in the coastal waters offshore from La Parguera and Guánica Bay, Puerto Rico. The instruments where the shelf drops off (yellow square and red triangle) survived Hurricane Maria and collected data important for storm forecasting.




CLOCKWISE FROM TOP LEFT: USGS; E. TUOHY/UNIV. OF PUERTO RICO–MAYAGÜEZ, USGS; O.M. CHERITON *ET AL/SCIENCE ADVANCES* 2021 readings every two minutes. Above this equipment, an electric thermometer extended to within 12 meters of the surface, registering temperature every five meters vertically every few seconds.

Working in concert, the instruments gave a high-resolution, seafloor-to-surface snapshot of the ocean's hydrodynamics on a near-continuous basis. The equipment had to sit level on the sloping seafloor so as not to skew the measurements and remain firmly in place. Little did the researchers know that the instruments would soon be battered by one of the most destructive storms in history.

## Becoming Maria

The word hurricane derives from the Caribbean Taino people's *Huricán*, god of evil. Some of the strongest of these Atlantic tropical cyclones begin where scorching winds from the Sahara clash with moist subtropical air over the island nation of Cape Verde off western Africa. The worst of these atmospheric disturbances create severe thunderstorms with giant cumulonimbus clouds that flatten out against the stratosphere. Propelled by the Earth's rotation, they begin to circle counterclockwise around each other — a phenomenon known as the Coriolis effect.

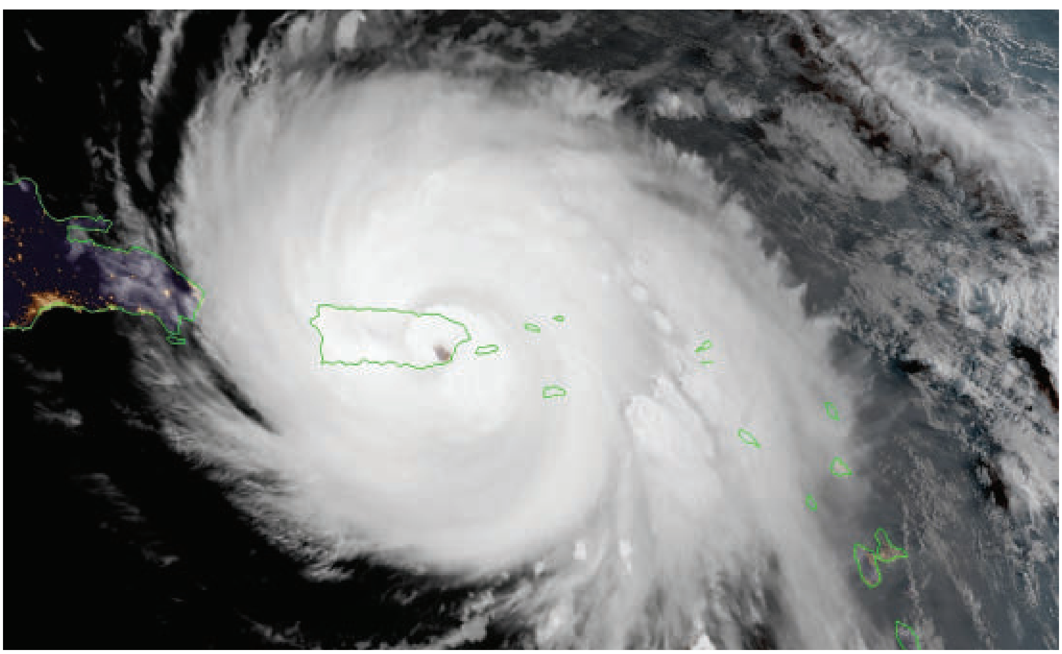
Weather conditions that summer had already spawned two monster hurricanes: Harvey and Irma. By late September, the extremely warm sea surface — 29° Celsius or hotter in some places — gave up its heat energy by way of evaporation into Maria's rushing winds. All hurricanes begin as an area of low pressure, which in turn sucks in more wind, accelerating the rise of hot air, or convection. Countervailing winds known as shear can sometimes topple the cone of moist air spiraling upward. But that didn't happen, so Maria continued to grow in size and intensity.

Meteorologists hoped that Maria would lose force as it moved across the Caribbean, weakened by the wake of cooler water Irma had churned up two weeks earlier. Instead, Maria tracked south, steaming toward the eastern Caribbean island of Dominica. Within 15 hours of making landfall, its maximum sustained wind speed doubled, reaching a house-leveling 260 kilometers per hour. That doubling intensified the storm from a milder (still dangerous) Category 1 to a strong Category 5.

NOAA's computer forecasting models did not anticipate such rapid intensification. Irma had also raged with unforeseen intensity.

After striking Dominica hard, Maria's eyewall broke down, replaced by an outer band of whipping thunderstorms. This slightly weakened Maria to 250 kilometers per hour before it hit Puerto Rico, while expanding the diameter of the storm's eyewall — the area of strong winds and heaviest precipitation — to 52 kilometers. That's close to the width of the island.

It's still not fully understood why Maria had suddenly gone berserk. Various theories point to the influence of hot towers — convective bursts of heat energy from thunderclouds that punch up into the stratosphere — or deep warm pools, buoyant freshwater eddies spilling out of the Amazon and Orinoco rivers into the Atlantic, where



CIRA/NOAA

Hurricane Maria made landfall on Puerto Rico early in the morning on September 20, 2017, and cut across the island diagonally toward the northwest. Its eyewall generated maximum sustained winds of 250 kilometers per hour and spanned almost the width of the island.

Oceanographer Olivia Cheriton realized that data on ocean currents told a new story about Hurricane Maria.

currents carry these pockets of hurricane-fueling heat to the Gulf of Mexico and the Caribbean Sea.

But even though these smaller-scale events may have a big impact on intensity, they aren't fully accounted for in weather models, says Hua Leighton, a scientist at the National Oceanic and Atmospheric Administration's hurricane research division and the University of Miami's Cooperative Institute for Marine and Atmospheric Studies. Leighton develops forecasting models and investigates rapid intensification of hurricanes.

"We cannot measure everything in the atmosphere," Leighton says.

Without accurate data on all the factors that drive hurricane intensity, computer models can't easily predict when the catalyzing events will occur, she says. Nor can models account for everything that happens inside the ocean during a hurricane. They don't have the data.

Positioning instruments just before a hurricane hits is a major challenge. But NOAA is making progress. It has launched a new generation of hurricane weather buoys in the western North Atlantic and remote control surface sensors called Saildrones that examine the air-sea interface between hurricanes and the ocean (*SN: 6/18/19, p. 24*).

Underwater, NOAA uses other drones, or gliders, to profile the vast areas regularly traversed by tropical storms. These gliders collected 13,200 temperature and salinity readings in 2020. By contrast, the instruments that the team set in Puerto Rico's waters in 2017 collected over 250 million data points, including current velocity and direction — a rare and especially valuable glimpse of hurricane-induced ocean dynamics at a single location.

Milton Carlo (left) and Evan Tuohy (right), shown in an earlier deepwater dive, helped place the current-monitoring instruments at the hard-to-reach sites where hurricane data were collected.

## A different view

After the storm passed, Storlazzi was sure the hurricane had destroyed his instruments. They weren't designed to take that kind of punishment. The devices generally work in much calmer conditions, not the massive swells generated by Maria, which could increase water pressure to a level that would almost certainly crush instrument sensors.

But remarkably, the instruments were battered but not lost. Sherman, Carlo and Touhy retrieved them after Maria passed and put them in crates awaiting the research group's return.

When Storlazzi and USGS oceanographer Kurt Rosenberger pried open the instrument casings in January 2018, no water gushed out. Good sign. The electronics appeared intact. And the lithium batteries had powered the rapid-fire sampling enterprise for the entire six-month duration. The researchers quickly downloaded a flood of data, backed it up and started transmitting it to Cheriton, who began sending back plots and graphs of what the readings showed.

Floodwaters from the massive rains brought by Maria had pushed a whole lot of polluted sediment to the reefs outside Guánica Bay, spiking PCB concentrations and threatening coral health. As of a few months after the storm, the pollution hadn't reached the deeper reefs.

Then the researchers realized that their data told another story: what happens underwater during a massive hurricane. They presumed that other researchers had previously captured a profile of the churning ocean depths beneath a hurricane at the edge of a tropical island.

Remarkably, that was not the case.

"Nobody's even measured this, let alone reported it in any published literature," Cheriton says. The team began to explore the hurricane

FROM TOP: O.M. CHERITON; MIKE ECHEVARRIA data not knowing where it might lead.

"What am I looking at here?" Cheriton kept asking herself as she plotted and analyzed temperature, current velocity and salinity values using computer algorithms. The temperature gradient that showed the ocean's internal or underwater waves was different than anything she'd seen before.

During the hurricane, the top 20 meters of the Caribbean Sea had consistently remained at or above 26° C, a few degrees warmer than the layers beneath. But the surface waters should have been cooled if, as expected, Maria's winds had acted like a big spoon, mixing the warm surface with cold water stirred up from the seafloor 50 to 80 meters below. Normally, the cooler surface temperature restricts the heat supply, weakening the hurricane. But the cold water wasn't reaching the surface.

To try to make sense of what she was seeing, Cheriton imagined herself inside the data, in a protective bubble on the seafloor with the instruments as Maria swept over. Storlazzi worked alongside her analyzing the data, but focused on the sediments circulating around the coral reefs.

Cheriton was listening to "An Awesome Wave" by indie-pop band Alt-J and getting goosebumps while the data swirled before them. Drawing on instincts from her undergraduate astronomy training, she focused her mind's eye on a constellation of data overhead and told Storlazzi to do the same.

"Look up Curt!" she said.

Up at the crest of the island shelf, where the seafloor drops off, the current velocity data revealed a broad stream of water gushing from the shore at almost 1 meter per second, as if from a fire hose. Several hours before Maria arrived, the wind-driven current had reversed direction and was now moving an order of magnitude faster. The rushing surface water thus became a barrier, trapping the cold water beneath it.

As a result, the surface stayed warm, increasing the force of the hurricane. The cooler layers below then started to pile up vertically into distinct layers, one on top of the other, beneath the gushing waters above.

Cheriton calculated that with the fire hose phenomenon the contribution from coastal waters in this area to Maria's intensity was, on average, 65 percent greater, compared with what it would have been otherwise.

Oceanographer Travis Miles of Rutgers University in New Brunswick, N.J., who was not involved in the research, calls Cheriton and the team's work a "frontier study" that draws researchers' attention to near-shore processes. Miles can relate to Cheriton and her team's accidental hurricane discovery from personal experience: When his water quality–sampling gliders wandered into Hurricane Irene's path in 2011, they revealed that the ocean off the Jersey Shore had cooled in front of the storm. Irene's onshore winds had induced seawater mixing across the broad continental shelf and lowered sea surface temperatures.

The Puerto Rico data show that offshore winds over a steep island shelf produced the opposite effect and should help researchers better understand storm-induced mixing of coastal areas, says NOAA senior scientist Hyun-Sook Kim, who was not involved in the research. It can help with identifying deficiencies in the computer models she relies on when providing guidance to storm-tracking meteorologists at the National Hurricane Center in Miami and the Joint Typhoon Warning Center in Hawaii.

And the unexpected findings also could help scientists get a better handle on coral reefs and the role they play in protecting coastlines. "The more we study the ocean, especially close to the coast," Carlo says, "the more we can improve conditions for the coral and the people living on the island." ■

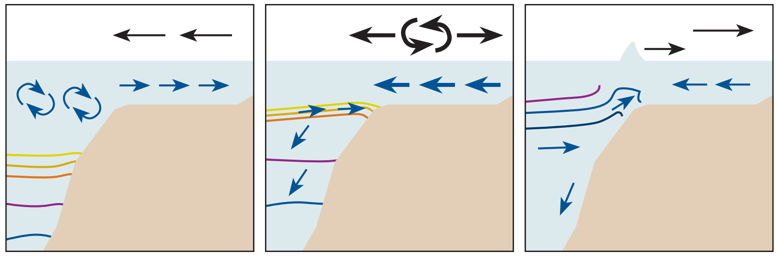
## Explore more

- USGS Coral Reef Project: Puerto Rico. June 25, 2021. on.doi.gov/3yZ1kLr.
- Olivia M. Cheriton *et al*. "Rapid observations of ocean dynamics and stratification along a steep island coast during Hurricane María." *Science Advances*. May 12, 2021.

*Martin J. Kernan is a freelance science and history writer based in central New York.*

**Hurricane Maria's effect on coastal waters**

**Up to 7 hours before the hurricane** | **3 hours before and 6 hours during Maria** | **After the storm**



Up to 7 hours before the hurricane: Water moves toward the shore, as wind travels from shore to ocean. Deeper, cool waters (blue and purple) are able to rise with ocean mixing.

3 hours before and 6 hours during Maria: Winds from the shore drive the current out to sea. The cooler water rises but can't reach the surface, so it is trapped under warmer waters (yellow).

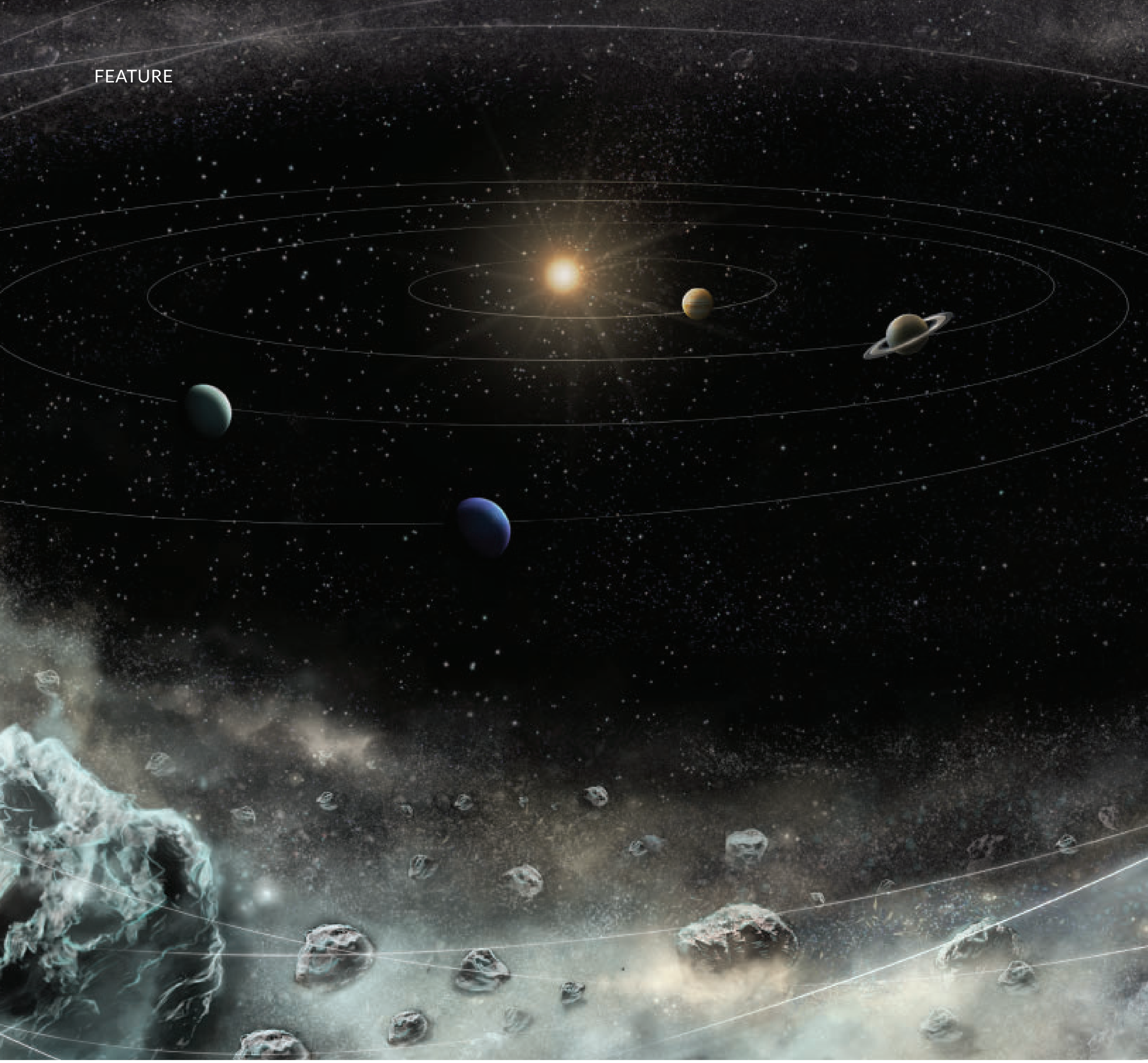
After the storm: The wind reverses direction and the surface current relaxes, allowing the cooler deep layers to finally surface.

### Fire hose effect

USGS data from the deep shelf south of Puerto Rico showed that Hurricane Maria's winds shifted the direction and flow of the surface water with such power that cool waters from deep in the Caribbean Sea were unable to rise to the surface and cool the hurricane.

SOURCE: O.M. CHERITON *ET AL*/ *SCIENCE ADVANCES* 2021

C. CHANG



# Frozen Worlds in Focus

The Kuiper Belt, discovered three decades ago, offers clues to the solar system's past **By Katherine Kornei**

NICOLLE R. FULLER/SAYOSTUDIO

On a Hawaiian mountaintop in the summer of 1992, a pair of scientists spotted a pinprick of light inching through the constellation Pisces. That unassuming object — located over a billion kilometers beyond Neptune — would rewrite our understanding of the solar system.

Rather than an expanse of emptiness, there was something, a vast collection of things in fact, lurking beyond the orbits of the known planets.

The scientists had discovered the Kuiper Belt, a doughnut-shaped swath of frozen objects left over from the formation of the solar system.

As researchers learn more about the Kuiper Belt, the origin and evolution of our solar system is coming into clearer focus. Closeup glimpses of the Kuiper Belt's frozen worlds have shed light on how planets, including our own, might have formed in the first place. And surveys of this region, which have collectively revealed thousands of such bodies, called Kuiper Belt objects, suggest that the early solar system was home to pinballing planets.

The humble object that kick-started it all is a chunk of ice and rock roughly 250 kilometers in diameter. It was first spotted 30 years ago this month.

## Staring into space

In the late 1980s, planetary scientist David Jewitt and astronomer Jane Luu, both at MIT at the time, were several years into a curious quest. The duo had been using telescopes in Arizona to take images of patches of the night sky with no particular target in mind. "We were literally just staring off into space looking for something," says Jewitt, now at UCLA.

An apparent mystery motivated the researchers: The inner solar system is relatively crowded with rocky planets, asteroids and comets, but there was seemingly not much out beyond the gas giant planets, besides small, icy Pluto. "Maybe there were things in the outer solar system," says Luu, who now works at the University of Oslo and Boston University. "It seemed like a worthwhile thing to check out."

Poring over glass photographic plates and digital images of the night sky, Jewitt and Luu looked for objects that moved extremely slowly, a telltale sign of their great distance from Earth. But the pair kept coming up empty. "Years went by, and we didn't see anything," Luu says. "There was no guarantee this was going to work out."

The tide changed in 1992. On the night of August 30, Jewitt and Luu were using a University of Hawaii telescope on the Big Island. They were employing their usual technique for searching for distant objects: Take an image of the night sky, wait an hour or so, take another image of the same patch of sky, and repeat. An object in the outer reaches of the solar system would shift position ever so slightly from one image to the next, primarily because of the movement of Earth in its orbit. "If it's a real object, it would move systematically at some predicted rate," Luu says.

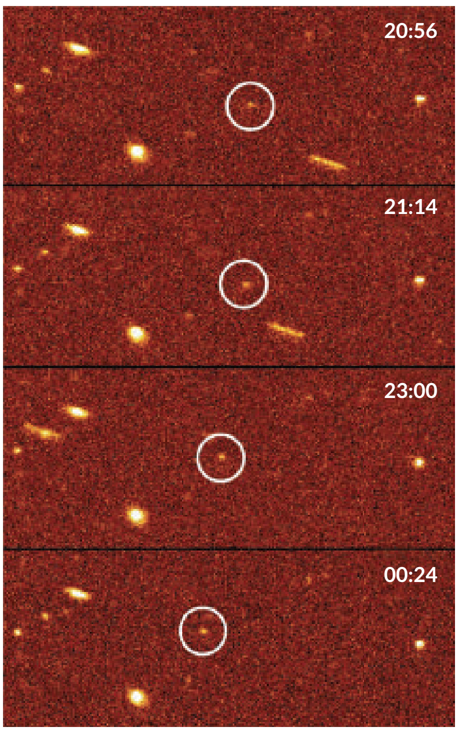
By 9:14 p.m. that evening, Jewitt and Luu had collected two images of the same bit of the constellation Pisces. The researchers displayed the

Rather than an expanse of emptiness, there was something, a vast collection of things in fact, lurking beyond the orbits of the known planets.

images on the bulbous cathode-ray tube monitor of their computer, one after the other, and looked for anything that had moved. One object immediately stood out: A speck of light had shifted just a touch to the west.

But it was too early to celebrate. Spurious signals from high-energy particles zipping through space — cosmic rays — appear in images of the night sky all of the time. The real test would be whether this speck showed up in more than two images, the researchers knew.

Jewitt and Luu nervously waited until 11 p.m. for the telescope's camera to finish taking a third image. The same object was there, and it had moved a bit farther west. A fourth image, collected just after midnight, revealed the object had shifted position yet again. This is something real, Jewitt remembers thinking. "We were just blown away."




The way the circled object shifted position in the sky (time stamps at right) told Jewitt and Luu that the object, dubbed 1992 QB1, was distant. It was the first evidence of the icy zone called the Kuiper Belt.

Based on the object's brightness and its leisurely pace — it would take nearly a month for it to march across the width of the full moon as seen from Earth — Jewitt and Luu did some quick calculations. This thing, whatever it was, was probably about 250 kilometers in diameter. That's sizable, about one-tenth the width of Pluto. It was orbiting far beyond Neptune. And in all likelihood, it wasn't alone.

Although Jewitt and Luu had been diligently combing the night sky for years, they had observed only a tiny fraction of it. There were possibly thousands more objects out there like this one just waiting to be found, the two concluded.

The realization that the outer solar system was probably teeming with undiscovered bodies was mind-blowing, Jewitt says. "We expanded the known volume of the solar system enormously." The object that Jewitt and Luu had found, 1992 QB1 (SN: 9/26/92, p. 196), introduced a whole new realm.

Just a few months later, Jewitt and Luu spotted a second object also orbiting far beyond Neptune (SN: 4/10/93, p. 231). The floodgates opened soon after. "We found 40 or 50 in the next few years," Jewitt says. As the digital detectors that astronomers used to capture images grew in size and sensitivity, researchers began uncovering droves of additional objects. "So many interesting worlds with interesting stories," says Mike Brown,

David Jewitt and Jane Luu, shown in Honolulu in the early 2000s, discovered the Kuiper Belt.

an astronomer at Caltech who studies Kuiper Belt objects.

Finding all of these frozen worlds, some orbiting even beyond Pluto, made sense in some ways, Jewitt and Luu realized. Pluto had always been an oddball; it's a cosmic runt (smaller than Earth's moon) and looks nothing like its gas giant neighbors. What's more, its orbit takes it sweeping far above and below the orbits of the other planets. Maybe Pluto belonged not to the world of the planets but to the realm of whatever lay beyond, Jewitt and Luu hypothesized. "We suddenly understood why Pluto was such a weird planet," Jewitt says. "It's just one object, maybe the biggest, in a set of bodies that we just stumbled across." Pluto probably wouldn't be a member of the planet club much longer, the two predicted. Indeed, by 2006, it was out (SN: 9/2/06, p. 149).

## Up-close look

The discovery of 1992 QB1 opened the world's eyes to the Kuiper Belt, named after Dutch-American astronomer Gerard Kuiper. In a twist of history, however, Kuiper predicted that this region of space would be empty. In the 1950s, he proposed that any occupants that might have once existed there would have been banished by gravity to even more distant reaches of the solar system.

In other words, Kuiper anti-predicted the existence of the Kuiper Belt. He turned out to be wrong.

Today, researchers know that the Kuiper Belt stretches from a distance of roughly 30 astronomical units from the sun — around the orbit of Neptune — to roughly 55 astronomical units. It resembles a puffed-up disk, Jewitt says. "Superficially, it looks like a fat doughnut."

The frozen bodies that populate the Kuiper Belt are the remnants of the swirling maelstrom of gas and dust that birthed the sun and the planets.

BOTH: D. JEWITT/UCLA

There's "a bunch of stuff that's left over that didn't quite get built up into planets," says astronomer Meredith MacGregor of the University of Colorado Boulder. When one of those cosmic leftovers gets kicked into the inner solar system by a gravitational shove from a planet like Neptune and approaches the sun, it turns into an object we recognize as a comet (SN: 9/12/20, *p.* 14). Comets that circle the sun once only every 200 years or more typically derive from the solar system's even more distant repository of icy bodies known as the Oort cloud.

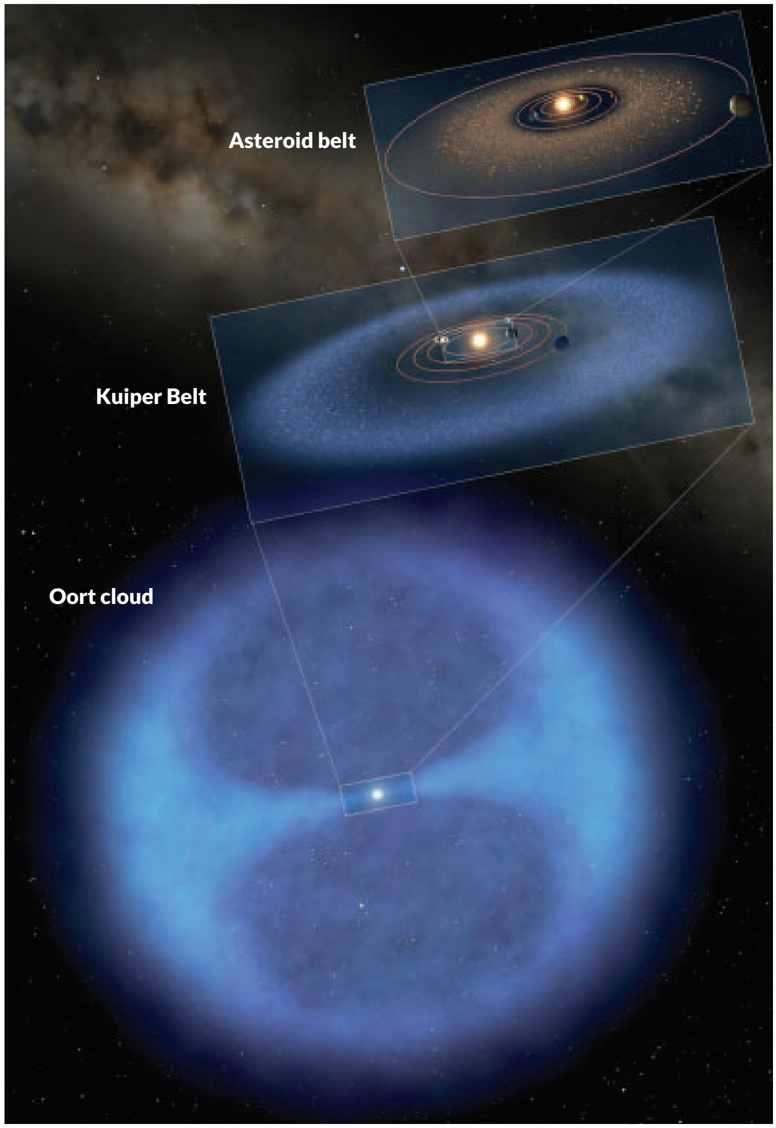
In scientific parlance, the Kuiper Belt is a debris disk. Distant solar systems contain debris disks, too, scientists have discovered. "They're absolutely directly analogous to our Kuiper Belt," MacGregor says.

In 2015, scientists got their first close look at a Kuiper Belt object when NASA's New Horizons spacecraft flew by Pluto (SN *Online*: 7/15/15). The pictures that New Horizons returned in the following years were thousands of times more detailed than previous observations of Pluto and its moons. No longer just a few fuzzy pixels, the worlds were revealed as rich landscapes of ice-spewing volcanoes and deep, jagged canyons (SN: 6/22/19, *p.* 12). "I'm just absolutely ecstatic with what we accomplished at Pluto," says Marc Buie, an astronomer at the Southwest Research Institute in Boulder, Colo., and a member of the New Horizons team. "It could not possibly have gone any better."

But New Horizons wasn't finished with the Kuiper Belt. On New Year's Day of 2019, when the spacecraft was almost 1.5 billion kilometers beyond Pluto's orbit, it flew past another Kuiper Belt object. And what a surprise it was. Arrokoth—its name refers to "sky" in the Powhatan/Algonquian language—looks like a pair of pancakes joined at the hip (SN: 12/21/19 & 1/4/20, *p.* 5). Roughly 35 kilometers long from end to end, it was probably once two separate bodies that gently collided and stuck. Arrokoth's bizarre structure sheds light on a fundamental question in astronomy: How do gas and dust clump together and grow into larger bodies?

One long-standing theory, called planetesimal accretion, says that a series of collisions is responsible. Tiny bits of material collide and stick together on repeat to build up larger and larger objects, says JJ Kavelaars, an astronomer at the University of Victoria and the National Research Council of Canada. But there's a problem, Kavelaars says.

As objects get large enough to exert a significant gravitational pull, they accelerate as they approach one another. "They hit each other too fast, and they don't stick together," he says. It would be unusual for a large object like Arrokoth, particularly with its two-lobed structure, to have formed from a sequence of collisions.



There are many places in the solar system where icy bodies congregate: the asteroid belt roughly between Jupiter and Mars (top), the doughnut-shaped Kuiper Belt beyond the gas giant planets (middle) and the most distant zone, the Oort cloud (bottom).

More likely, Arrokoth was born from a process known as gravitational instability, researchers now believe. In that scenario, a clump of material that happens to be denser than its surroundings grows by pulling in gas and dust. This process can form planets on timescales of thousands of years, rather than the millions of years required for planetesimal accretion. "The timescale for planet formation completely changes," Kavelaars says.

If Arrokoth formed this way, other bodies in the solar system probably did too. That may mean that parts of the solar system formed much more


In 2019, New Horizons flew by Arrokoth (above), a roughly 35-kilometer-long Kuiper Belt object.

FROM TOP: MARK GARLICK/SCIENCE SOURCE; NASA, JHU-APL, SWRI

The Canada-France-Hawaii Telescope, near the summit of Mauna Kea on Hawaii's Big Island, has revealed hundreds of Kuiper Belt objects.

The Vera C. Rubin Observatory in Chile is expected to spot about 40,000 Kuiper Belt objects with its 8.4-meter mirror and the world's largest digital camera.

rapidly than previously believed, says Buie, who discovered Arrokoth in 2014. "Already Arrokoth has rewritten the textbooks on how solar system formation works."

What they've seen so far makes scientists even more eager to study another Kuiper Belt object up close. New Horizons is still making its way through the Kuiper Belt, but time is running out to identify a new object and orchestrate a rendezvous. The spacecraft, which is currently 53 astronomical units from the sun, is approaching the Kuiper Belt's outer edge. Several teams of astronomers are using telescopes around the world to search for new Kuiper Belt objects that would make a close pass to New Horizons. "We are definitely looking," Buie says. "We would like nothing better than to fly by another object."

## All eyes on the Kuiper Belt

Astronomers are also getting a wide-angle view of the Kuiper Belt by surveying it with some of Earth's largest telescopes. At the Canada-France-Hawaii Telescope on Mauna Kea — the same mountaintop where Jewitt and Luu spotted 1992 QB1 — astronomers recently wrapped up the Outer Solar System Origins Survey. It recorded more than 800 previously unknown Kuiper Belt objects, bringing the total number known to roughly 3,000.

This cataloging work is revealing tantalizing patterns in how these bodies move around the sun, MacGregor says. Rather than being uniformly distributed, the orbits of Kuiper Belt objects tend to be clustered in space. That's a telltale sign that these bodies got a gravitational shove in the past, she says.

The cosmic bullies that did that shoving, most astronomers believe, were none other than the solar system's gas giants. In the mid-2000s, scientists first proposed that planets like Neptune and Saturn probably pinballed toward and away from the sun early in the solar system's history. That movement explains the strikingly similar orbits of many Kuiper Belt objects, MacGregor says. "The giant planets stirred up all of the stuff in the outer part of the solar system."

Refining the solar system's early history requires observations of even more Kuiper Belt objects, says Meg Schwamb, an astronomer at Queen's University Belfast in Northern Ireland. Researchers expect that a new astronomical survey, slated to begin next year, will find roughly 40,000 more Kuiper Belt objects. The Vera C. Rubin Observatory, being built in north-central Chile, will use its 3,200-megapixel camera to repeatedly photograph the entire Southern Hemisphere sky every few nights for 10 years. That undertaking, the Legacy Survey of Space and Time, or LSST, will revolutionize our understanding of how the early solar system evolved, says Schwamb, a cochair of the LSST Solar System Science Collaboration.

It's exciting to think about what we might learn next from the Kuiper Belt, Jewitt says. The discoveries that lay ahead will be possible, in large part, because of advances in technology, he says. "One picture with one of the modern survey cameras is roughly a thousand pictures with our setup back in 1992."

But even as we uncover more about this distant realm of the solar system, a bit of awe should always remain, Jewitt says. "It's the largest piece of the solar system that we've yet observed." ■

## Explore more

- NASA Solar System Exploration. Kuiper Belt. go.nasa.gov/3oZ4Qzi

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*Katherine Kornei is a freelance science journalist based in Portland, Ore.*

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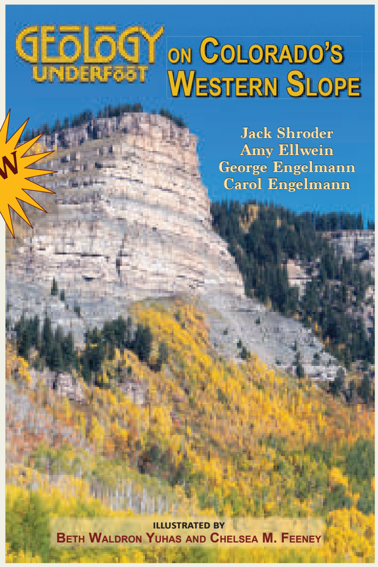


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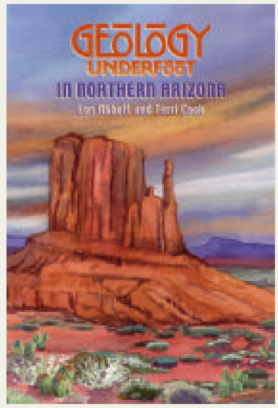


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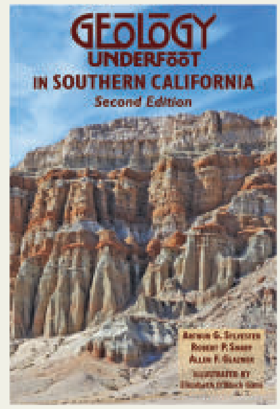


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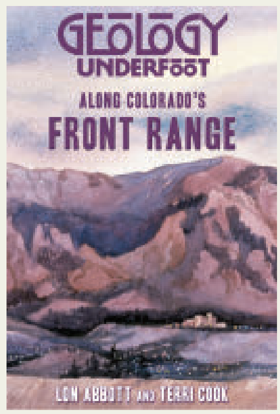


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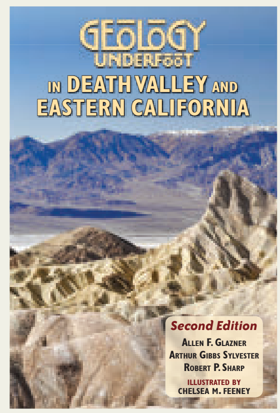


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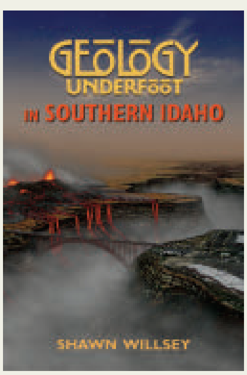


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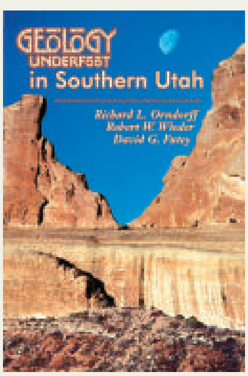


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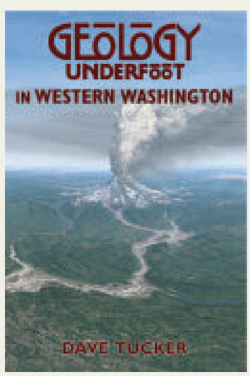


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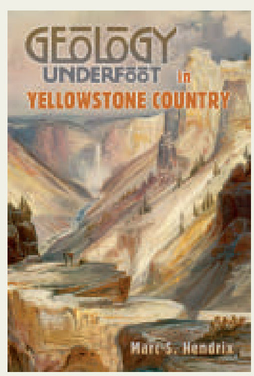


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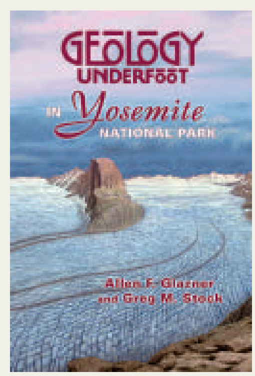


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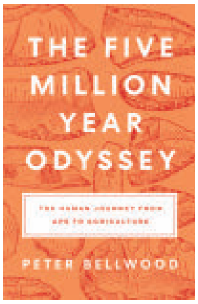



**The Five-Million-Year Odyssey**
*Peter Bellwood*
PRINCETON UNIV., $29.95

BOOKSHELF

# Take a globe-trotting tour of human evolution

Archaeologist Peter Bellwood's academic odyssey wended from England to teaching posts halfway around the world, first in New Zealand and then in Australia. For more than 50 years, he has studied how humans settled islands from Southeast Asia to Polynesia.

So it's fitting that his new book, a plain-English summary of what's known and what's not about the evolution of humans and our ancestors, emphasizes movement. In *The Five-Million-Year Odyssey*, Bellwood examines a parade of species in the human evolutionary family — he collectively refers to them as hominins, whereas some others (including *Science News*) use the term hominids (SN: 9/25/21, p. 20) — and tracks their migrations across land and sea. He marshals evidence indicating that hominids in motion continually shifted the direction of biological and cultural evolution.

Throughout his tour, Bellwood presents his own take on contested topics. But when available evidence leaves a debate unresolved, he says so. Consider the earliest hominids. Species from at least 4.4 million years ago or more whose hominid status is controversial, such as *Ardipithecus ramidus*, get a brief mention. Bellwood renders no verdict on whether those finds come from early hominids or ancient apes. He focuses instead on African australopithecines, a set of upright but partly apelike species thought to have included populations that evolved into members of our own genus, *Homo*, around 2.5 million to 3 million years ago. Bellwood hammers home the point that stone-tool making by the last australopithecines, the first *Homo* groups or both contributed to the evolution of bigger brains in our ancestors.

The action speeds up when *Homo erectus* becomes the first known hominid to leave Africa, roughly 2 million years ago. Questions remain, Bellwood writes, about how many such migrations occurred and whether this humanlike species reached distant islands such as Flores in Indonesia, perhaps giving rise to small hominids called hobbits, or *Homo floresiensis*. What's clear is that *H. erectus* groups journeyed across mainland Asia and at least as far as the Indonesian island of Java.

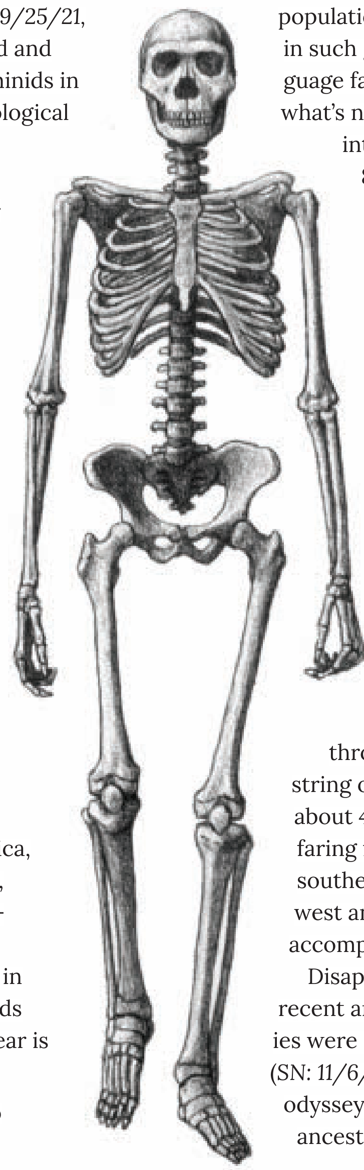
Intercontinental migrations flourished after *Homo sapiens* debuted, around 300,000 years ago in Africa. Bellwood regards *H. sapiens*, Neandertals and Denisovans as distinct species that interbred in certain parts of Asia and Europe. He suggests that Neandertals disappeared around 40,000 years ago as they mated with members of more numerous *H. sapiens* populations, leaving a genetic legacy in people today. But he does not address an opposing argument that different *Homo* populations at this time, including Neandertals, were too closely related to have been separate species and that it was intermittent mating among these mobile groups that drove the evolution of present-day humans (SN: 12/18/21 & 1/1/22, p. 30).

Bellwood gives considerable attention to the rise of food production and domestication in Europe and Asia after around 9,000 years ago. He builds on an argument, derived from his 2004 book *First Farmers*, that expanding populations of early cultivators migrated to new lands in such great numbers that they spread major language families with them. For instance, farmers in what's now Turkey spread Indo-European languages into much of Europe sometime after roughly 8,000 years ago, Bellwood contends.

He rejects a recent alternative proposal, based on ancient DNA evidence, that horse-riding herders of Central Asia's Yamnaya culture brought their traditions and Indo-European tongues to Europe around 5,000 years ago (SN: 11/25/17, p. 16). Too few Yamnaya immigrated to impose a new language on European communities, Bellwood says. Similarly, he argues, ancient Eurasian conquerors, from Alexander the Great to Roman emperors, couldn't get speakers of regional languages to adopt new ones spoken by their outnumbered military masters.

Bellwood rounds out his evolutionary odyssey with a reconstruction of how early agricultural populations expanded through East Asia and beyond, to Australia, a string of Pacific islands and the Americas. Between about 4,000 and 750 years ago, for instance, seafaring farmers spread Austronesian languages from southern China and Taiwan to Madagascar in the west and Polynesia in the east. Precisely how they accomplished that remarkable feat remains a puzzle.

Disappointingly, Bellwood doesn't weigh in on a recent archaeological argument that ancient societies were more flexible and complex than long assumed (SN: 11/6/21, p. 34). On the plus side, his evolutionary odyssey moves along at a brisk pace and, like our ancestors, covers a lot of ground. — *Bruce Bower*



*Homo erectus* (illustrated), the first known hominid to venture outside Africa, journeyed across Asia.

MAURICIO ANTÓN, PUBLISHED WITH ALAN TURNER/WIKIMEDIA COMMONS (CC BY 4.0)


JULY 2, 2022

## Higgs boson Q&A

*The discovery of the Higgs boson filled in a missing piece of the standard model of particle physics, which describes matter and its interactions. A decade later, physicists continue to probe the particle for clues to some of the universe's biggest questions,* ***Emily Conover*** *reported in "The Higgs boson at 10"* (SN: 7/2/22, p. 18).

**Conover's** tale of the Higgs boson thrilled physics enthusiasts, inspiring many comments and questions. In the piece, she explained that a Higgs boson is a wave in the Higgs field, an invisible property that pervades the cosmos. When elementary particles interact with the field, they gain mass. More massive particles interact more strongly with the field. Reader **Lewis Holcombe** wanted to know if elementary particles have zero mass before they interact with the field.

That's exactly the idea, **Conover** says. "In the early moments of the universe, before the Higgs field 'turned on,' all the fundamental particles were massless," she says. "But the standard model doesn't explain why different particles interact with the Higgs field by the amounts they do, and thus have the masses we measure."

Since the Higgs field imparts mass, reader **Paul Leonard** wondered if the field also is responsible for gravity.

The Higgs field is not responsible for gravity, **Conover** says. Although mass and gravity are related, they are different concepts. "Gravity is not part of the standard model," she says. "We don't have a working theory of gravity at the particle physics level yet."

In the standard model, forces are transmitted by particles. Scientists think that there exists another particle, not included in the standard model, called a graviton, which transmits gravity, **Conover** says. If it exists, the graviton is expected to be a massless particle with no electric charge. But it will be extremely difficult to find, she says, because gravity is very weak compared with the standard model forces: electromagnetism, the weak force and the strong force.

Reader **Brad Ruben** wondered about other standard model particles: quarks. A top quark is about as heavy as a gold atom. That large mass is reflected in measurements of the particle's interactions with the Higgs field, **Conover** reported. Since quarks make up protons and neutrons, which are the building blocks of atoms, **Ruben** asked how a single quark can weigh as much as an atom.

The top quark's mass is no contradiction, **Conover** says. According to the simplest image of protons' and neutrons' innards, the particles don't contain top quarks. Protons are made up of two up quarks and one down quark, whereas neutrons have two down quarks and one up quark, she says. A closer look reveals a more complex image. "For instance, inside the proton, there are not only quarks, but also gluons. These are massless particles that carry the strong force, which 'glues' the quarks together," **Conover** says. "There is also a 'sea' of various types of quarks and antiquarks that last only for brief instants in the proton." The energies and other subtle properties of these subatomic particles all contribute to the mass of the proton.

## Tech takes time

*Lightweight subatomic particles called neutrinos could help monitor nuclear submarines to ensure that the uranium-rich fuel many use isn't weaponized,* ***Emily Conover*** *reported in "Neutrinos could spy nuclear rogues"* (SN: 7/2/22, p. 12).

Reader **John Oxman** asked how useful this monitoring technology would be, considering all countries that currently have nuclear submarines already possess nuclear weapons.

Non-nuclear weapon states could get nuclear submarines in the future, **Conover** says. For example, Australia is set to acquire such subs with the help of the United States and the United Kingdom. "Even if the need for this type of monitoring is not immediate, the process of implementing and perfecting monitoring technologies, especially a new type that uses neutrinos, is very lengthy," she says. "For such a technology to be useful, researchers have to anticipate the need well in advance."

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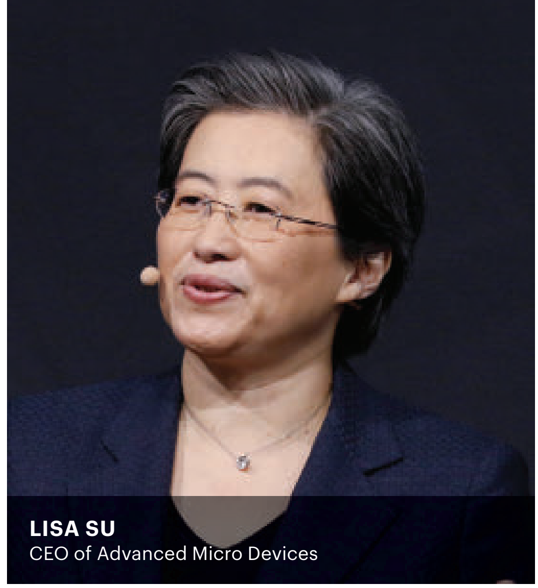


**LISA SU**
CEO of Advanced Micro Devices

Maya Ajmera, President & CEO of the Society for Science and Publisher of *Science News*, chatted with Lisa Su, CEO of Advanced Micro Devices (AMD), a multinational semiconductor company that develops computer processors and related technologies. Su is an alumna of the 1986 Science Talent Search (STS), a competition owned and produced by the Society for Science. She was inducted into the National Academy of Engineering in 2018 and was appointed to President Biden's Council of Advisors on Science and Technology in 2021.

**How did STS impact your life? You went to Bronx High School of Science, a school where many students have competed in STS over the years.**

My STS project was the first large project that I completed on my own. It was ambitious, and it forced me to think broadly about what I wanted to work on for a few months. I also recall hoping that my project would amount to something. It was a great experience.

**Was your project focused on engineering or mathematics?**

I did a math project centered on number theory and how to think about math.

**Growing up, your father was a mathematician and your mother was an accountant and an entrepreneur. Did your parents' background and expertise shape your aspirations?**

My parents had a large influence on how I grew up and how I spent my time. When I was in grade school, my father would quiz me in math tables after dinner. That's how math became something that I enjoyed. I also enjoyed understanding how things work, especially physical things.

My brother had these model car toys that sometimes would stop working and I was interested in understanding why. I would open them up, take them apart and realize: "Oh, there's a loose wire there. If I connect this wire, then the car will start working again." So that was how I got into engineering and developed the desire to fix and work on things.

**Beginning with your time as a student at MIT, much of your career has been spent improving semiconductor technology and leading teams in those efforts. When did you know that you wanted to focus on engineering? When did the business piece come into play?**

MIT was a great experience and I enjoyed being surrounded by other people who had similar interests. I majored in electrical engineering, which was the most popular major as well as the most difficult major at the time.

I thought it was so cool that during our introductory classes, we were actually building circuits, building computers and programming things. I enjoyed that aspect of engineering.

My mother was an entrepreneur who started her own business, and I had a chance to observe her experience. When it came time to lead my own company, it was fun to put together both the process of building things and the process of running businesses.

**Semiconductors are an essential component of nearly every electronic device. What is it about the field that continues to interest you? What keeps you excited and motivated?**

The beauty of semiconductors is that they really do touch every aspect of your life. When I started in this field more than 25 years ago, it wasn't that obvious. I don't think everybody understood how important semiconductors were. Now, everything in our lives runs on processors built with semiconductors, including computers, phones and washing machines. What I found really interesting was that, through a process of basic fabrication, you are able to build something that's very complex.

This field has continued to be as exciting as it was 25-plus years ago because we keep improving the capabilities of semiconductors. I love the idea that something I worked on or that we worked on as a team can show up in your house.

**When you were named CEO of AMD, the company faced steep challenges. Since then, AMD has grown substantially and cemented itself as an industry leader. How did you get the company back on track?**

In our industry, it's all about making long-term bets. What was most important for me and for my team was having a long-term vision of where the semiconductor road map was going to go. We knew it would take three to five years to really see the results of some of the directional decisions that were made. Beyond that, sometimes it's about deciding what you're not going to do.

**Less than 10 percent of Fortune 500 companies are led by female CEOs. As one of those leaders and the first female CEO of AMD, what do you think needs to happen to increase representation at the highest levels of industry?**

First, there are fewer women in engineering than men. A lot of the work needs to be done in STEM education to expand access and bring women into the engineering workforce. While no one can guarantee career success, more opportunities are helpful.

I was helped along the way by people who gave me opportunities and put large problems in front of me. I am a big believer in giving women and underrepresented minorities, or frankly just high-potential people, really challenging opportunities early on in their career.

We're not there yet—by a long shot—but I think there's a lot more constructive dialog taking place now than there ever has been before.

AMD CEO Lisa Su launched new products at the Consumer Electronics Show in 2022.

**Last year, you received the Robert N. Noyce medal, the highest honor bestowed by the Institute of Electrical and Electronics Engineers (IEEE). Looking back on your career, what accomplishment are you most proud of?**

I am a product person through and through. So launching a new processor is probably my proudest moment. Out of all of the processors that I've launched during my career, probably the first generation of our Zen processor was my favorite. But honestly, they're all like my kids, so I love all my products.

**The nature and complexity of your work requires forecasting the needs of the market several years down the road. Where do you see the field of computing technology heading?**

It is pretty much like a crystal ball, trying to figure out what's going to happen over the next decade. I do think that there are several important computing trends, including high-performance computing, which is providing more performance at lower power, as well as artificial intelligence, which has an amazing array of applications. The other aspect is recognizing that for us to continue the pace of innovation that we've been experiencing, we need more interdisciplinary development—hardware folks working with software folks working with system designers—to really optimize the entire system.

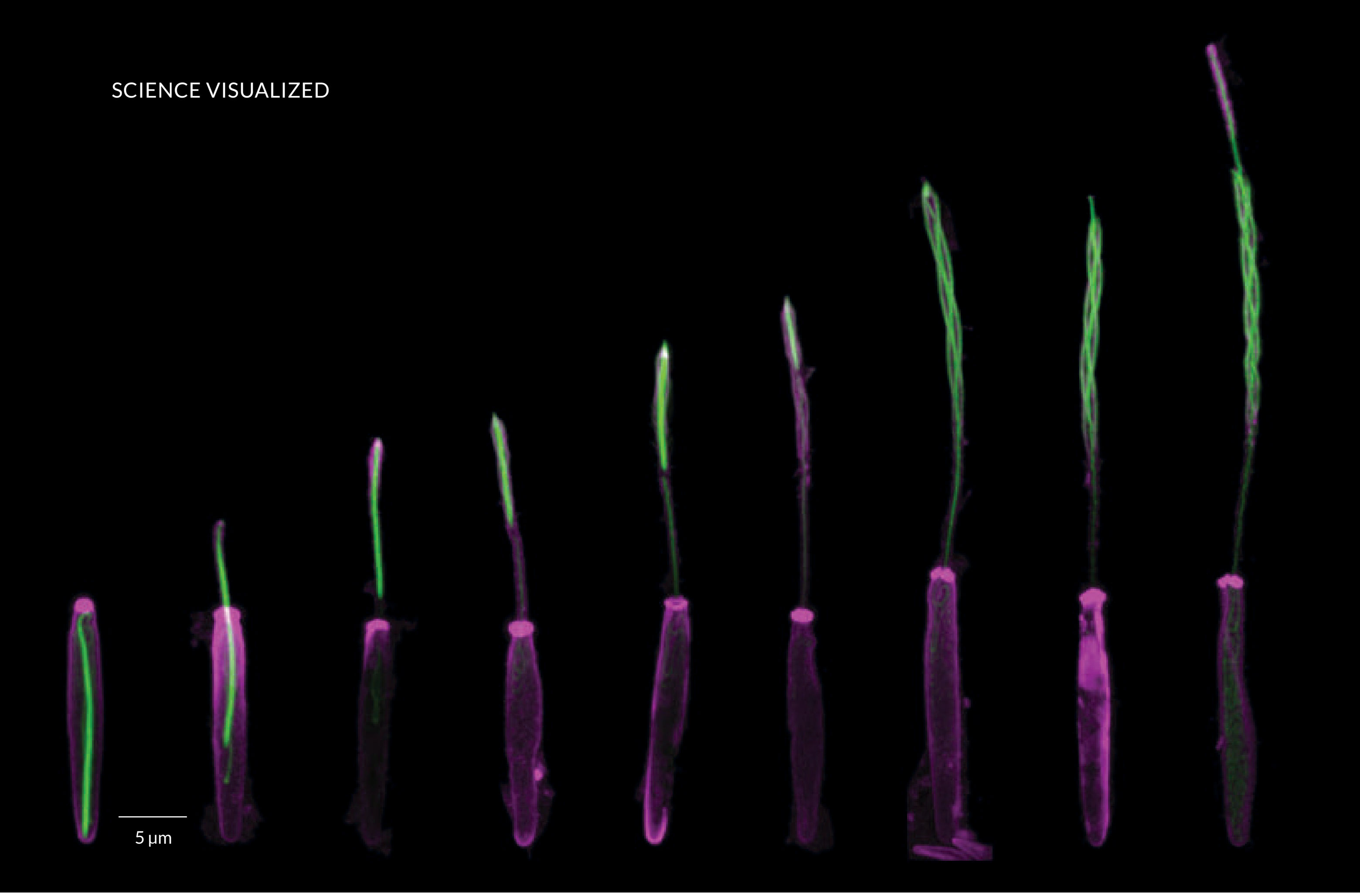
**Who inspired you as a young person, and who inspires you today?**

That may be the same. My inspiration has always been my mother. She and my dad immigrated to the United States right after I was born, in 1969. Watching her work hard to build her own business and to build her life here in the United States was an inspiration and continues to be an inspiration to me. It's amazing what you can do when you put your mind to it.

**What advice do you have for young people just starting out in higher education or their careers?**

I would encourage young people to dream big and be ambitious about what they can do. You have to dream it to actually achieve it. Plan your career, your education or your life in five-year segments. It's hard to know where you want to be in 25 years, but you can certainly identify things you would like to accomplish in the next five years. Share those ambitions with people because they will want to help you if you're open about your ambitions.

Lastly, the best piece of advice I got as a young engineer was from one of my mentors who advised me to run toward problems. You will learn an incredible amount. It's been one of the best pieces of advice because, if you think about it, there are a lot of talented individuals in the world. But what you need is a combination of being smart, working hard and being in the right place at the right time. Running toward problems helps you be in the right place at the right time.




# How sea anemones launch their venomous stingers

A new look at the starlet sea anemone's stingers gets right to the point.

Live-animal images and 3-D computer reconstructions reveal the complex architecture of the creature's needlelike weapons. Like harpoons festooned with venomous barbs, the stingers rapidly transform as they fire, biologists Matt Gibson and Ahmet Karabulut and colleagues report June 17 in *Nature Communications*. Scientists can now see in detail "what this apparatus looks like before, during and after firing," says Gibson, of the Stowers Institute for Medical Research in Kansas City, Mo.

In the wild, the starlet sea anemone (*Nematostella vectensis*) can live in salty lagoons or shallow estuaries, where freshwater rivers meet the sea. Its tubular body burrows into the mud, and a crown of Medusa-like tentacles reaches up into the water, waiting for dinner to drift by (SN: 6/15/13, *p.* 8). Each tentacle packs hundreds of stingers that can mean death for brine shrimp or other prey.

These stingers are among the fastest micromachines in nature. An anemone can jab a predator in about a hundredth of a second, says Karabulut, also of the Stowers Institute. Scientists had an idea of how the stingers worked but had never gotten so up close and personal until now.

Fluorescence microscopy images (above) show the precise step-by-step mechanics of the speedy shooters as they fire (from left to right). The stinger launches a shaft (stained green) from a pressurized capsule (pink). The shaft extends, and a venomous thread races up through it and into an animal's soft tissue. Computer visualizations derived from scanning electron microscopy reveal the 3-D structure of the stingers (left, shown firing from top to bottom): The venomous thread (pink) starts out coiled around the shaft (blue), while connectors (yellow) link different parts of the apparatus together and tiny barbs (not visible) speckle the thread.

Each stinger is good for just one shot. "It's a one-hit wonder," Karabulut says. "Once *Nematostella* uses it, it's gone." — *Meghan Rosen*

ALL: THE GIBSON LAB/STOWERS INSTITUTE FOR MEDICAL RESEARCH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