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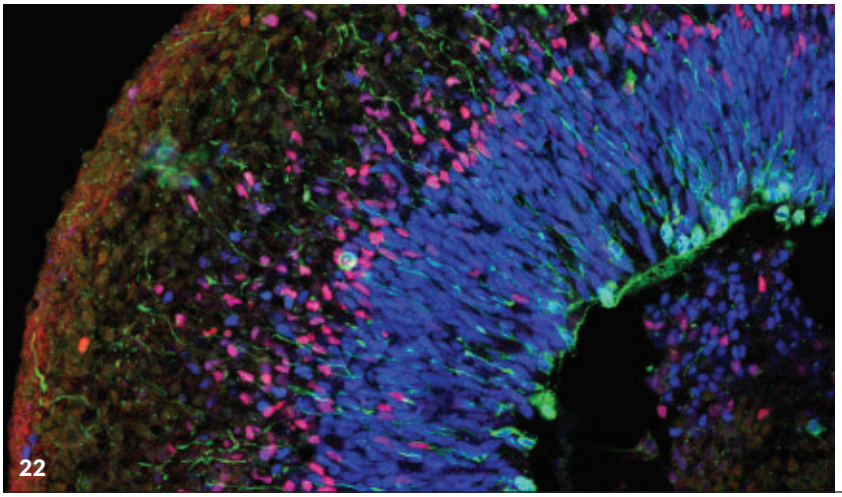

Features

News

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Departments

COVER Fossil finds have pushed aside old views of dinos, like the 1853 beasts in London's Crystal Palace Park (background). *Nicolle Rager Fuller*

A Note from Maya Ajmera

I am thrilled to introduce *Science News*' new Editor in Chief, Nancy Shute, who takes the helm of Science News Media Group at an exciting inflection point for journalism. Nancy will be managing the *Science News* newsroom and overseeing its digital transformation. As we approach the Society's centennial year in 2021, I could not be more impressed with who we have chosen to steer our ship.

Nancy has extensive experience in science journalism, coming to us from NPR where she cohosted NPR's health blog, *Shots*, and contributed news and radio features to NPR's *All Things Considered* and *Morning Edition*. She also has written for national publications, including *National Geographic* and *Scientific American*, and served as assistant managing editor at *U.S. News & World Report*.

I know she will be a great asset to *Science News*.

—Maya Ajmera, CEO and Publisher

Building a bright future for science journalism

As a longtime reader of *Science News*, I'm delighted to join the staff of this remarkable publication, which has been explaining the complexities of science, medicine and technology for more than 90 years. *Science News* hasn't been standing still; people can find our breaking news and in-depth coverage in the flagship magazine as well as on the *Science News* website, which drew more than 10 million users in 2017, and also on Facebook (2.7 million followers) and Twitter (another 2.7 million).

Science News for Students and the *Science News* in High Schools program, which connects students in over 4,300 high schools and their teachers with the magazine, are introducing the next generation to key issues in research, science policy and public health that affect not just the future of science, but the future of us all.

The world of journalism is evolving rapidly. In the months to come, we here at *Science News* will be exploring how we can better serve our core readers while also introducing our top-quality science journalism to new audiences. We'll be investigating innovations in journalism around the world and thinking big about what new platforms or technologies could make *Science News* stronger, better and more accessible. Who better than science journalists to help invent the news delivery systems of the future?

Twelve years ago, few among us would have imagined that we'd be reading the news on the lock screens of our smartphones. I certainly can't imagine how we'll be reading a decade from now. But I'm looking forward to finding out.

Rest assured, our commitment to rigorous reporting, accuracy, fairness and transparency will remain at the core of our mission at *Science News*. I'm looking forward to moving into the future with you and for you, our readers.

—Nancy Shute, Editor in Chief

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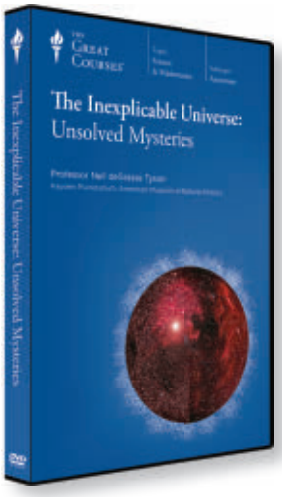

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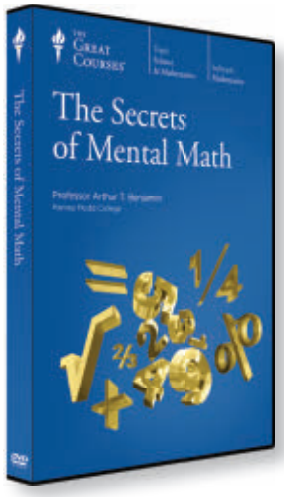

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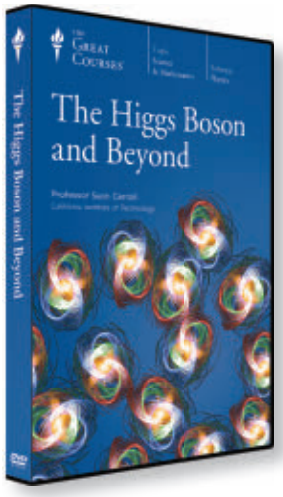

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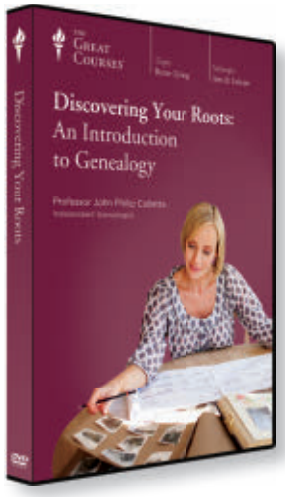

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Excerpt from the March 2, 1968 issue of *Science News*

50 YEARS AGO

Kidneys lead the field

While the drama of human heart transplants has grasped the public interest, kidney transplants are ahead in the field.... Although only three little girls are now surviving liver transplants, the liver is a promising field for replacement.... The donor, of course, must be dead; no one can live without his liver.

UPDATE: Kidney patients, who could receive organs from family members, had up to a 75 percent one-year survival rate in 1968. Liver recipients were less lucky, having to rely on unrelated, postmortem donations. Liver patients' immune systems often attacked the new organ and one-year survival was a low 30 percent. Cyclosporine, an immune-suppressing drug available since 1983, has made a big difference. Now, about 75 percent of adults are alive three years after surgery, and children's odds are even better. The liver is still a must-have organ, and the need for donor livers has climbed. Today, the options have expanded, with split-liver transplants and partial transplants from living donors.

Cream-colored petals curl over a cacao flower's male parts. Ants visit, but tinier insects do the pollinating.

IT'S ALIVE

Our beloved chocolate depends on *this*?

It's a wonder we have chocolate at all. Talk about persnickety, difficult flowers.

Arguably some of the most important seeds on the planet — they give us candy bars and hot cocoa, after all — come from pods created by dime-sized flowers on cacao trees. Yet those flowers make pollination just barely possible.

Growers of commercial fruit crops expect 50 to 60 percent of flowers to make a fruit, or pod, says Emily Kearney of the University of California, Berkeley. In some places, cacao crops manage to be that prolific. But worldwide norms run closer to 15 to 30 percent. In the traditional Ecuadorian plantings that Kearney studies, cacao achieves a mere 3 to 5 percent pollination.

The first sight of a blooming cacao tree (*Theobroma cacao*) can be "disconcerting," Kearney says. That's because

SCIENCE STATS

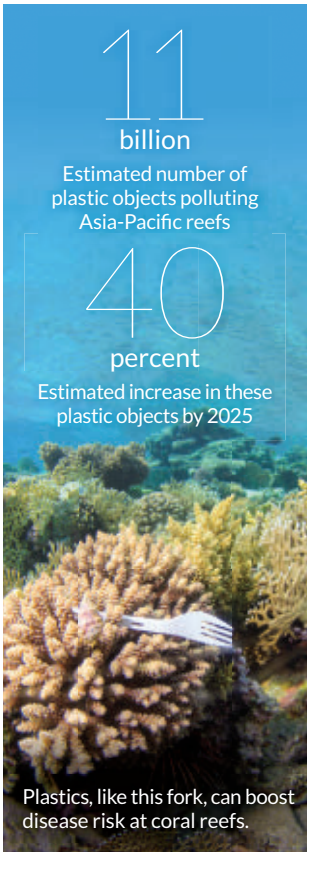
Coral reefs are sick of plastic

More than 11 billion plastic objects are polluting Asia-Pacific coral reefs, a new study estimates. Reefs littered with plastic were at least 20 times as likely to have diseased corals as unpolluted reefs, researchers say.

When corals die, they break down, robbing underwater organisms of their reef habitats. Based on current trends, the amount of plastic trapped in Asia-Pacific reefs is projected to increase 40 percent by 2025, further endangering corals, scientists report in the Jan. 26 *Science*.

"Plastic has pits and pores. It's the perfect vessel for microbes to colonize," says Joleah Lamb, a marine biologist at Cornell University. Microbes can cause devastating diseases in coral, she says.

From 2011 and 2014, the researchers surveyed 159 reefs in the Asia-Pacific region, home to more than half the world's coral reefs. The group documented diseased coral and any plastic debris larger than about the size of a Ping-Pong ball. Plastic levels varied dramatically by location, with Australian reefs having the lowest levels and Indonesian reefs the highest. That variation was strongly associated with how much plastic waste each country produced, and how the debris was managed, the researchers say. — *Dan Garisto*



Plastics, like this fork, can boost disease risk at coral reefs.

FROM TOP: E. KEARNEY; JENNY LORD/SHUTTERSTOCK

most flowers come directly out of the trunk, rather than sprouting from branches as in many other trees. For cacao, special trunk pads burst into little pale constellations of five-pointed starry blossoms. Some trunks, says Kearney, "are completely covered with flowers."

Those flowers make nothing easy. Each petal curves into a tiny hood that fits down around the male, pollen-making structure. A honeybee trying to reach the pollen would be a useless, giant blimp. Instead, flies not much bigger than a poppy seed, in the biting midge subfamily Forcipomyiinae, crawl up into the hoods and do — something.

But what? The flower offers no nectar for the midges to collect. So far, researchers haven't even demonstrated that there's an odor luring in the midges. Some biologists have mused that red spikes on the flowers offer nutritious nibbling for midges, but Kearney knows of no tests of this notion.

Plump pods from *Theobroma cacao* trees hold dozens of seeds and vary considerably in color.

Another hitch: 100 to 250 grains of pollen are required to fertilize the 40 to 60 seeds that will make up a cacao pod (resembling a wrinkled, swollen cucumber in shades of purple, yellow or orange). Yet midges typically emerge from a flower hood dappled with just a few to 30 grains of the sticky white stuff.

What's more, the midge, dusted with that little bit of pollen like "clumpy sugar," Kearney says, can't just hike over to the same bloom's female part, like a white-bristled paintbrush encircled by red spikes. Pollen is useless for fertilizing any blooms on the tree it came from or on really close relatives.

"If we want to get answers about the cacao pollination system," Kearney says, "I think it's the wild individuals that are going to open up the field," instead of cultivated cacao.

The trees evolved in the Amazon Basin and a northern bit of the South American Pacific coast. There, they often grow in clusters of siblings that a monkey unintentionally planted when sucking pulp from a pod and dropping the seeds.

To Kearney, those frail midges seem unlikely to fly the distance from too-close sibling clusters to unrelated trees that offer better cross-pollination chances. So she wonders: Could the cacao with its coy reproductive system have a clandestine, strong-flying native pollinator species that scientists just haven't noticed? — *Susan Milius*

TEASER

Gel might thwart MRSA infections

A new ointment could help take down drug-resistant bacteria.

In human skin samples and mice, the medicine completely cleared wounds of MRSA, the strain of *Staphylococcus aureus* that is resistant to methicillin and other antibiotics, as well as antibiotic-resistant *Acinetobacter baumannii*. Both microbes cause serious infections in people. Researchers in the Netherlands and Austria created the gel's key ingredient, a chain of amino acids called SAAP-148, by improving on a bacteria-fighting peptide found in humans.

The synthetic peptide prevents pathogens from forming biofilms — colonies of microbes enveloped in a protective slime that shields them from antibiotics — the researchers report online January 10 in *Science Translational Medicine*. Bacteria living in a biofilm can be 10 to 1,000 times as hard to kill as their free-floating counterparts. SAAP-148 also wipes out microbes that hunker down in a dormant, drug-tolerant state during an antibiotic assault, ready to lead a bacterial resurgence after treatment ends.

After being exposed to SAAP-148 for four weeks, the microbes did not develop strong resistance. These results are "quite promising," says microbiologist David Weiss of Emory University School of Medicine in Atlanta, who wasn't involved in the work. Studies of the gel in humans are slated to begin this year. — *Maria Temming*

SAY WHAT?

A killer whale says 'hello'

Ready for sketch comedy she's not. But a 14-year-old killer whale named Wikie has shown promise in mimicking unfamiliar sounds, such as a human "hello" — plus some rude noises.

Scientists recorded Wikie at her home at Marineland in Antibes, France, imitating another killer whale's loud raspberry sounds, as well as a trumpeting elephant and humans saying such words as "one, two, three." The orca's efforts were "recognizable" as attempted copies, comparative psychologist José Zamorano Abramson of Complutense University of Madrid and colleagues report January 31 in *Proceedings of the Royal Society B*. Just how close Wikie's imitations come to the originals depends on whether you're emphasizing the rhythm or other aspects of sound, Abramson says.

Six people and a computer program judged Wikie's mimicry skills. She did better at some sounds, like blowing raspberries and saying "hello-hello," than saying "bye-bye."

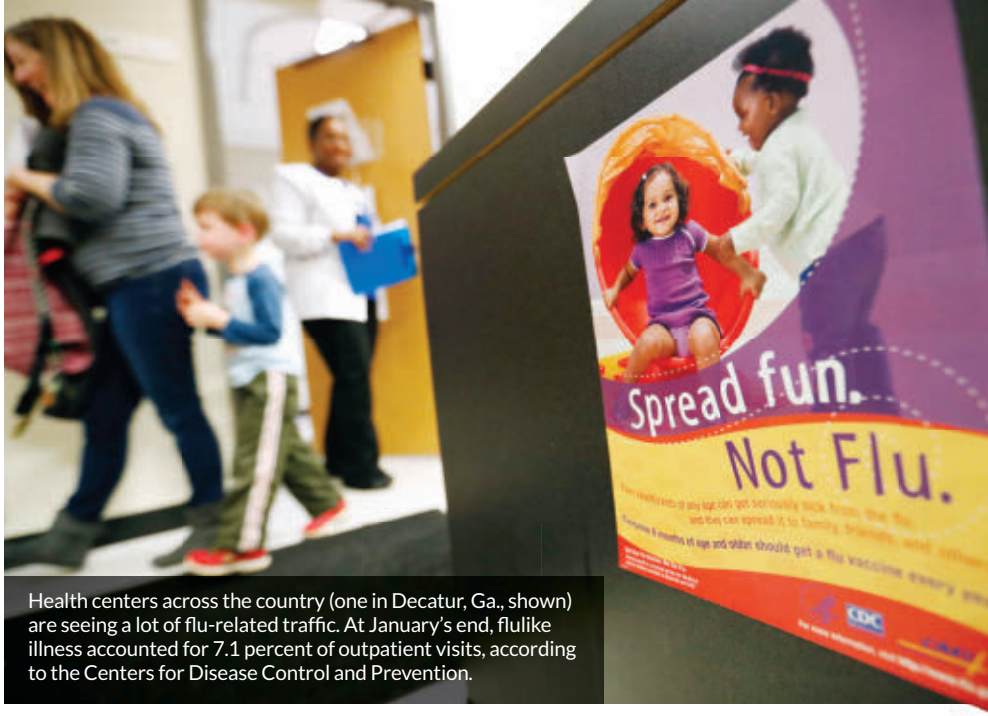
The research supports the idea that imitation plays a role in how killer whales develop their elaborate dialects of bleating pulses. Cetaceans are rare among mammals in that, like humans, they learn how to make the sounds their species uses to communicate. — *Susan Milius*

To hear a killer whale's humanlike "hello," visit **bit.ly/SN_whalemimicry**

BODY & BRAIN

An intimate look at how flu spreads

Data from a college campus could boost infection control



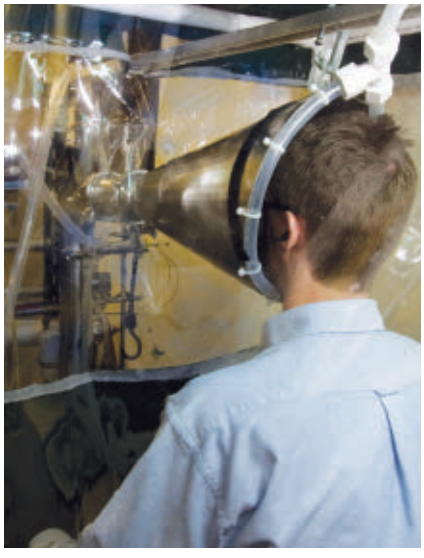
Health centers across the country (one in Decatur, Ga., shown) are seeing a lot of flu-related traffic. At January's end, flulike illness accounted for 7.1 percent of outpatient visits, according to the Centers for Disease Control and Prevention.

BY AIMEE CUNNINGHAM

COLLEGE PARK, MD. — Campus life typically challenges students with new opportunities for learning, discovery — and intimacy with germs. Lots of germs.

That makes dormitories and their residents an ideal natural experiment to trace the germs' paths. "You pack a bunch of college kids into a very small environment.... We're not known as being the cleanliest of people," says sophomore Parker Kleb at the University of Maryland in College Park.

Kleb is a research assistant for an ongoing study tracking the spread of respiratory viruses through a student population. The study's goal is to better understand how these viruses move around, in order to help keep illness at bay — all the more pressing as the current flu season is on track to be among the worst recorded in the United States.



This apparatus, dubbed Gesundheit-II, collects aerosol droplets from exhaled breath. The detection of infectious influenza virus in these breath samples suggests that just breathing may spread the flu.

Called "CATCH the Virus," which stands for Characterizing and Tracking College Health, the study traces the trajectory of viral infections using blood and breath samples and nasal swabs from ailing freshmen and their closest contacts. (The team's tagline: It's snot your average research study.)

Donald Milton, an environmental and occupational health physician-scientist, heads the project. On a recent day, he described the study to a classroom of freshmen he hopes to recruit. He ticked off questions the research seeks to answer: What is it that makes people susceptible to getting sick? What makes them contagious? And how do they transmit a virus to others?

"Maybe your house, your room has something to do with whether you're at risk of getting infected," Milton said.

He had a receptive audience. His listeners were members of the College Park Scholars' Global Public Health program, so infection control is right up their alley. "How sick do we have to be?" one student asked. It's the culprit that matters, she's told. The study covers acute respiratory infections due to influenza viruses, adenoviruses, coronaviruses or respiratory syncytial virus, known as RSV.

Of most interest, however, is influenza. "Flu is important to everybody," says Milton. Influenza is thought to spread among humans in three ways: touch; coughing and sneezing, which launches droplets containing virus from the lungs onto surfaces; and exhalation, which sheds aerosols, smaller suspended droplets (*SN: 6/29/13, p. 9*).

How much each of these modes of transmission contributes to the spread of viruses is a point of fierce debate, says Milton. And that makes infection control difficult, especially in hospitals. "If we don't understand how [viruses] are transmitted, it's hard to come up with policies that are really going to work," he says.

Milton and colleagues recently reported that people with the flu can shed infectious virus particles just by breathing. Of 134 fine-aerosol samples taken when patients were breathing normally, 52 contained infectious influenza virus — or 39 percent, according to the study, published online January 18 in *Proceedings of the National Academy of Sciences*. Those fine-aerosol particles of respiratory tract fluid are 5 micrometers in diameter or less, small enough to stay suspended in the air and potentially contribute to airborne transmission of the flu, the researchers say.

"This could mean that just having good cough and sneeze etiquette — sneezing or coughing into tissues — may not be enough to limit the spread of influenza," says virologist Andrew Pekosz of Johns Hopkins University, who was not

FROM TOP: DAVID GOLDMAN/AP PHOTO; UMD SCHOOL OF PUBLIC HEALTH

involved with the study. "Just sitting in your office and breathing could fill the air with infectious influenza."

The CATCH study aims to find out if what's in the air is catching. In two University of Maryland dorms, carbon dioxide sensors measure how much of the air comes from people's exhalations. In addition, laboratory tests measure how much virus sick students are shedding into the air. To get those samples, students sit in a ticket booth–sized contraption called the Gesundheit-II and breathe into a giant cone. These data can help researchers estimate students' airborne exposure to viruses, Milton says.

Another key dataset comes from DNA testing of the viruses infecting the students. "The virus mutates reasonably fast," Milton says, and the more people it has moved through, the more changes it will have. By combining this molecular chain of transmission with the social chain of transmission, the researchers will try to "establish who infected whom, and where, and how," Milton says.

The goal is to enroll 130 students in CATCH. It's doubtful they'll all get sick, but not that many students from this initial group are needed to start the ball rolling, says Jennifer German, a virologist and CATCH student engagement coordinator. "For every index case that has an infection we're interested in, we're following four additional contacts," she says. "And then if any of those contacts becomes sick, we'll get their contacts and so on."

The study began in November. As of the end of January, German says, researchers have collected samples from five sick students, but only one was infected with a target virus, influenza. The researchers now are following three contacts from that case.

Timing and the size of the current flu outbreak may be on the researchers' side. Kleb says that students are still waiting for this season's flu to sweep through the dorms. "Once one person gets sick, it goes around to everyone on the floor," he says. "I'm very interested to see what happens in the next few weeks, and how the study will hopefully benefit." ■

NITIN ARORA AND CAROLYN COYNE/UNIV. OF PITTSBURGH

BODY & BRAIN

Zika relatives can also damage a fetus

Tests in mice reveal other flaviviruses can cause deadly harm

BY AIMEE CUNNINGHAM

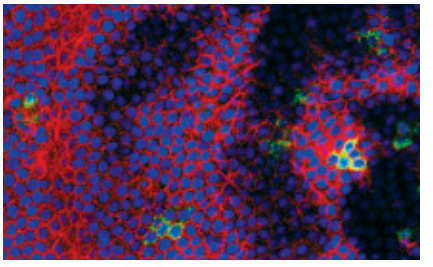
Zika virus may not be the black sheep of the family. Two related viruses also cause defects in the fetuses of infected mice, researchers find.

Some scientists have speculated that Zika's capacity to harm a fetus might be unique among its kind, perhaps due to a recent change in the virus's genetics (*SN: 10/28/17, p. 9*). Others have argued that this dangerous ability might have always been there. It just wasn't until the 2015–2016 epidemic in the Western Hemisphere that enough pregnant women were affected for public health researchers to identify the association with fetal defects (*SN: 12/24/16, p. 19*).

But new work suggests this capacity is not Zika's alone. Pregnant mice infected with West Nile or Powassan virus — both flaviviruses, like Zika — showed fetal harm. Over 40 percent of infected fetuses died. Among pregnant mice infected with one of two other mosquito-borne viruses unrelated to Zika, all of the fetuses survived, scientists report online January 31 in *Science Translational Medicine*.

The research suggests that "many viruses, including some similar to Zika, can infect the placenta and the cells of the baby," says George Saade, an obstetrician-gynecologist and cell biologist at the University of Texas Medical Branch at Galveston. "This list keeps growing and highlights the risks from viruses that we are not very familiar with."

Like Zika, West Nile and Powassan are neurotropic, meaning they target nerve cells. Both viruses can cause inflammation of the brain or the membranes surrounding it. West Nile is transmitted to humans by mosquitoes that have bitten infected birds. From 1999 to 2016, there were more than 46,000 cases reported to the U.S. Centers for Disease Control and Prevention. Powassan, spread by ticks that have fed on infected rodents (*SN: 8/19/17, p. 16*), is less widespread; 98 cases were reported from 2007 to 2016.



West Nile virus (green in this micrograph) grows in a sample of human placental tissue. In tests in mice, West Nile harmed fetuses.

Jonathan Miner, a virologist at the Washington University School of Medicine in St. Louis, and colleagues conducted early work in mice demonstrating that Zika could harm fetuses (*SN: 6/11/16, p. 15*). The new study tests four other viruses: the two flaviviruses and two alphaviruses, chikungunya and Mayaro, which also have led to outbreaks in Zika-affected areas.

The researchers infected 14 mice early in their pregnancies with one of the four viruses. By late pregnancy, 12 out of 30 fetuses from West Nile–infected mice had died, and half of the 16 fetuses from Powassan-infected mice had died. All fetuses from mice with chikungunya and Mayaro virus survived. The flaviviruses also multiplied more efficiently than the alphaviruses in lab samples of human placental tissue.

Zika, West Nile and Powassan share genetic similarities, Miner says. "So there may be certain features of those virus genes and proteins in that particular family that confers this ability to infect certain cell types," he says. Scientists don't yet fully understand those features.

Past studies have raised the possibility of fetal damage from infections with flaviviruses other than Zika, Miner says. A 2006 study of 77 pregnant women infected with West Nile virus reported that two had infants with microcephaly, the birth defect lately associated with Zika that results in unusually small and damaged brains. ■

LIFE & EVOLUTION

Tricky turns give slow prey a chance

Tracking hunters and hunted reveals successful escape moves

This cheetah and other big predators may be more athletic than their prey, but speed isn't the only factor in life-and-death chases.

BY SUSAN MILIUS

First, a note to any impala suddenly rushed by a cheetah: Do not — repeat, do not — just zoom straight off as fast as four hooves can carry you.

The best escape move, according to analysis of the most detailed chase data yet from big cat predators as well as their prey, is some fluky turn, even though turning requires a slower stride. Swerve far enough and the cheetah will be racing too fast to make the same turn.

Overall, cheetahs and lions are more athletic than the impalas and zebras they chase, says Alan Wilson of the Royal Veterinary College of the University of London. But prey still have a chance, he and colleagues report online January 24 in *Nature*. The team worked with researchers in Botswana to collect abundant motion data — several hundred thousand strides' worth — from wild animals and reconstruct their sprints and turns. "You're actually doing a step-by-step dissection," Wilson says, "which is pretty cool."

Wilson, a veterinarian and research scientist who describes himself as "an equipment geek," began collecting data in 2011 on cheetah chases (*SN: 7/13/13, p. 9*). "Typically your tracking collar will tell you where an animal is once an hour, or once every five minutes if you're lucky," he says. His team designed collars that record data for calculating position, speed and acceleration multiple times a second. The collar falls off after a certain length of time so researchers can retrieve it and download the data.

Wilson's team collected collar data for two predator-prey groups in Botswana's savannah — cheetahs and impalas, and lions and zebras — though none of the collared cats were recorded chasing the collared prey. Comparing the information from more than 5,500 running episodes, the team found that each predator could outdo its typical prey by about 38 percent in speed. The predators also had about 37 percent greater acceleration and 72 percent better deceleration. The team also nipped samples of muscle fiber and brought them to England to measure muscle contraction power. Both predators had about 20 percent more fiber power in a leg muscle than the prey.

To see how an impala or zebra might escape such formidable hunters, the researchers created stride-by-stride computer simulations of hypothetical pursuits. At top speeds, prey had few options for veering to where a predator couldn't pounce. The best hope for prey

ATOM & COSMOS

Dark matter globs may hide in galaxy

Scientists might find signs of complex structures in halos

BY EMILY CONOVER

Clumps of dark matter may be sailing through the Milky Way and other galaxies.

Typically thought to form featureless blobs surrounding entire galaxies, dark matter could also collapse into smaller clumps — similar to normal matter condensing into stars and planets — a study proposes. Thousands of collapsed dark clumps could constitute 10 percent of the Milky Way's dark matter, researchers from Rutgers University in Piscataway, N.J., report in the Feb. 2 *Physical Review Letters*.

Dark matter is necessary to explain the motions of stars in galaxies. Without the extra mass, astronomers can't justify why stars move at the speeds they do. Calculations suggest that a spherical "halo" of invisible, unidentified massive particles surrounds each galaxy.

But the halo might be only part of the story. "We don't really know what dark matter at smaller scales is doing," says theoretical physicist Matthew Buckley, who coauthored the study with physicist Anthony DiFranzo. More complex structures might be hiding within the halo.

To collapse, dark matter would need a way to lose energy, slowing particles as gravity pulls them into the center of the clump, so they can glom on to one another rather than zipping right through. In normal matter, this energy loss occurs via electromagnetic interactions. But the most commonly proposed type of dark matter particles, weakly interacting massive particles, or WIMPs, have no such way to lose energy.

Buckley and DiFranzo imagined what might happen if an analogous "dark electromagnetism" allowed dark matter particles to interact and radiate energy. The duo considered how dark matter would behave if it were like a pared-down version of normal matter, composed of two types of charged particles — a dark proton and a dark electron. Those particles could interact and radiate energy in the form of dark photons.

The researchers found that small clouds of such dark matter could collapse, but larger clouds, the mass of the Milky Way, for example, couldn't; they have too much energy to get rid of. This finding means that the Milky Way could harbor a vast halo, with a sprinkling of dark matter clumps within. By picking particular masses for the hypothetical particles, the researchers calculated the number and sizes of clumps that could be floating through the Milky Way.

In Buckley and DiFranzo's scenario, the dark matter can't squish down to the

ANTERO TOPP/SHUTTERSTOCK

came at slower speeds, when they could pivot more to the side. Lending credence to these results, actual collar records showed a lot of running at merely moderate speeds by both predator and prey.

The detailed data allowed for an unprecedented level of analysis, says biomechanist Paolo Domenici of the Institute for Coastal Marine Environment's center near Oristano, Italy. Five or 10 years ago, he notes, measurements of animal athletics came mostly from treadmills or other lab setups without a sense of what real-world emergency might prompt particular motions.

This study "definitely adds a major piece of the puzzle in the predator-prey arms races," Domenici says. Now "it would be interesting to test predator-prey systems in other environments."

Predators hunt in varied ways, adds comparative biomechanist Talia Moore of the University of Michigan in Ann Arbor, who has studied the escape hops of little desert rodents called jerboas. She hopes the paper inspires more analysis of the diversity of predation, including animals that hunt by ambush. ■

size of a star. Before the clumps get that small, they reach a point where they can't lose any more energy. So a single clump might be hundreds of light-years across.

The result, says theoretical astrophysicist Dan Hooper of Fermilab in Batavia, Ill., is "interesting and novel" but "leaves a lot of open questions." Without knowing more about dark matter, it's hard to predict what kind of clumps might form.

Scientists have looked for the gravitational effects of unidentified, star-sized objects, which could be made either of normal matter or dark matter, known as MACHOs. But such objects turned out to be too rare to make up a significant fraction of dark matter. Larger clumps, however, haven't been ruled out.

Scientists looking for the effects of unexplained gravitational tugs on stars may be able to determine whether galaxies are littered with such clumps. "I don't think people have looked," Buckley says. "It was a blind spot." ■

EARTH & ENVIRONMENT

Farms emit a lot of NO_x pollution

These gases contribute to acid rain and toxic smog

BY CAROLYN GRAMLING

California's crops are creating some noxious air.

The Golden State is at the vanguard in reducing U.S. auto emissions of nitrogen oxide gases, which help produce toxic smog and acid rain. But the NO_x problem isn't limited to auto exhaust. California's agricultural lands are now responsible for as much as 51 percent of total NO_x emissions across the state, researchers report January 31 in *Science Advances*.

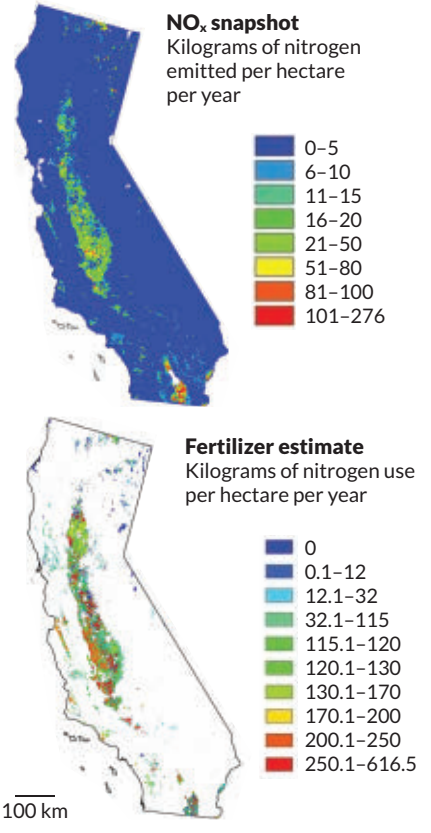
The catchall "NO_x gases" generally refers to two pollution-promoting gases: nitric oxide, or NO, and nitrogen dioxide, or NO_2. Those gases react with sunlight to produce ozone in the lowest layer of the atmosphere, where the ozone can cause respiratory problems. Between 2005 and 2008, regulations issued by the California Air Resources Board on transportation exhaust reduced NO_x levels in cities such as Los Angeles by 9 percent per year. But nitrogen fertilizer use is also a significant source of NO_x gases to the atmosphere.

NO_x gases are produced in oxygen-poor soils when microbes break apart nitrogen compounds in the fertilizer. Release from fertilized soils increases at high temperatures due to increased microbial activity, says Darrel Jenerette, an ecologist at the University of California, Riverside, not involved in the study.

Jenerette and others have studied local NO_x emissions from California soils. But Maya Almaraz, an ecologist at the University of California, Davis, and colleagues designed a study to examine emissions statewide — from above and below. In a plane equipped with instruments, including a chemiluminescence analyzer, the team measured concentrations of the gases above the San Joaquin Valley, part of California's fertile Central Valley, over six days at the end of July and beginning of August. The team also simulated NO_x emissions from soils across the state, and compared those data with data on nitrogen fertilization.

Croplands are contributing 20 to 51 percent of the total NO_x in California's air, the team reports. In the simulations, those soil emissions were particularly sensitive to climate, especially temperature, and rates of nitrogen input. That finding suggests that regions using more nitrogen fertilizer will also see greater emissions — and emissions will increase as temperatures rise.

Top-down airborne measurements combined with a bottom-up perspective from soil provides "strong evidence" for the results, Jenerette says. The study also highlights the urgency of taking steps to better manage nitrogen fertilizer use in a warming world, he says. ■



Fertile ground Simulations that averaged fertilizer and climate data over several decades revealed that California's Central Valley had the highest NO_x emissions from soils in the state (top), matching areas with high nitrogen fertilizer use (bottom, white is non-crop areas).

M. ALMARAZ ET AL/SCIENCE ADVANCES 2018

LIFE & EVOLUTION

Toads will regret eating this beetle

Small prey without any sting possess a surprising defense

BY SUSAN MILIUS

Toad versus bombardier beetle is almost a fair fight. Toads are much bigger, can tongue-strike in an eyeblink and swallow all kinds of nasty stuff. But bombardier beetles can shoot hot steam and noxious chemicals from their back ends.

In lab face-offs, more than 40 percent of *Pheropsophus jessoensis* bombardiers escaped alive after being swallowed by toads, researchers at Kobe University in Japan report February 7 in *Biology Letters*. These lucky beetles were vomited up — in one case, 107 minutes after being gulped — covered with goo, but still able to pull themselves together and walk away. Fifteen of 16 beetles coughed up into daylight lived for at least 17 days, with one still going 562 days later.

Scalding internal beetle blasts proved vital in persuading the toads to spit up the bugs, ecologists Shinji Sugiura and Takuya Sato report. After prodding some beetles into spraying until no more defensive chemicals remained, the team fed the defenseless beetles to toads. The toads kept almost all of these beetles down.

The bombardier group of more than 600 beetle species has become a textbook example of chemical defense (*SN Online: 4/30/15*). When provoked, the beetles mix two substances inside their abdomens that react explosively, and shoot out a noxious stream that can reach around 100° Celsius. Yet the defenses are understudied, Sugiura says.

P. jessoensis beetles are common in East Asia. In the lab, wild-caught toads (*Bufo japonicus* and *B. torrenticola*) willingly swallowed these beetles. With each big gulp, the researchers listened for the sound of a beetle blast inside the toad. "Not easy to hear," Sugiura says, but it's possible to catch a slight *bu* or *vu* sound.

Surviving beetles spent from 12 to 107 minutes in a toad stomach, averaging in the 40-minute range. To vomit, a toad has to sort of turn its stomach inside out, which isn't a quick process. So far, researchers don't know if beetles have tricks for coping with toad stomach acid.

A bombardier beetle regurgitated by a toad comes out covered in slime, but later manages to get up and walk away.

Making a toad give back its lunch is an accomplishment. "Toads are tough," says evolutionary ecologist Rick Shine of the University of Sydney, who has studied cane toads.

Gregory Brown, also at the University of Sydney, says the hot chemical blast would be like "having a small bomb go off" in the stomach. "What does surprise me," he says, "is that the defense only worked around 50 percent of the time." ■

MATH & TECHNOLOGY

New laser offers a more stable beam

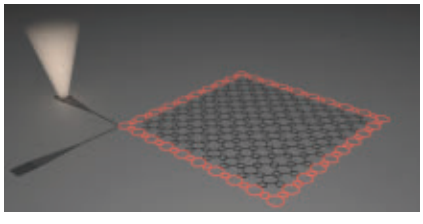
Design based on exotic materials is also energy-efficient

BY MARIA TEMMING

A new type of laser is modeled after an exotic class of materials called topological insulators. And it's proving more reliable and energy-efficient than its conventional counterparts, paving the way for possible use in quantum communication and next-generation electronics.

Described online February 1 in *Science*, the device is composed of a grid of semiconductor rings that convert energy into particles of light. The device channels these photons in one direction around the grid until they are emitted as a beam.

The design borrows from the concept behind topological insulators — a kind of material that blocks electric current through its interior but let electrons surf along its surface (*SN: 5/22/10, p. 22*). Scientists have engineered devices that similarly steer sound waves, but researchers had debated whether that same kind of control could be exerted over the light particles generated inside lasers (*SN: 5/2/15, p. 9*).



In a new type of laser (illustrated), energy injected into the outer rings of a lattice (red) generates light particles that travel around the outer edge of the grid to a corner, where they escape as a single beam (top left).

To turn on the laser, the researchers feed light or electrical energy into the grid's outer rings, which convert that energy into the laser's light. The rings are linked together by racetrack-shaped loops precisely positioned to steer those light particles along a one-way path. While only the outer rings transmit the laser light, the whole grid is needed to guide the photons, says Boubacar Kante, an electrical and computer engineer at the University of California, San Diego, who wasn't involved in the work.

Ferrying light along the grid's outer edge in a single direction makes the laser more immune to manufacturing errors or malfunctions that can cripple lasers, says study coauthor Mordechai Segev, a scientist at the Israel Institute of Technology in Haifa. If photons encounter a defect, like a missing ring, they can't bounce back or scatter, which would waste energy. Instead, the photons are forced to go around the rough patch and continue on.

Such reliable lasers could be used for sending information in a quantum network or to build better optical circuits. ■

FROM TOP: S. SUGIURA (CC BY 4.0); M.A. BANDRES *ET AL*/*SCIENCE* 2018

Watch a video of a beetle escaping at **bit.ly/SN_bombardier**

ATOM & COSMOS

Cosmos with no weak force still works

Lacking neutron decay, alternate universe might form stars, life

BY LISA GROSSMAN

Not all fundamental forces are created equal. An alternate universe that lacks the weak nuclear force — one of the four fundamental forces that govern all matter in our universe — could still form galaxies, stars, planets and perhaps life, researchers argue online January 19 at arXiv.org.

Scientists think our universe wouldn't exist, or at least wouldn't support life, without certain physical laws. For instance, if gravity were much stronger than it is, most matter would collapse into black holes; if it were weaker, there wouldn't be galaxies or planets. The strong nuclear force holds atomic nuclei together, and the electromagnetic force carries light across the universe.

"Those three forces ... are part of the deal," says theoretical astrophysicist Fred Adams of the University of Michigan in Ann Arbor. But the weak nuclear force — responsible for making neutrons decay into protons, electrons and neutrinos — might not be essential. "That's the only one you can get rid of entirely without messing everything up," Adams says.

Our universe might be part of an infinite multiverse, where cosmoses governed by different rules exist side by side. "People talk about universes like they're very fine-tuned; if you changed things just a little bit, life would die," Adams says. But "the universe and stars have a lot more pathways to success."

Adams and colleagues simulated how matter was created in the Big Bang and then condensed into stars, but without the weak nuclear force. One consequence of that force's neutron decay is that most of our universe's ordinary matter is made of hydrogen (a single proton and electron). Stars fuse protons into helium and heavier elements and then scatter them into space, helping to create everything from planets to physicists. With no weak force, a universe would be filled with neutrons that didn't decay — a dead end for building heavier elements.

Such a universe could still create complex matter if it started out with fewer neutrons and more free protons than our universe did. That way, neutrons and protons could link up and make deuterium, or heavy hydrogen. So Adams and colleagues tweaked the simulated universe's initial neutron and proton content, too.

Stars fueled with deuterium would still shine, the simulations show. The stars would be a little hotter, larger and redder than our stars, but these stars would still create all of the elements that our stars do.

The study is one of the first to seriously explore the consequences of a "weakless" universe by tweaking the numbers, says astrophysicist Martin Rees of the University of Cambridge. ■

HUMANS & SOCIETY

Stone tool advance reached India early

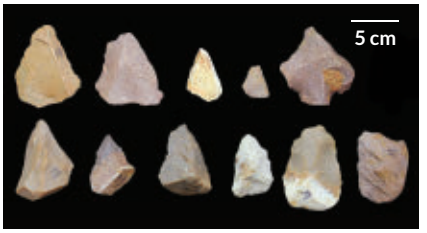
Technological revolution didn't depend on *Homo sapiens*' arrival

BY BRUCE BOWER

Stone-tool makers in what's now India redesigned their products in a revolutionary way much earlier than once thought.

Excavated stone artifacts document a gradual shift from larger, handheld cutting implements to smaller pieces of sharpened stone, known as Middle Paleolithic tools, by around 385,000 years ago, researchers report in the Feb. 1 *Nature*. That shift mirrors a similar change seen in tools from a variety of hominid populations elsewhere between about 400,000 and 200,000 years ago, including African *Homo sapiens* and European Neandertals.

Unlike earlier groups, Middle Paleolithic toolmakers followed a set of steps to prepare rocks before pounding off flaked tools. Many researchers had assumed the transition from hand axes to Middle Paleolithic implements didn't happen until *H. sapiens* traveling from Africa brought the skill to South Asia around 140,000 to 90,000 years ago.



These sharpened stones unearthed in India suggest hominids there made big changes in toolmaking before *Homo sapiens* left Africa.

But the findings suggest that some other hominid population introduced new toolmaking approaches to the region long before *H. sapiens* originated in Africa about 300,000 years ago. These other hominids mingled to varying extents with local groups, who then developed variations on the tools, says a team led by archaeologists Kumar Akhilesh and Shanti Pappu of the Sharma Centre for Heritage Education, India in Chennai.

The team studied about 7,200 artifacts, ranging in age from about 385,000 to 172,000 years ago, found at the southeastern Indian site Attirampakkam. Previous work uncovered hand axes and artifacts dated to 1.77 million to 1.07 million years ago (*SN: 4/23/11, p. 12*). It's unclear which hominids inhabited the area, or whether hominids lived there continuously.

Populations that preceded *H. sapiens* in India probably developed regional versions of Middle Paleolithic tools over several hundred thousand years, says archaeologist Michael Petraglia of the Max Planck Institute for the Science of Human History in Jena, Germany. Genetic evidence suggests *H. sapiens* spread across South Asia only after 60,000 years ago.

Archaeologist Daniel Adler of the University of Connecticut in Storrs argues that Middle Paleolithic innovations in South Asia probably developed in fits and starts among small, scattered *Homo* populations. Those groups shared a common toolmaking ancestry, "but perhaps little else," he says. ■

GENES & CELLS

Microbes possess varied defenses

CRISPR isn't bacteria's only system for fighting invaders

BY LAUREL HAMERS

Long before researchers adapted it as a precise gene-editing tool, CRISPR had another job: defending bacteria against viral invaders. And it's far from alone. Ten sets of bacterial genes have similar defense roles, researchers report online January 25 in *Science*.

The discovery "probably more than doubles the number of immune systems known in bacteria," says Joseph Bondy-Denomy, a microbiologist at the University of California, San Francisco who wasn't involved in the study.

Bacteria are vulnerable to deadly viruses called phages, which can hijack bacteria's genetic machinery and force them to produce viral DNA. Some bacteria protect themselves against phage attacks with a built-in CRISPR/Cas system, storing pieces of past invaders' DNA so bacteria can recognize and cut out that foreign DNA in the future (*SN: 4/15/17, p. 22*). Only about 40 percent of bacteria have CRISPR systems, says study coauthor Rotem Sorek, a microbial genomicist at the Weizmann Institute of Science in Rehovot, Israel. That's why he and colleagues are hunting for other defenses.

Defense-related genes tend to cluster in the genome, Sorek says. His team sifted through genetic information from 45,000 microbes, flagging groups of genes with unknown functions that are located near known defense-related genes.

Many of the microbes with these gene families hail from exotic locations like the seafloor. So the researchers used the genomic data to synthesize the relevant bits of DNA and inserted them into *E. coli* and *Bacillus subtilis*, which can grow in the lab. Then the team tracked how well the bacteria resisted phage attacks when various genes in a family were deleted. If removing some of the genes affected the bacteria's ability to fight off phages, that result suggested the gene group is a defense system.

Nine groups of bacterial genes turned out to be antiphage defense systems, and one system protected against plasmids, another source of foreign DNA.

The data also revealed a possible shared origin between bacterial immune systems and similar defenses in more complex organisms, Sorek says. Some of the genes contain fragments of DNA that are crucial to the innate immune systems in plants, invertebrates and mammals.

Bondy-Denomy predicts the research will unleash a flurry of studies to figure out how these newfound defense systems work and whether they too might be co-opted as biotechnology tools. ■

SHARMA CENTRE FOR HERITAGE EDUCATION, INDIA

"The more time I spent studying engineering in college, the more I realized I would never be bored in my career."

BY ARCONIC FOUNDATION

Meet Chelsea Cummings, an Additive Manufacturing Engineer focused on new product introduction of metal 3D printed aerospace parts at Arconic, in Austin, Texas. Early on, she knew that STEM education was a pathway for her to solve complex engineering challenges. Having earned her engineering degree from Arizona State University, she's now helping develop and build high-performance aerospace parts that will one day fly people around the world and into deep space.

How did you get interested in a STEM career?

Chelsea: I think I realized pretty early on that I was more interested in problem solving than anything else. Many career paths involve memorizing and executing certain strategies, but STEM encourages me to explore how many ways a problem can be solved, and it seems more is gained by solving problems differently every time. I was unsure exactly which field I wanted to end up in at first, but the more time I spent studying engineering in college, the more I realized I would never be bored in my career. I felt my professional excitement really took off when I discovered metal 3D printing for the first time. Now, metal 3D printing, or additive manufacturing, is offered at most universities in some form or another, so students can get involved even earlier.

Who was/is a role model for you?

Chelsea: Dr. Linda Chattin, an engineering professor I had for several classes was very inspirational to me. She had forged a path in industry when it was even less common for women to pursue engineering, and was one of the very best professors I had in college. She truly believed engineering was for anyone who was willing to work for it and led her classes as such. She also was anything but dull, breaking the much exhausted (in my opinion) stereotype that some still have about engineers. Her knowledge, motivation, and humor left a lasting impression on me.

What it is about what you do that excites you?

Chelsea: I am a visual, hands-on person, so the exciting part of work for me is that it's tangible. I get to build things from metal powder with lasers, and perform experiments to yield results that I can then directly apply back into what I am creating. I also get to work with highly sophisticated machines and software that enable me to visually analyze builds and data. It is hard not to be excited about going to work in the morning when a build has been running overnight. I love starting the day by seeing a real aerospace part that I modeled, programmed and 3D printed.

ATOM & COSMOS

What will it take to go to Venus?

Scientists test ways to overcome the planet's hostility

BY LISA GROSSMAN

There's a planet just next door that could explain the origins of life. It was probably once covered in oceans (*SN Online: 8/1/17*). It may have been habitable for billions of years (*SN Online: 8/26/16*). Astronomers are desperate to land spacecraft there.

No, not Mars. The tantalizing planet is Venus. But despite all its appeal, Venus is one of the hardest places in the solar system to get to know. That's partly because modern Venus is famously hellish, with temperatures hot enough to melt lead and choking clouds of sulfuric acid.

"If you wanted sinners to fry in their own juice, Venus would be the place to send them," V.S. Avduevsky, deputy director of the Soviet Union's spaceflight control center, said in 1976 after his country's Venera 9 and 10 landers returned their dismal view of the planet's landscape (*SN: 6/19/76, p. 388*).

Today, would-be Venus explorers say they have the technology to master those damning conditions. "There's a perception that Venus is a very difficult place to have a mission," says planetary scientist Darby Dyar of Mount Holyoke College in South Hadley, Mass. "Everybody knows about the high pressures and temperatures on Venus, so people think we don't have technology to survive that. The answer is that we do."

And researchers are actively developing more Venus-defying technology while vying for the financial support needed to get a mission off the ground.

In 2017, five Venus projects — including a mapping orbiter, a probe that would taste the atmosphere while falling through it and landers that would zap rocks with lasers — failed to get NASA's green light for flight. But all were considered technologically ready to go, and the laser team got funding for technology development.

"NASA's mission selection process is highly competitive," says Thomas Zurbuchen, associate administrator for NASA's science mission programs in Washington, D.C. "Earth's so-called 'twin' planet Venus is a fascinating body, and of tremendous interest to our science community.... The Venus community should continue to compete for future missions."

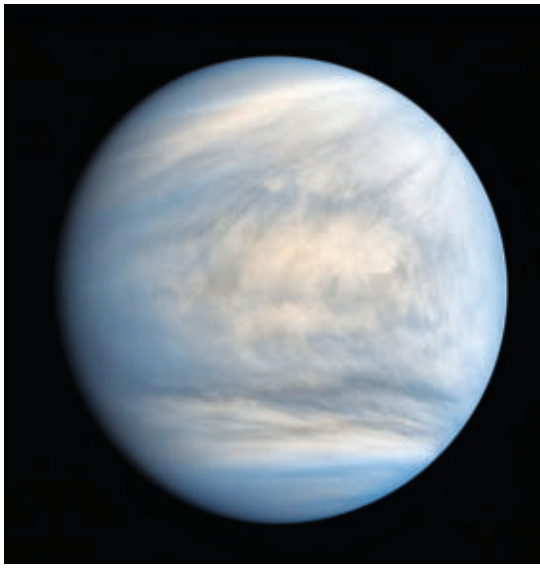
Visiting Venus

From afar, Venus and Earth would look like equally promising targets in the search for alien life. Both are roughly the same size and mass, and Venus lies close to the sun's habitable zone, where temperatures enable stable liquid water on a planet's surface.

"We need to understand what made a planet go down the Venus path rather than the Earth path," says David Grinspoon, an astrobiologist with the Planetary Science Institute who is based in Washington, D.C.

A few orbiters have visited Venus in the past decade, including the European Space Agency's Venus Express from 2006 to 2014, and the Japanese space agency's Akatsuki, in orbit since December 2015. But despite dozens of proposed missions spanning almost 30 years, no NASA spacecraft has visited Earth's twin since the Magellan craft ended its mission in 1994 by plunging into Venus' atmosphere and burning up. Nor has any spacecraft landed on the Venusian surface since 1985.

One obvious barrier is Venus' thick atmosphere which, in recent images from Akatsuki, makes the planet look like a smooth, milky marble. The atmosphere is 96.5 percent carbon dioxide, which blocks scientists' view of the surface in almost all wavelengths of light. As recently as 2011, astronomers thought it was impossible to use spectroscopy — a technique that splits light from an object into different wavelengths to tell an object's composition — from orbit to reveal what Venus' surface is made of.



From the outside, you would never know how hostile Venus' surface is. This false-color image of the planet from the Akatsuki spacecraft shows a cloud-covered atmosphere as complex and dynamic as Earth's.

But it turns out that Venus' atmosphere is transparent to at least five wavelengths of light that can help identify different minerals. Venus Express proved it would work: Looking at one infrared wavelength allowed astronomers to see hot spots that might be signs of active volcanism (*SN Online: 6/19/15*). An orbiter using the other four wavelengths, too, could do even more, Dyar says.

Ground truth

To really understand the surface, scientists want to go there. But a lander would have to contend with the opaque atmosphere while looking for a safe place to touch down. The best map of Venus' surface, based on radar data from Magellan, is too low resolution to show rocks or slopes that could topple a lander, says James Garvin of NASA's Goddard Space Flight Center in Greenbelt, Md.

Garvin and colleagues are testing a computer-vision technique called Structure from Motion that could help a lander map a landing site on the way down. Quickly analyzing many images of stationary objects taken from different angles as the spacecraft descends can create a 3-D rendering of the ground.

DAMIA BOUIC/DARTS/ISAS/JAXA

A tryout in a helicopter over a quarry in Maryland showed that the technology could plot boulders less than half a meter across, about the size of a basketball hoop. "With a handful of GoPro pictures, we made beautiful little topographic maps," Garvin says. "We can do it at Venus even with this crappy atmosphere that is so murky you wouldn't think it works." He plans to present the experiment this month in The Woodlands, Texas, at the Lunar and Planetary Science Conference.

Once a lander has made it to Venus' surface, its next challenge is survival.

The first landers on Venus, the Soviet Venera spacecraft in the 1970s and '80s, lasted about an hour each. The longevity record set by Venera 13 in 1982 was two hours and seven minutes. The planet's surface is about 460° Celsius and the pressure is about 90 times that of Earth's at sea level, so spacecraft don't have long before some crucial component is melted, crushed or corroded by the acidic atmosphere.

Modern missions are not expected to do much better: one hour minimum, five hours optimistically and 24 hours "in your wildest dreams," Dyar says.

But a team at NASA's Glenn Research Center in Cleveland is designing a lander that could last months. "We're going to try to live on the surface of Venus," says engineer Tibor Kremic of NASA Glenn Research.

Instead of using bulk to absorb heat or countering it with refrigeration, the proposed lander, called LLISSE for Long-Lived In Situ Solar System Explorer, would use simple electronics made of silicon carbide that can withstand Venusian temperatures.

The group has tested the circuits in a Venus simulation chamber called GEER (Glenn Extreme Environment Rig).

"Think of a giant soup can," but with 6-centimeter-thick walls, Kremic says. The circuits still worked after 21.7 days in a simulated Venus atmosphere, reported Philip Neudeck of NASA Glenn Research in 2016 in *AIP Advances*. Scheduling issues put an end to the experiment, but the circuits could have lasted longer, says NASA Glenn electronics engineer Gary Hunter.

Ultimately, the team wants to build a prototype lander that can last for 60 days. On Venus, that would be long enough to act as a weather station, monitoring changes in the atmosphere over time and so learning about its activity. "That has never been done before," Kremic says.

> "We need to understand what made a planet go down the Venus path rather than the Earth path."
>
> DAVID GRINSPOON

Reading rocks

And that presents the next challenge: Planetary scientists have to figure out what the data are saying.

Rocks interact with the Venusian atmosphere differently than with Earth's or Mars' atmospheres. Mineralogists identify rocks based on the light they reflect and emit, but high temperature and pressure can shift light in ways that depend on the mineral's crystal structure. Even when scientists get data on Venusian rocks, interpretation could be tricky.

"We don't even know what to look for," Dyar says.

Ongoing experiments at GEER are helping set the baseline. Scientists can leave rocks and other materials in the chamber for months at a time just to see what happens. Dyar and her colleagues are doing similar experiments in a high-temperature chamber at the Institute of Planetary Research in Berlin.

"We try to understand the physics of how things happen on the Venus surface so we can be better prepared when we explore," Kremic says.

Two of the mission concepts NASA didn't green-light use different strategies. VISAGE, for Venus In Situ Atmospheric and Geochemical Explorer, would have brought powdered rocks into a chamber inside the lander that maintains Earthlike conditions and measured the rocks there.

VICI, or Venus In situ Composition Investigations, would take a hands-off approach: Shoot rocks with a laser and analyze the resulting puff of dust. The Mars Curiosity rover uses that technique, but the density of Venus' atmosphere could make the results challenging to understand. Researchers are testing the technique in a Venus simulation chamber at Los Alamos National Laboratory in New Mexico.

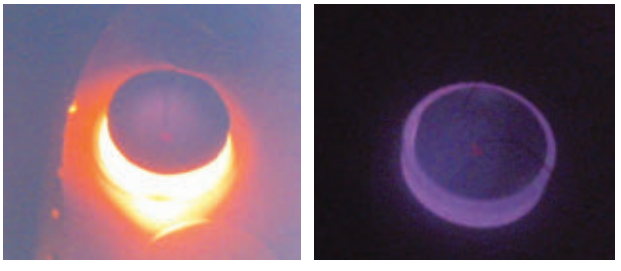
"We're convinced it will work," says VICI principal investigator Lori Glaze of NASA Goddard. "We just need to do some more work to convince the rest of the community."

There's hope on the horizon, if Venus explorers can shrink their ambitions. Last year, NASA established a program called Venus Bridge to see if any missions to Venus can fly for $200 million or less. That figure is less than half the cost — and in some cases much less than half — of the recently proposed missions.

"The Venus community is torn on this idea," Dyar says. It would be hard to make meaningful headway on science questions for that little, she notes. But it may take multiple piecemeal missions to understand Venus anyway, she adds. "We'll get the frosting on one trip and the cake on a different trip."

In the meantime, the Venus hopefuls soldier on.

"My new favorite saying for the Venus community is, 'Never give up, never surrender,' " Glaze says. "We keep trying." ■



J. HELBERT/DLR, EUROPLANET

Unlike a stainless steel cup (left), a cup made from a new kind of ceramic (right) barely glows under Venus-like conditions. Without the interfering glow, scientists can better understand how minerals in the cup will emit and reflect light on Venus.

BODY & BRAIN

Test could predict Alzheimer's risk

Analysis detects small bits of amyloid-beta floating in blood

BY LAUREL HAMERS

A new blood test might reveal whether someone is at risk of getting Alzheimer's disease.

The test measures blood plasma levels of a sticky protein called amyloid-beta. This protein can start building up in the brains of Alzheimer's patients decades before there are any outward signs of the disease. Typically, it takes a brain scan or spinal tap to discover these A-beta clumps, or plaques, in the brain. But evidence is growing that A-beta levels in the blood can be used to predict whether a person has these brain plaques, researchers report in the Feb. 8 *Nature*.

These new results mirror those of a smaller 2017 study by a different team of scientists. "It's a fantastic confirmation of the findings," says Randall Bateman, an Alzheimer's researcher at Washington University School of Medicine in St. Louis who led the earlier study. "What this tells us is that we can move forward with this [test] approach with fairly high confidence that this is going to pan out."

There's no existing treatment for Alzheimer's that can slow or stop the disease's progression, so catching it early can't currently improve a patient's outcome. But a blood test could help researchers more easily identify people who might be good candidates for clinical trials of early interventions, says Steven Kiddle, a biostatistician at the University of Cambridge who wasn't part of either study.

Creating such a blood test has been challenging: Relatively little A-beta floats in the bloodstream compared with how much accumulates in the brain. And many past studies haven't found a consistent correlation between the two.

In the new study, researchers used mass spectrometry, a more sensitive measuring technique than used in most previous tests, which allowed the detection of smaller amounts of the protein. Instead of looking at the total level of the protein in the blood, the team calculated the ratios between different types of A-beta, says coauthor Katsuhiko Yanagisawa, a gerontologist at the National Center for Geriatrics and Gerontology in Obu, Japan.

Yanagisawa and his colleagues analyzed brain scans and blood samples from a group of 121 Japanese patients and a group of 252 Australian patients. Some participants had Alzheimer's, some didn't, and some had mild cognitive impairments that weren't related to Alzheimer's.

Using the ratios, the researchers were able to discriminate between people who had A-beta plaques in the brain and those who didn't. A composite biomarker score, created by combining two different ratios, predicted the presence or absence of A-beta plaques in the brain with about 90 percent accuracy in both patient groups, the team found.

The results are promising, Kiddle says, but the test needs more refining before it can be used in the clinic. Another wild card: the cost. It's still not clear whether the blood test will be more affordable than a brain scan or a spinal tap. ■

SPACEX

ATOM & COSMOS

SpaceX launched its biggest rocket yet

It's another record for SpaceX. At 3:50 p.m. EST on February 6, the private spaceflight company launched the Falcon Heavy rocket for the first time.

The Heavy — essentially three SpaceX Falcon 9 rocket boosters strapped together — is the most powerful rocket launched since the Saturn V, which shot astronauts to the moon during the Apollo program in the 1960s and '70s. SpaceX hopes to use the Heavy to send humans into space. The company is developing another rocket to eventually send people to Mars (*SN: 1/20/18, p. 22*).

Two boosters safely returned to Cape Canaveral, Fla.; the third missed the target and hit the Atlantic Ocean. Part of SpaceX's program is to reuse rockets, which brings down the cost of space launches. As of early February, the company had successfully landed the boosters of its Falcon 9 rockets 21 times and had reflown rockets six times. The company successfully landed a reused rocket for the first time in March 2017.

But the cargo from February's launch is headed elsewhere. The rocket carried SpaceX CEO Elon Musk's red Tesla Roadster, which is now aimed toward the asteroid belt. "I love the thought of a car drifting apparently endlessly through space and perhaps being discovered by an alien race millions of years in the future," Musk tweeted in December. — *Lisa Grossman*

GEOLOGIC ROAD TRIP OF THE MONTH

VALLEY OF FIRE STATE PARK

A large area of brightly colored rock of the Aztec Sandstone is exposed at Valley of Fire State Park, about 45 miles northeast of Las Vegas. The sandstone solidified from a huge area of shifting dunes that existed 200 to 175 million years ago, in Jurassic time, when the region lay within 10 degrees of the equator. The sea of sand was similar to the Sahara Desert today. The source of the sand was westward-flowing rivers eroding the enormous Appalachian Mountains that formed during the assembly of Pangaea. The Aztec Sandstone, which is also exposed at Red Rock Canyon west of Las Vegas, is equivalent to the Navajo Sandstone of the Colorado Plateau. Prior to Cenozoic time, the Aztec Sandstone was much closer to the outcrops of Navajo Sandstone in southwestern Utah; it has since been transported to its current position by extensional Basin and Range faulting.

The Aztec Sandstone is composed of well-rounded grains of almost pure quartz sand with no clay or silt. A prominent feature of the sandstone exposures is the crossbedding, which forms when the wind shifts directions. As the dune field got buried by successive layers of sand, the grains of sand gradually cemented together into hard sandstone. The color of the sandstone is attributed to minerals, particularly red iron oxide (hematite) and hydroxide that coated the grains during deposition and to some extent sulfides, and to the remobilization of minerals as groundwater moved through the rock during and after the sand solidified into rock.

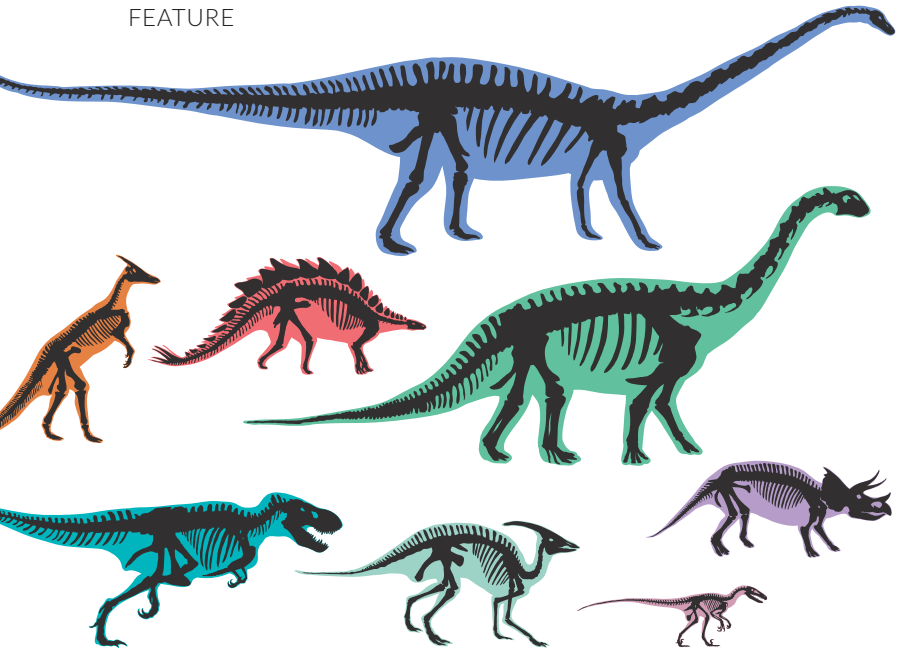
To reach Valley of Fire State Park, take exit 75 from I-15 north of Las Vegas. The road crosses an expanse of dry desert for 7 miles before crossing a slight rise that marks the California Wash fault, an active and potentially dangerous fault (see road guide I-15 in this chapter). After crossing the fault, the road passes into Paleozoic rocks of two different Sevier thrust sheets. The erosion of the overlying thrust sheets here opened a window into the Jurassic rock below.

From the west entry station to east of the visitors' center, the road parallels the Valley of Fire Wash, which has carved the valley along the axis of an anticline. Exposed in the core of the anticline are the easily eroded mudstones, siltstones, and sandstones of the Triassic Moenkopi, Chinle, Moenave, and Kayenta Formations. The more resistant, younger Jurassic Aztec Sandstone is preserved on both sides of the anticline, as are the very resistant limestones to the south of the valley. Remnants of the Horse Spring Formation, deposited on the landscape in Miocene time, are also visible from the highway.

Most of the points of interest in the park are in the Aztec Sandstone to the north of the Valley of Fire Road, and some side roads provide access in that area. The sandstone mass is crisscrossed by joints and faults, along which erosion has created crevices, passageways, and drainages and lots of nooks and crannies. Two miles into the park is a turnoff to the north for Atlatl Rock, known for its petroglyphs, which were carved into the desert varnish on the sandstone by early peoples who lived in the area about 3,000 years ago. Another reason to climb the metal staircase to the petroglyphs lies overhead, in the sandstone slab overhanging the petroglyphs at the top of the stairs. Look closely to find approximately eight mammal-like reptile footprints on the bottom of the slab. These fossil tracks are known as *Brasilichnium* and are thought to have been made by a small mammal-like reptile. Few body fossils of the unknown creature have been preserved. Across the road from the Atlatl Rock turnoff is a turnoff to see petrified logs, remnants of ancient pines now preserved along the crest of the Valley of Fire anticline.

The visitors' center is situated at the base of the cliffs north of the road. Inside, along the windows looking south across the valley, is a discussion of the geologic history of the area. The view south is of the Muddy Mountains, composed of gray Cambrian through Pennsylvanian strata of the Muddy Mountain thrust sheet.

View southeast from the area of the west entry station to Valley of Fire State Park. The orange-red Aztec Sandstone contrasts vividly with the gray Paleozoic rocks of the Muddy Mountain thrust sheet. In the middleground, the Cambrian Bonanza King rocks are nearly vertical and are overlain by the reddish-brown Miocene Rainbow Gardens Member of the Horse Spring Formation. The banded gray strata on the far left horizon are Cambrian carbonates.



WHAT MAKES A DINOSAUR?

Defining what's unique about these 'fearfully great lizards' gets harder with new fossil finds

By Carolyn Gramling

The depression in *Teleocrater*'s hip bone (bottom half) marks where the leg bone fit into the pelvis. Dinosaurs have a complete hole in that part of the hip socket.

"There's a very faint dimple here," Sterling Nesbitt says, holding up a palm-sized fossil to the light. The fossil, a pelvic bone, belonged to a creature called *Teleocrater rhadinus*. The slender, 2-meter-long reptile ran on all fours and lived 245 million years ago, about 10 million to 15 million years before scientists think dinosaurs first appeared.

Nesbitt, a paleontologist at Virginia Tech in Blacksburg, tilts the bone toward the overhead light, illuminating a small depression in the fossil. The dent, about the size of a thumbprint, marks the place where the leg bone fit into the pelvis. In a true dinosaur, there would be a complete hole there in the hip socket, not just a depression. The dimple is like a waving red flag: Nope, not a dinosaur.

The hole in the hip socket probably helped dinosaurs position their legs underneath their bodies, rather than splayed to the sides like a crocodile's legs. Until recently, that hole was among a handful of telltale features paleontologists used to identify whether they had their hands on an actual dinosaur specimen.

Another no-fail sign was a particular depression at the top of the skull. Until *Teleocrater* mucked things up. The creature predated the dinosaurs, yet it had the dinosaur skull depression.

The once-lengthy list of "definitely a dinosaur" features had already been dwindling over the past few decades thanks to new discoveries of close dino relatives such as *Teleocrater*. With an April 2017 report of *Teleocrater*'s skull depression (*SN Online: 4/17/17*), yet another feature was knocked off the list.

Today, just one feature is unique to Dinosauria, the great and diverse group of animals that inhabited Earth for about 165 million years, until some combination of cataclysmic asteroid and volcanic eruptions wiped out all dinosaurs except the birds.

"I often get asked 'what defines a dinosaur,'" says Randall Irmis, a paleontologist at the Natural History Museum of Utah in Salt Lake City. Ten to 15 years ago, scientists would list perhaps half a dozen features, he says. "The only one to still talk about is having a complete hole in the hip socket."

The abundance of recent discoveries of dinosauromorphs, a group that includes the dinosaur-like creatures that lived right before and alongside early dinosaurs, does more than call diagnostic features into question. It is shaking up long-standing ideas about the dinosaur family tree.

To Nesbitt, all this upheaval has placed an even more sacred cow on the chopping block: the uniqueness of the dinosaur.

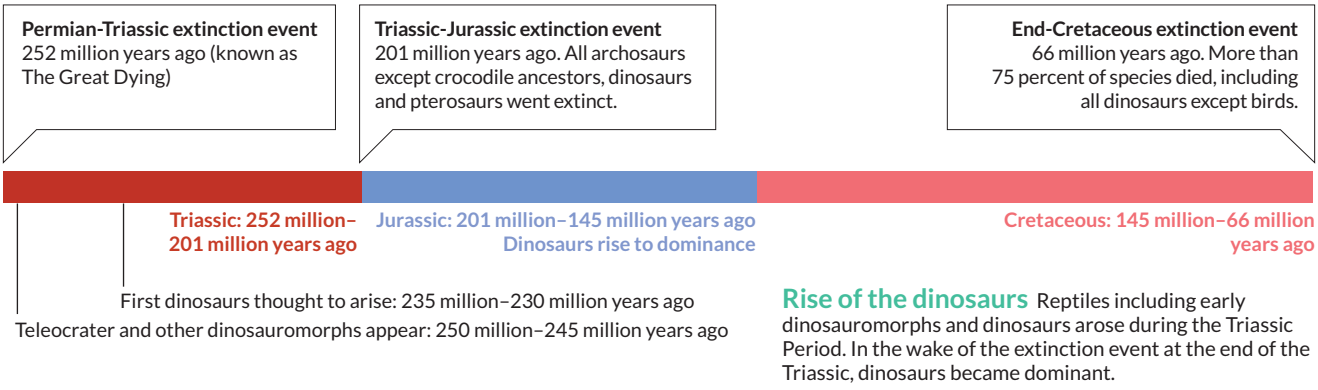
"What is a dinosaur?" Nesbitt says. "It's essentially arbitrary."

Shared traits

In 1841, British paleontologist Sir Richard Owen coined the term "dinosaur." Owen was contemplating the fossil remains of three giant creatures — a carnivore named *Megalosaurus*, the plant-eating *Iguanodon* and the heavily armored *Hylaeosaurus*. These animals shared several important features with one another but not other animals, he determined. (In particular, he noted, the creatures' giant legs were upright and tucked beneath their bodies, and each of the animals had five vertebrae fused together and welded to the pelvis.)

Owen decided the animals should be biologically classified together as their own group, or taxon. He named the group "Dinosauria" for "fearfully great lizards."

FROM TOP: GLUIKI/SHUTTERSTOCK; S.J. NESBITT



Rise of the dinosaurs Reptiles including early dinosauromorphs and dinosaurs arose during the Triassic Period. In the wake of the extinction event at the end of the Triassic, dinosaurs became dominant.

In Owen's day, it was a bit easier to spot similarities between fossils, says paleontologist Stephen Brusatte of the University of Edinburgh. "Back then, there were so few dinosaurs. But the more fossils you find, the patterns become more complicated," he says. "With every new discovery, you get a different view of what features define a dinosaur. It's nowhere near as clear-cut as it used to be."

Dino survivors

The largest extinction of species on Earth, the "Great Dying," happened about 252 million years ago at the end of the Permian Period (*SN: 9/19/15, p. 10*). About 96 percent of marine species and 70 percent of land species succumbed.

In the period that followed, the Triassic, spanning 252 million to 201 million years ago, new reptilian species arose and flourished. This was the time of the dinosauromorphs, crocodylians (the ancestors of crocodiles) and, of course, the dinosaurs themselves. No one knows exactly when dinosaurs arose, although it was probably around 230 million years ago.

For tens of millions of years, the dinosaurs lived alongside numerous other reptile lineages. But at the end of the Triassic, dramatic climate change played a role in another mass extinction. Dinosaurs somehow survived and went on to dominate the planet during the Jurassic Period.

Paleontologists once assumed the dinosaurs were somehow superior, with physical features that helped them outcompete the other reptiles. "But that's not borne out by new dinosaur relatives," Nesbitt says. Dinosaurs and dinosauromorphs, researchers found, were very similar. The new bonanza of dinosauromorph fossils reveals a repeating pattern of parallel evolution, such as lengthening legs or having legs oriented directly under the body. In short, Nesbitt says, dinosaurs "are not doing anything different than their closest relatives."

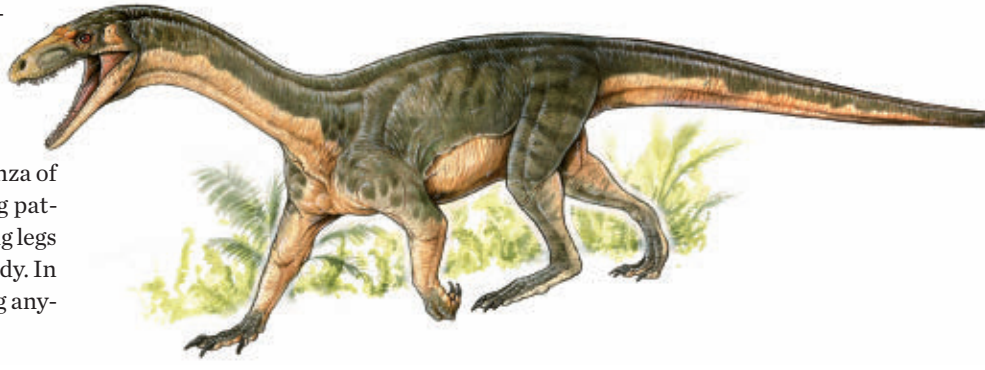
On the heels of those discoveries, many paleontologists suspect that the reason for dinosaurs' rapid expansion in the Jurassic is simply that the creatures took advantage of the sudden availability of ecological niches left behind by their long-dead cousins from the Triassic.

But that doesn't explain why dinosaurs survived the extinction at the end of the Triassic, while their dinosauromorph cousins (and most of the crocodylians) died out. That's a question no one yet has answered.

Maybe dinosaurs had some anatomical characteristics that helped them survive, suggests Max Langer, a paleontologist at the University of São Paulo. "But we don't know what those features were."

Uprooting the family tree

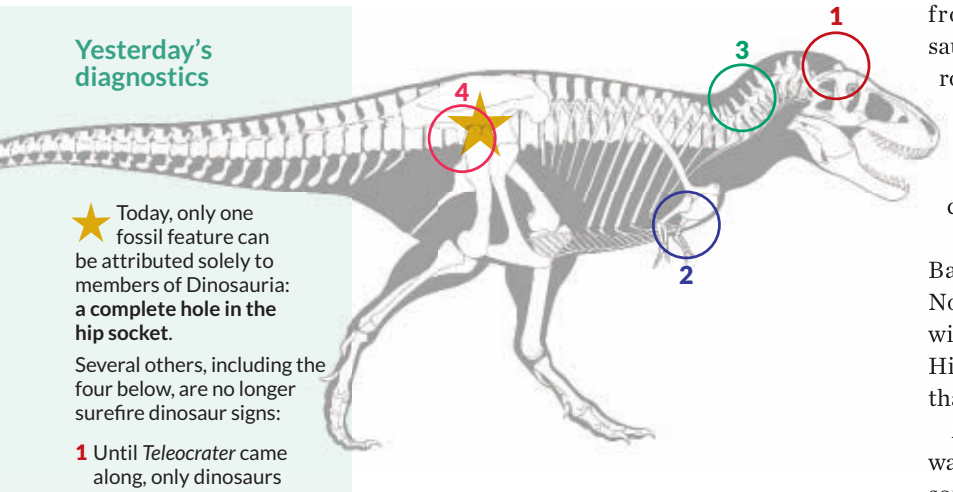
To identify the animal that left behind a fossil, paleontologists pore over the bone, noting each bump, groove and hole, measuring the length of a tibia bone or counting the digits on a forelimb. Before powerful computers were available, scientists constructed evolutionary trees by noting which species share different bumps and grooves, and assessing whether those features (also called characters) were inherited from a common ancestor, or passed along to descendants.



The dinosauromorph *Teleocrater rhadinus* had a skull depression once thought to be unique to dinosaurs.

FROM TOP: C. CHANG; MUSEO ARGENTINO DE CIENCIAS NATURALES "BERNARDINO RIVADAVIA" (BUENOS AIRES, ARGENTINA); ARTWORK BY GABRIEL LIO

Yesterday's diagnostics



Today, only one fossil feature can be attributed solely to members of Dinosauria: **a complete hole in the hip socket**.

Several others, including the four below, are no longer surefire dinosaur signs:

1 Until *Teleocrater* came along, only dinosaurs were known to have a **deep depression at the top of the skull**, an attachment site for some jaw muscles probably related to bite strength.

2 Dinosaurs and some other dinosauromorphs such as *Silesaurus opolensis* have an **enlarged crest on the upper arm bone** where muscles attached.

3 Along with dinosaurs, dinosauromorphs *S. opolensis* and *Asilisaurus kongwe* may have had **epipophyses**, bony projections at the back of the neck vertebrae.

4 An extra (fourth) muscle attachment site, called a **trochanter**, at the point on the femur that meets the hip is also found in dinosauromorph *Marasuchus lilloensis*.

SOURCES: S.J. NESBITT *ET AL*/ *NATURE* 2017; S.L. BRUSATTE *ET AL*/ *EARTH-SCIENCE REVIEWS* 2010

Langer calls that approach to phylogenetic analyses "old-fashioned." Today, scientists use computer algorithms to help construct elaborate phylogenetic, or evolutionary, trees. But the fossil characters are still the raw data required to create those trees, and the analyses are only as good as those data. Different researchers may choose different features to consider, and may interpret the fossils differently, too. Those concerns hit home among dinosaur researchers last year, when a team proposed a fundamental reorganization of the dinosaur evolutionary tree.

For about 130 years, the basic structure of the dinosaur family tree was considered relatively stable. Dinosaurs were split into two main lines based on the shape of the hips. Both lines had the hole in the hip socket, still considered unique to all dinosaurs. One line known as the ornithischians, also had a pubis bone that pointed down toward the tail. That group includes giant herbivores such as the three-horned *Triceratops* and plate-armored *Stegosaurus*. The other line's pubis bone pointed down toward the front, a hip shape shared by long-necked sauropods such as *Brachiosaurus* and by carnivorous theropods such as *Tyrannosaurus rex*. With those hip similarities, sauropods and theropods have long been considered closer "sister" groups, while ornithischians were seen as more distant relations.

But in March 2017, Ph.D. student Matthew Baron and vertebrate paleontologist David Norman of the University of Cambridge, along with paleobiologist Paul Barrett of the Natural History Museum in London, proposed upending that long-standing arrangement.

At the heart of their paper, published in *Nature*, was the observation that ornithischians have been somewhat overlooked in previous phylogenetic analyses. The herbivorous ornithischians were a really diverse bunch, with a spectacular array of frills and armors and horns and crests.

So the researchers decided to see how different the family tree would look if an analysis included many more ornithischian species. The team incorporated some 457 different fossil characters from 74 species of all kinds of dinosaurs and dinosaur relatives (*SN: 4/15/17, p. 7*).

The newly constructed tree might as well have been from a whole different forest. It shuffled the three big groups around, putting ornithischians and theropods together into a new group and suggesting that sauropods had split off earlier.

Baron and his coauthors found that the ornithischians had more than 20 features in common with predatory theropods.

The paper made a splash, but many paleontologists were skeptical. The bar to revise a tree that had stood decades of previous phylogenetic analyses ought to be pretty high, Brusatte says.

Indeed, one point arising from the study was just how subjective phylogenetic analyses can be, Irmis says. Which species a study includes clearly affects how the tree turns out, he says. Plus, he adds, "a slight difference in how one person interprets the anatomy of a fossil or a particular character can make a cumulatively huge difference."

Langer, Brusatte and several paleontologist colleagues decided to tackle the character interpretation part of the problem head on. "When the paper came out, there was this flurry of excitement," Brusatte says. "But a lot of us noticed right away that there wasn't a huge amount of description about the characters." The concern was that, if the fossils weren't carefully examined and the characters properly assessed, those errors could dramatically skew the results.

An 1859 illustration of *Megalosaurus bucklandii* (left) shows one of the first three animals to be classified as a dinosaur. Later fossil finds of *Megalosaurus* and other large theropods led to more modern reconstructions (right).

CLOCKWISE FROM TOP: C. CHANG; LADYOFHATS/WIKICOMMONS; SAMUEL GRISWOLD GOODRICH/WIKICOMMONS

So the researchers divvied up the task of traveling around the world to visit the fossils included in the original paper and to reassess all 457 characters described — in person. "It was essentially a replication study," Brusatte says.

The team went in expecting to cast doubt on the tree created by Baron, Norman and Barrett — or possibly to completely debunk it. But that didn't exactly happen.

Langer, Brusatte and their coauthors reported last November in *Nature* that their analyses showed that the original, 130-year-old evolutionary tree was still the best fit to the dinosaur dataset used by Baron's team.

But, they found, the original tree wasn't *that* much more likely to be correct than the newly described tree. "This is the thing that really blew us away: It wasn't actually a statistically significant result," Brusatte says. In fact, the often-accepted tree wasn't even that much more likely than an older, *third* arrangement of the tree that grouped ornithischians closer to the other herbivores in the family, the long-necked sauropods, and left the fierce theropods as the outliers.

"There is currently great uncertainty about early dinosaur relationships and the basic structure of the dinosaur family tree," the researchers concluded. "It seems that the flood of new discoveries over the past decades has revealed unexpected complexity."

Brusatte adds: "We shouldn't rewrite the textbooks just yet. But we've taken what we thought was a certainty and turned it into a mystery — and a big mystery, at that."

Catch-22

How the different dinosaur groups are related to one another may seem like insider baseball, Nesbitt says. But the evolutionary tree is the common ground, the framework within which researchers can discuss dinosaur evolution, dinosaur origins and what binds all dinosaurs together. "It makes it difficult to ask questions about how features are evolving if we can't have some agreed-upon taxonomy," he adds.

Similarly, without an agreed-upon evolutionary tree, it's hard to know which anatomical features to follow through the tree — such as any that might have helped dinosaurs survive the end-Triassic extinction. Each arrangement of the evolutionary tree seems to highlight different features as being particularly important, Langer says. "If you don't know how the tree is arranged, you can't say which feature characterizes [dinosaurs]."

The thorny problem revolves around which to tackle first: How to define a dinosaur or how to redraw the dinosaur family tree?

But Langer suggests the answer, as always, is to return to the fossils. In the paper by Langer and his coauthors, they make a plea for researchers to do the mundane work. "We proposed that we need more ... anatomical descriptions and definition of characters," Langer says. "It's boring to do, but people have to do more of this."

Finding *Teleocrater*

As Nesbitt cradles the *Teleocrater* pelvic bone, he turns to a tall cabinet of wide, shallow drawers. He slides open a drawer filled with dozens of carefully labeled boxes, each holding one or more bones from *Teleocrater*, collected during a 2015 expedition to Tanzania's Ruhuhu Basin.

The first known fossils of *Teleocrater rhadinus*, to date the only species of the genus *Teleocrater*, were actually discovered in the 1930s. But those fossils — a few bits of vertebrae, pelvis and limb — languished unidentified in London's Natural History Museum for several decades.

The Ruhuhu Basin, an area dating to between 247 million and 242 million years ago, was a popular place in the Triassic. The site contains abundant fossils, diverse assemblages of Triassic animals including relatives of crocodylians, giant-headed amphibians and ancient relatives of modern mammals called cynodonts.

In 2010, Nesbitt described a species of dinosauromorph from the Ruhuhu Basin dubbed *Asilisaurus kongwe*. But on his 2015 expedition, he was hoping to find more evidence that would help identify the mysterious *Teleocrater* — perhaps even a skull.

He hit pay dirt: His team found a bone bed containing at least three *Teleocrater* individuals, including a braincase and jawbone. The skull was a particularly exciting find, because it showed the team that *Teleocrater*, clearly a nondinosaur from other features, had the skull depression, just like a true dinosaur.

Paleontologists tend to say that finding more fossils from early dinosaurs and their close relatives is the surest way to fill in the gaps on how the creatures evolved and to tidy up the family tree.

Nesbitt laughs. "Now we have way more fossils," he says, "and it's way messier." ■

Explore more

- Kevin Padian. "Palaeontology: Dividing the dinosaurs." *Nature*. March 23, 2017.

Twisting tree

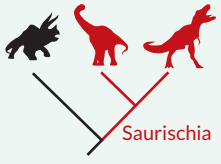
The dinosaur family tree has three main branches: herbivorous ornithischians, long-necked sauropods and fierce theropods. Their relationships may be shifting.

Ornithischians (e.g. *Triceratops*)

Sauropods (*Brachiosaurus*)

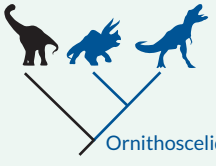
Theropods (*Tyrannosaurus rex*)

TRADITIONAL VIEW



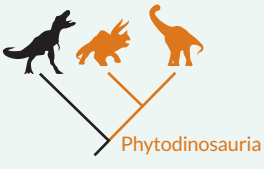
Based on hip shape, sauropods and theropods were thought to be more closely related to each other than to ornithischians.

BARON *ET AL* HYPOTHESIS



A March 2017 analysis of a longer list of ornithischian species concluded that ornithischians and theropods are closely related.

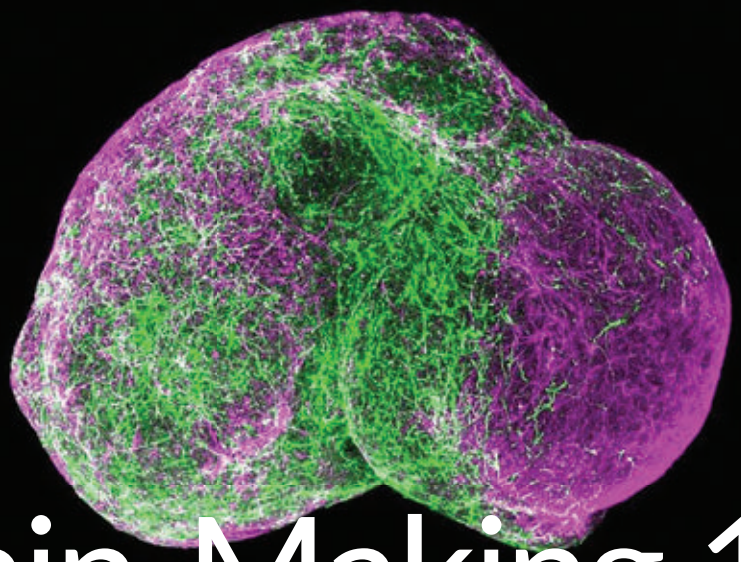
HERBIVORE HYPOTHESIS



A November 2017 analysis upheld the traditional view but found that other arrangements are almost equally likely — including a view that clusters herbivorous ornithischians and sauropods together.

SOURCE: M.C. LANGER *ET AL*/*NATURE* 2017

C. CHANG



As blobs of two types of brainlike tissue fuse, interneurons (green) migrate from the left clump to the right, linking with neurons (not stained) in the right blob. On both sides, neural support cells called glia appear in purple.

PAŞCA LAB/STANFORD UNIV.

Brain-Making 101

Self-assembling clumps bring a dose of 3-D reality to studies of human organs

By Ingfei Chen

In a white lab coat and blue latex gloves, Neda Vishlaghi peers through a light microscope at six milky-white blobs. Each is about the size of a couscous grain, bathed in the pale orange broth of a petri dish. With tweezers in one hand and surgical scissors in the other, she deftly snips one tiny clump in half.

When growing human brains, sometimes you need to do some pruning.

The blobs are 8-week-old bits of brainlike tissue. While they wouldn't be mistaken for Lilliputian-sized brains, some of their fine-grained features bear a remarkable resemblance to the human cerebral cortex, home to our memories, decision making and other high-level cognitive powers.

Vishlaghi created these "minibrains" at the Eli and Edythe Broad Center of Regenerative Medicine and Stem Cell Research at UCLA, where she's a research assistant. First she immersed batches of human pluripotent stem cells — which can morph into any cell type in the body — in a special mix of chemicals.

The free-floating cells multiplied and coalesced into itty-bitty balls of neural tissue. Nurtured with meticulously timed doses of growth-supporting ingredients, the cell clumps were eventually transferred to petri dishes of broth laced with Matrigel, a gelatin-like matrix of proteins.

On day 56, the blobs display shadowy clusters of neural "rosettes." Under a laser scanning microscope, razor-thin slices of those rosettes reveal loose-knit layers of a variety of dividing neural stem cells and the nerve cells, or neurons, they give rise to. The layered structures look similar to the architecture of a human fetal brain at 14 weeks of gestation.

Across the globe, labs such as this one, led by UCLA developmental biologist and neuroscientist Bennett Novitch, are cultivating thousands of these brainy clumps for research. Less than five years ago, a team of biologists in Austria and the United Kingdom and one in Japan wowed the world when they announced they had made rudimentary bits of 3-D human cerebral cortex in a dish. Since then, researchers have been eagerly tinkering with techniques for producing these miniature brain models, like chefs obsessively refining their favorite recipes.

"It's like making a cake: You have many different ways in which you can do it," says Novitch, who prefers using the Japanese method with a few tweaks. "There are all sorts of little tricks that people have come up with to overcome some of the common challenges."

For instance, because the brain blobs lack a built-in blood supply, they must absorb enough oxygen and nutrients from the tissue-culture broth to remain healthy. To help, some labs

circulate the broth around the tissue clumps. The UCLA researchers choose instead to grow theirs at higher oxygen levels and chop the blobs at the 35-day mark, when they are as wide as three millimeters, and then about every two weeks after. Sounds radical, but the slicing gives cells on the inside — some of which start dying — exposure to much-needed oxygen and nutrients. Those divided bits then continue growing separately. But cutting can be done only so many times before the expanding rosette structures inside are damaged.

With all the experimenting, researchers have cooked up a lot of innovations, including some nifty progress reported in just the last year. Scientists have concocted tiny versions of several brain regions ranging from the hypothalamus, which regulates body temperature, thirst and hunger, to the movement-controlling basal ganglia. Electrical chatter among neurons, reflecting active brain circuits, has been detected. And research groups have recently begun linking bits of specific regions like Legos. Scientists have even observed some early developmental processes as they happen within the human brain blobs.

Stem cell payoff

The work is part of a broader scientific bonanza that comes from coaxing human stem cells to self-assemble into balls of organlike tissue, known as organoids, that are usually no bigger than a lentil. Although the organoids don't grow enough to replicate entire human organs, these mini-versions can mimic the 3-D cellular infrastructure of everything from our guts to our lungs. That's something you can't get from studies of rodents, which have different biology than humans do.

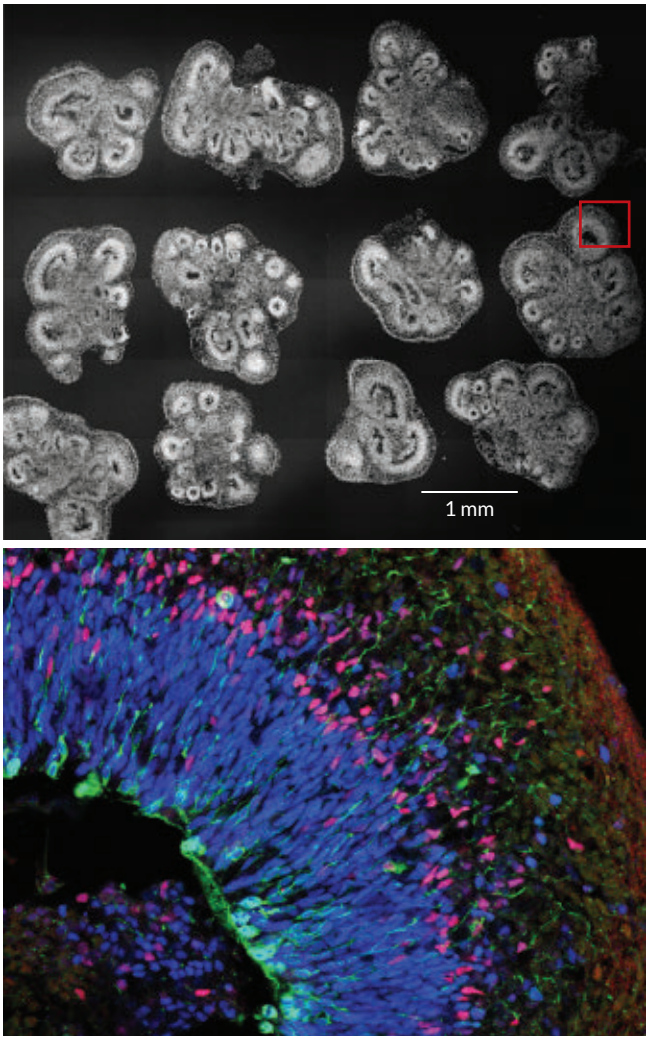
Mini-organ models promise enormous advantages for understanding basic human biology, teasing apart human disease processes, and offering an accurate testing ground for finding or vetting drug therapies. And by creating personalized organoids from the reprogrammed cells of patients, scientists could study disease in a very individualized way — or maybe even use organoid structures to replace certain damaged tissues, such as in the liver or spinal cord.

"Organoids offer an unprecedented level of access into the inner workings of the human brain," Novitch says, noting that our brains are largely off-limits to poking and cutting into for research. If scientists can study accurate models of working neural circuits in these brain bits, he and others say, researchers might finally get a handle on uniquely human neurological conditions. Such disorders, which include epilepsy and, experts theorize, schizophrenia and autism (*SN Online: 7/17/15*), can arise when the brain's communication networks develop off-kilter.

But the research is still in its early days. Although there's been exciting headway, studies sometimes overstate the extent to which human brain organoids reproduce features of actual developing brain tissue, says stem cell biologist Arnold Kriegstein of the University of California, San Francisco. The minimodels still lack many basic components, including certain cell types, a blood-vessel network and inputs from other neural regions.

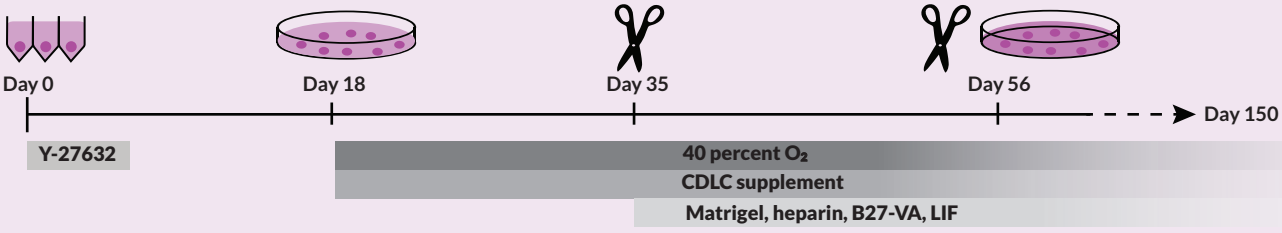
Another stumbling block is that brain organoids can vary a lot from protocol to protocol, or even batch to batch within the same lab. "The major focus now needs to be on reproducibility, and

By eight weeks, brainlike clumps (top) show neural clusters called rosettes. Within one cluster (red box, expanded at bottom), stem cells (blue and teal) churn out layers of neural precursor cells (pink) and neurons (not stained).



BOTH: M. WATANABE *ET AL*/*CELL REPORTS* 2017

How to build a brain Methods for making bits of brainlike tissue tap the innate tendency of human pluripotent stem cells to form neural tissue. Here's one group's process. SOURCE: M. WATANABE *ET AL/CELL REPORTS* 2017



Day 0: Around 9,000 stem cells are transferred into V-shaped wells and suspended in a cocktail of vitamins, amino acids and (for the first six days) Y-27632, a chemical to prevent the stem cells from committing suicide. Within a few days, the multiplying cells self-aggregate into tiny balls of neural tissue. The broth is refreshed every two to three days.

Day 18: The enlarging neural balls are moved into petri dishes of broth with CDLC, a supplement that provides fats. High oxygen levels (40 percent oxygen, 5 percent carbon dioxide) help the tissue absorb enough oxygen. Well-defined clusters, or rosettes, show early layers of various types of developing neural cells by weeks four to five.

Day 35: At 2 to 3 millimeters wide, the brainlike organoids are cut in half to give cells inside more access to nutrients and oxygen. The tissue clumps are nurtured in new broth infused with growth enhancers: a gelatin-like matrix of support proteins called Matrigel, B27 vitamin supplement, heparin and the growth promoter LIF.

Day 56: Organoids are again snipped in half and transferred to new petri dishes made of oxygen-permeable plastic to optimize access to oxygen for healthy growth. From here on, the organoids are halved every two weeks or so, routinely surviving as long as 150 days.

being able to get an approach that you can rely on to give you the same outcome each time," Kriegstein says.

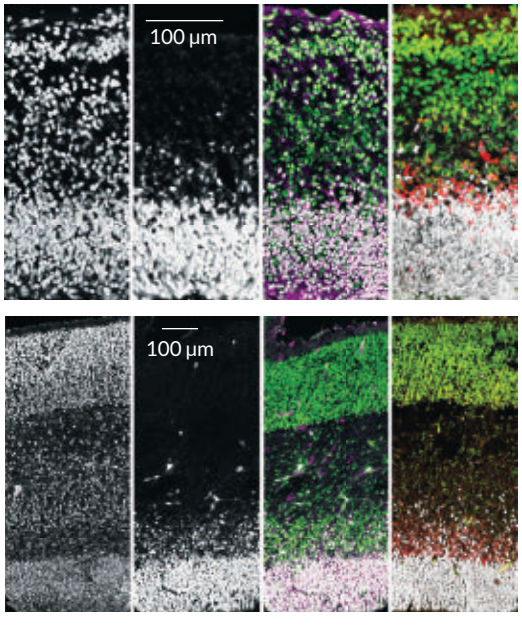
DIY organs

For decades, biology research has relied on cell lines grown in flat sheets in petri dishes, but those sheets lack the structural complexity of living tissue. Then came pioneering work that unveiled the do-it-yourself magic of stem cells raised free-floating in broth.

Organlike tissue bits can be generated from pluripotent stem cells that are either plucked from embryos or created by taking a person's adult skin or blood cells and chemically inducing them to revert to an embryonic-like state. Starting in the mid-2000s, Yoshiki Sasai's team at the RIKEN Center for Developmental Biology in Kobe, Japan, demonstrated how to grow brainlike structures using embryonic stem cells, first from mice and then humans.

In their groundbreaking study in 2013 in *Proceedings of the National Academy of Sciences*, the researchers used chemical cues to direct human embryonic stem cells to form a specific region of the human cortex. (Tragically, Sasai committed suicide the next year, after two stem cell studies that he coauthored were retracted amid scientific misconduct charges against a research colleague [*SN: 12/27/14, p. 25*]. Before his death, Sasai was cleared of any direct involvement. The discredited studies were not related to the organoid research.)

A few months before the 2013 Sasai team paper, Madeline Lancaster and Juergen Knoblich of the Institute of Molecular Biotechnology in Vienna and U.K. colleagues demonstrated their more freewheeling, landmark approach to growing brain organoids (*SN: 9/21/13, p. 5*). The recipe, described in *Nature*, allows human pluripotent stem cells to spontaneously attempt to assemble



In cross sections of 8-week-old brain organoids (top row), loose-knit cell layers roughly resemble the tighter bands in 14-week-old human fetal brain tissue (bottom row). The last column shows a zone of neural progenitor cells (red) and an outer layer of neurons (green).

FROM TOP: ADAPTED BY T. TIBBITTS; M. WATANABE *ET AL/CELL REPORTS* 2017

into a tiny approximation of a whole brain by making whatever brain structures the stem cells choose.

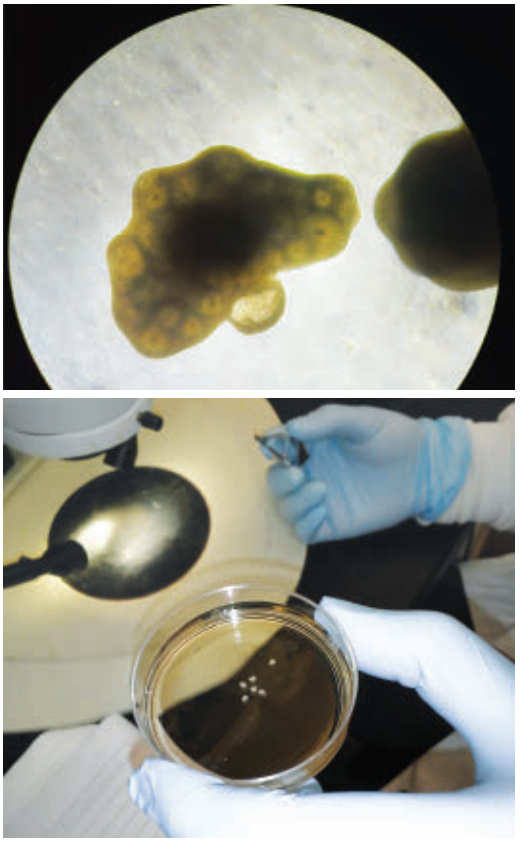
Meanwhile, biologists elsewhere were whipping up other types of organoids, starting instead with adult stem cells. These rare, damage-repairing cells are found in many organs (including the brain), but the cells can transform into only a limited range of cell types. In 2009, Hans Clevers of the Hubrecht Institute in Utrecht, the Netherlands, announced that his lab unexpectedly created a miniature version of a gut while cultivating adult stem cells that the team had discovered in mouse intestinal tissue. Grown in a drop of Matrigel with a trio of growth-inducing factors, these cells coalesced into little spheres containing tiny projections that resembled the fingerlike villi that absorb nutrients in the gut.

Scientists soon were concocting tiny facsimiles of human stomachs, livers, kidneys, lungs and more (*SN: 12/28/13, p. 20*). "We essentially are discovering the vitality of what the stem cells actually do," says Clevers, who is president of the International Society for Stem Cell Research. "We give [the cells] a little push, and they do whatever they're good at."

The trick is knowing exactly which ingredients to use to make different organs. For pluripotent stem cells, that means exposing them to just the right growth factors or inhibitors at just the right times, over about a month, says James Wells of the Center for Stem Cell and Organoid Medicine at Cincinnati Children's Hospital Medical Center. Some of those essential instructions are well-known from decades of research on embryo development in fish, chickens and rodents; the same chemical cues generally work for all animals with spinal cords, including people.

However, for many body parts, organoid makers must suss out recipe instructions from scratch. Working with Jorge Múnera and other colleagues, Wells recently produced a minimodel of a human colon using human induced pluripotent stem cells. But first, the team conducted months of experiments on frog and mouse embryos to identify the signals for forming a colon. "It took a while to figure out what the special sauce was," Wells says.

Some scientists have distant dreams of using organoid methods to grow full-size livers or kidneys in the lab for transplantation. A more attainable goal may be regenerative tissue transplants, for example, replacing dying liver cells in someone with early-stage liver disease with chunks of healthy stem cells from a personalized liver organoid. Or, in patients who've had part of the small intestine removed, tiny pieces of gut organoid tissue could be implanted and, after growing larger, connected to the intestine.



Under a microscope, rosettes of neural cells are visible along the perimeter of an 8-week-old brain organoid (top). The center, where cells have died, is dark. With surgical scissors, a UCLA biologist (bottom) prepares to snip one of those organoids in half to give inner cells more access to oxygen and nutrients from the broth in the dish.

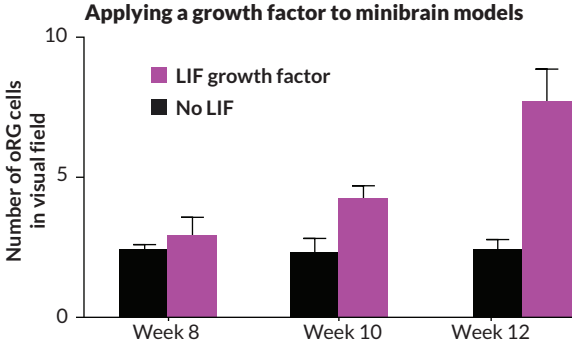
FROM TOP: N. VISHLAGHI/UCLA; INGFEI CHEN

Head games

The human brain, meanwhile, is vastly more complicated than any other organ. It's unlikely that scientists will ever be able to build a full replica. While the initial brain-making recipes were stunning for what they could achieve, they left much room for improvement. In the years since the 2013 debut of human brain organoids, research groups have worked to grow bigger brain tissue clumps and more uniform structures.

The Austrian method for making whole-brain organoids, in particular, produced a random mix of neural regions laid out in a topsy-turvy manner. But bioengineering tricks may help. In a study last year, Lancaster, now at the MRC Laboratory of Molecular Biology in Cambridge, England, and Knoblich got more consistent results by adding polymer filaments as scaffolding to guide the organization of the minibrain models.

Other scientists, following the Japanese approach, which generally gives more predictable results, have concentrated on coaxing out specific



Helping hand Neural stem cells called outer radial glial (oRG) cells help fuel the expansion of the unusually big human brain. A growth factor called LIF tripled the number of oRG cells in growing minibrains by week 12.
SOURCE: M. WATANABE *ET AL*/*CELL REPORTS* 2017

cell types or structural features of the real brain. For instance, one constraint is that the organoids form slowly, more or less sticking to the same timeline of development as does a human brain during gestation. But without a blood supply, growth is limited; the brain bits reach only a few millimeters in size. That means organoid models are often short on cell types from later development stages, such as cells called astrocytes. These star-shaped cells are crucial for creating and curating the connections between neurons, and also may help with forming memories (*SN Online: 11/15/17*).

Astrocytes don't fully mature in a baby's brain until after birth. But Stanford University neuroscientist Sergiu Paşca has crafted a method for making and maintaining 4-millimeter-wide balls of human cortex–like tissue (he calls them spheroids) in 3-D culture for an extended time. Last August in *Neuron*, his team described organoids that survived for more than 20 months — long enough, analyses showed, for astrocytes to mature and function in ways that mimic their real-brain counterparts.

Of great interest, also, are the outer radial glial (oRG) cells, neural stem cells that are pivotal for constructing the unusually big cortex that's unique to humans; oRG cells are scarce in mouse brains. When Novitch's lab group at UCLA tried the original Japanese and Austrian organoid-making recipes, the output of oRG cells was underwhelming. So Novitch worked with Vishlaghi and postdoctoral researcher Momoko Watanabe to refine the protocol to pump up the cells' production and reliably generate better cerebral blobs.

Among other tweaks, Novitch's team added a dash of a molecule dubbed LIF, which recent studies by others had suggested can spur the oRGs to multiply. It worked, leading to a threefold increase in the oRG populations and enhanced growth of upper neuron layers. The researchers shared their revised protocol last October in *Cell Reports*.

On a different front, labs have begun assembling more complex minibrain models, like playing with self-directed Legos. For two months, Paşca's team at Stanford grew spheroids in separate sets of dishes that mimicked either cortex tissue or an adjacent underlying region known as the subpallium. Then the researchers put the different bits side-by-side and left them overnight in a culture tube. Similar to how the two regions normally connect in the developing brain, the little pieces knew what to do. "By the next day they are essentially fused to each other," says Paşca, who announced the results in May in *Nature*.

During the fusion process, the researchers took time-lapse videos of long, spaghetti-like cells called interneurons migrating from a spheroid of the subpallium into a cortexlike spheroid.

"They don't crawl, they actually jump," Paşca says. The images capture aspects of a hallmark phenomenon that normally unfolds during the second and third trimester of fetal gestation.

Testing ground

Once on the other side, interneurons form a circuit with — and quell the activity of — excitatory neurons in the cortexlike tissue, electrophysiological tests suggest. If not quieted, excitatory neurons will trigger neighboring cells to fire. In the real brain, maintaining a proper balance in neural network activity is important; disruptions in it appear to foster disorders such as epilepsy, and perhaps schizophrenia and autism.

Indeed, in the same paper, the Stanford team reported new discoveries using personalized brain spheroids derived from induced pluripotent stem cells of patients with Timothy syndrome — a rare condition caused by an overactive calcium channel found mainly in the brain and heart. Patients with the disorder have epilepsy, autism and heart problems. In the patients' spheroids, interneurons migrated inefficiently but, by adding drugs that blocked the dysfunctional calcium channel, the researchers could reverse the problem. The brain organoids made these intriguing observations possible, Paşca says. "We couldn't have done this in any other way."

Organoid experiments by others have, meanwhile, helped confirm that the Zika virus targets and kills oRG cells and other neural precursor cells, contributing to small brain size in infected infants.

In a 2016 study, Johns Hopkins University

T. TIBBITTS

neuroscientists Guo-li Ming and Hongjun Song reported on their own techniques for creating brain bits that have a well-defined zone of oRG cells. After infecting these organoids with the Zika virus, the researchers observed a collapse of cortexlike tissue that may partly explain the stunted brain growth (*SN: 4/2/16, p. 26*). 2-D cell-culture and mouse experiments also provided key evidence of the virus's modus operandi; although the rodent brain doesn't harbor the full contingent of human neural stem cells, it has blood vessels and immune-system components that organoids lack.

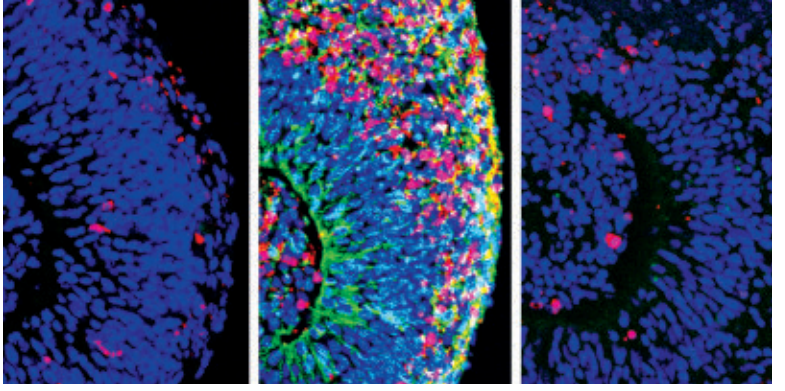
In search of Zika-fighting treatments, Ming and Song, both now at University of Pennsylvania, and their colleagues have been screening thousands of compounds in 2-D cell cultures, and then validating the most promising candidates with tests in 3-D brain organoids. The team has found several potential antiviral and neuron-protecting agents to pursue. Novitch's UCLA lab group has likewise used its brain organoids to pinpoint additional receptors by which the virus may gain entry into neural stem cells, and identified a few other drug leads for blocking infection.

Organoids may also prove valuable for tailoring treatments for patients, says David Panchision, chief of the developmental neurobiology program at the National Institute of Mental Health in Bethesda, Md. Researchers might generate personalized brain organoids from the reprogrammed skin cells of individuals with, say, schizophrenia and test which medications work best for patients with particular genetic profiles of the illness.

In the Netherlands, based on research reported in 2016 in *Science Translational Medicine*, Clevers and colleagues are already using personalized gut organoids, derived from rectal biopsies, to test whether cystic fibrosis patients will benefit from available drugs. Tailored regenerative therapies with 3-D substructures of neural tissue may also be possible, Panchision adds, for conditions like Parkinson's disease or spinal cord injury.

Growing pains

For now, though, scientists have hefty challenges to overcome. Much work remains in optimizing how faithfully the bits of tissue reproduce normal brain function and architecture, Panchision says. For one thing, the organoids are developmentally young and don't reflect a mature brain. And researchers must figure out how to build in some core features: the necessary blood vessels, immune-system cells called microglia and connections from other brain regions, such as the thalamus and cerebellum. Not to mention steroid and thyroid hormones, which also shape brain growth.



Images show 4-week-old brain organoids with no infection (left) and with Zika infection (middle, virus is green, dead stem cells are pink). Treatment with the drug duramycin before exposure to Zika largely staves off infection and cell death (right).

A brain organoid infected by Zika virus at 28 days old is severely stunted two weeks later (top) compared with a healthy organoid of the same age (bottom).

However, scientists don't necessarily need or want to create a comprehensive replica of the human brain in a dish, Panchision and others point out. Rather, the goal is to build robust and reliable models for studying specific aspects of brain function.

Thus the pressing need for standardized, reproducible organoid-making recipes. Novitch's group and many other labs are still trying to figure out why the brain bits can vary so much in size, composition and structure. Part of the trouble is the ingredients: Subtle variations in tissue-culture chemicals and Matrigel, or in different stem cell lines and how they are grown first in 2-D culture, can have a big impact on how the organoids turn out, Novitch says.

At the same time, researchers need to do a more thorough job of analyzing brain organoids to know what's actually in them at different developmental time points, compared with actual human fetal brain tissue, says UCSF's Kriegstein. It's otherwise hard to say whether a brain blob truly recapitulates the neural tissue that scientists claim it does. Labs have started tackling the problem with a tool called single-cell transcriptome analysis, which gives readouts of all the genes that are active in individual cells.

"Greater rigor is needed," Kriegstein says. "And I am sure we will eventually get there." ■

Explore more

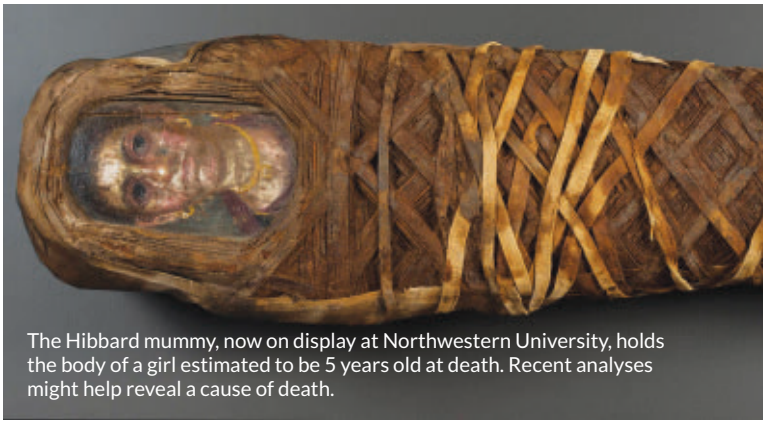
- Elizabeth DiLullo and Arnold Kriegstein. "The use of brain organoids to investigate neural development and disease." *Nature Reviews Neuroscience*. October 18, 2017.

Ingfei Chen is a freelance science writer based in Northern California.

FROM TOP: NOVITCH LAB/UCLA; XUYU QIAN *ET AL*/*CELL* 2016

EXHIBIT

Latest tech unravels mysteries of Egyptian mummy portraits



The Hibbard mummy, now on display at Northwestern University, holds the body of a girl estimated to be 5 years old at death. Recent analyses might help reveal a cause of death.

Everybody's a critic. Even back in second century Egypt.

While digging in Tebtunis in northern Egypt in the winter of 1899–1900, British archaeologists stumbled upon portraits of affluent Greco-Egyptians placed over the faces of mummies. One grave contained an ink and chalk sketch, a bit larger than a standard sheet of printer paper, of a woman from around the years A.D. 140 to 160. The sketch includes directions from an unidentified source to the artist to paint the "eyes softer."

That ancient critique is now the name of a temporary exhibit at Northwestern University's Block Museum of Art in Evanston, Ill. "Paint the Eyes Softer: Mummy Portraits from Roman Egypt" features the sketch, along with six more intact or nearly intact Egyptian funeral portraits, one still attached to its mummy. All were discovered more than a century ago but recently examined using modern scientific tools.

The relics from this time period don't resemble your granddad's King Tut. Egyptians applied a new approach to mummies during the Roman-dominated era from the first through third centuries A.D. These mummies featured portraits of the deceased held in place by the linens wrapping the dead. Such paintings served as a prelude to other panel paintings in the ancient world, including Christian icons.

"Paint the Eyes Softer"
THROUGH APRIL 22
NORTHWESTERN UNIVERSITY'S BLOCK MUSEUM OF ART

Excavators separated the portraits from the mummies, which were supposed to have been together for eternity, says Essi Rönkkö, Block's curatorial associate for special projects. Five of the portraits, on loan along with other materials from the University of California, Berkeley, are highlighted in one of the exhibit's showcases: two men, a boy and two women. These lifelike paintings of well-dressed people in Roman attire stare back at you through the mists of time. The soulful (soft?) eyes draw you in and make you wonder who these people were and what their lives were like.

The exhibit uses a series of labels, some with photographs, to trace the discovery of the portraits and explain Egyptian funerary techniques. Two mummy masks from the mid-third century B.C. to the mid-second century A.D. are also on display. The masks present an idealized image of the deceased in repose, ready for the afterlife.

Funerary portraits discovered from ancient Egypt (one at far left) covered the faces of mummies. A sketch (right) on the back of another portrait has instructions in Greek to paint the "eyes softer."

Northwestern students and researchers last fall applied modern analytical tools from archaeology, medicine and molecular biology to the portraits. The studies reveal that two types of wood were used in the portraits. Most panels were made from sycamore fig — a material native to Africa, including Egypt. A thin panel on one portrait was made from limewood found only in Central Europe. Ingredients for pigments were also imported, from Spain and Greece. The sources point to complex and far-reaching trade patterns.

A computerized analysis of brushstrokes and paints suggests the male portraits came from the same workshop. All three wore a purple shoulder sash created with a blend of indigo and a red pigment extracted from the madder plant (*SN: 3/5/16, p. 17*).

Tucked away in a corner is another exhibit highlight: an intact mummy with a still-attached portrait of a girl, estimated to be 5 years old at the time she died. Low lighting protects the mummy and, along with solemn music, provides a respectful tone. Known as the Hibbard mummy, the girl's body was found in Hawara, not far from Tebtunis.

The new research reveals that salts were harming the underlying linen as embedded soil reacted to changes in temperature and humidity. CT scanning reveals no blunt force trauma or other cause of death. The mummy was the first ever to be brought to the Argonne National Laboratory in Illinois, where it was exposed to synchrotron radiation from the lab's Advanced Photon Source. High-energy X-ray beams could offer new information about the mummy.

The exhibit points out the unknowns and unknowables. Were the paintings idealized or realistic? Were they displayed before or only after the person died?

And finally, what do the instructions for "softer" eyes mean? "It could be shorthand for a specific style or linguistic meaning we no longer have access to," Rönkkö says. "Perhaps it serves as a metaphor for the many aspects about these objects that — even with the latest technology at our fingertips — remain a mystery." — *Howard Wolinsky*

TOP: COURTESY GARRETT-EVANGELICAL THEOLOGICAL SEMINARY, EVANSTON, IL; BOTTOM, BOTH: COURTESY OF THE PHOEBE A. HEARST MUSEUM OF ANTHROPOLOGY AND THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

Congratulations to the 40 Regeneron Science Talent Search Finalists!

Society for Science & the Public and Regeneron are proud to announce the 40 finalists in the Regeneron Science Talent Search 2018, the nation's oldest and most prestigious science and math competition for high school seniors. These finalists were selected from 300 scholars and more than 1,800 entrants based on the originality and creativity of their scientific research, as well as their achievement and leadership both inside and outside of the classroom. The finalists will travel to Washington, D.C., from March 8 to 14, where they will undergo a rigorous judging process and compete for more than $1.8 million in awards.

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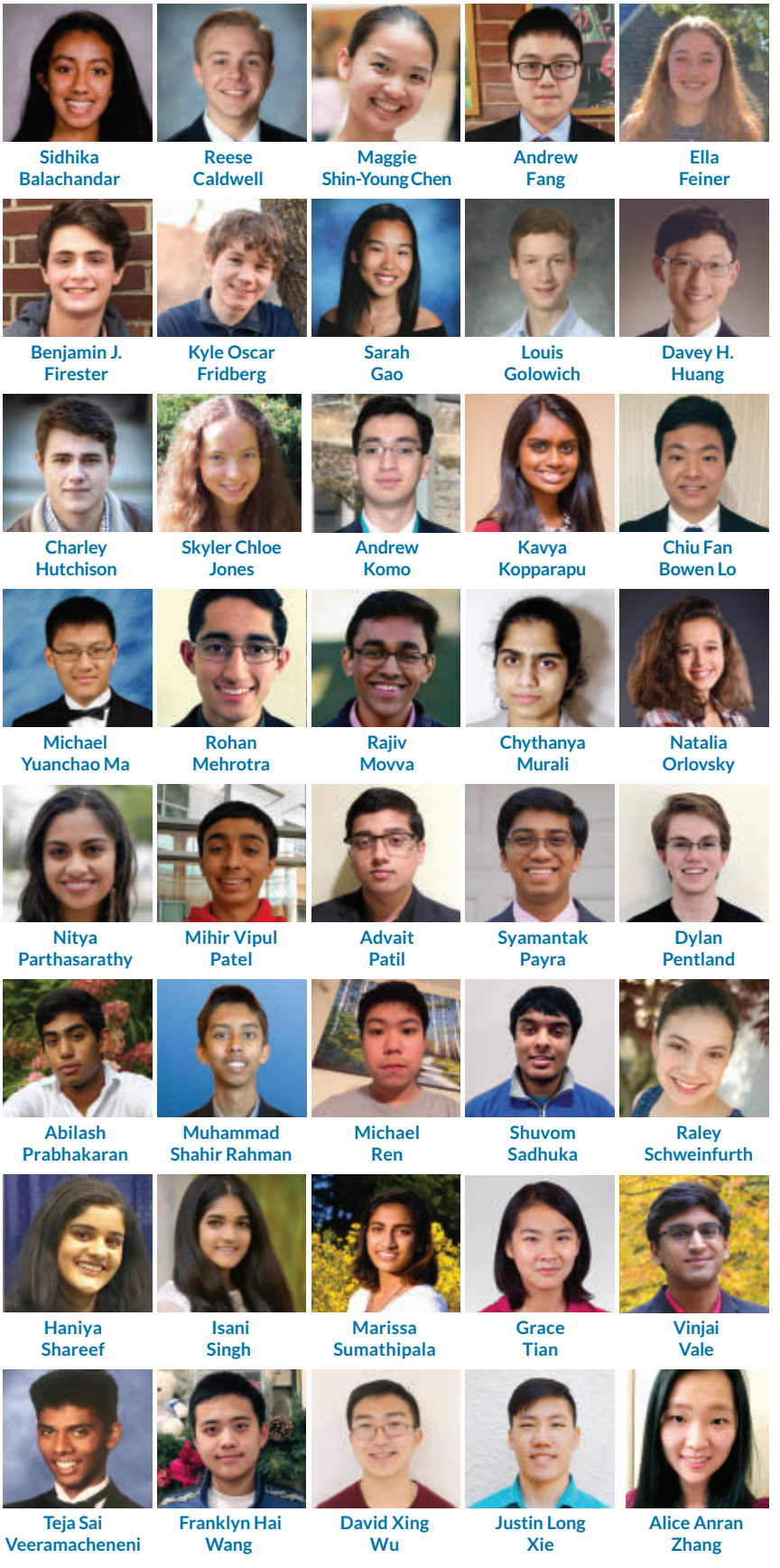

JANUARY 20, 2018

Mission: Mars

*The possibility that human visitors could carry Earth-based microbes to the Red Planet has roiled the Mars research community, **Lisa Grossman** reported in "Mucking up Mars"* (SN: 1/20/18, p. 22). Reader **Bruce Merchant** speculated that Mars would need a protective global magnetic field to sustain a life-friendly environment. But the planet's core cannot generate such a field, he wrote. **Merchant** suggested that the presence or absence of magnetic fields might be one way to tell whether a planet could support life. "Can we determine that for exoplanets?" he asked.

It's unclear if a planet needs a core that produces a magnetic field to support any kind of life, **Grossman** says, "but that question is definitely something astrobiologists fret about." We don't have a way to determine from afar if an exoplanet has a core that would generate magnetic fields, she says. "But finding life on a planet with no magnetic field would be one way to test how necessary such fields are."

Moral dilemma

*If CRISPR and other gene-editing tools are approved for use in human embryos, some parents may feel morally obligated to use such a tool to give their children the best life possible, **Tina Hesman Saey** reported in "Will 'better' babies become a moral must-do?"* (SN: 1/20/18, p. 4). Several readers weighed in with their views on human gene editing.

Karla Garcia thought that using genetic editing to eliminate disease and improve life expectancy would be OK. But the technology shouldn't be used for "human enhancement," she wrote. "The fear of a class of genetically enhanced people is reason enough not to mess with the DNA."

Readers on Twitter had similar sentiments. "It could go down the route of eugenics," **Annabel Ladomery** wrote. **Ashley Anand** pointed out that a moral obligation is not the same as a legal requirement. But **Andrew Patterson** wondered if parents who choose to genetically alter their children could be held legally responsible for any unforeseen problems. "What if the child later objects to having been 'designed?' " he asked.

The moral obligation, **Tony Cusano** wrote on Facebook, "will be to stay out of the way" until scientists better understand the complexity of human biology.

Keen eye

*An AI program discovered that the star system Kepler 90 has an eighth world that had been overlooked in exoplanet searches, **Maria Temming** reported in "Artificial intelligence finds new planet"* (SN: 1/20/18, p. 12). *Kepler 90 is now tied with our solar system for the known planetary family with the most members.* Online reader **Jim Reed** wondered about the likelihood of the Kepler space telescope spotting another solar system like ours.

Kepler wouldn't detect an entire solar system identical to ours, but the telescope could find individual planets passing in front of their host star.

If Kepler looked at our solar system from a thousand light-years away, the telescope could probably detect only Venus or Earth, says **Jeff Coughlin**, an astronomer at the SETI Institute in Mountain View, Calif., and NASA's Ames Research Center at Moffett Field, Calif. Mercury and Mars wouldn't block enough sunlight for Kepler to spot them. And the outer giant planets take so long to orbit the sun that the telescope wouldn't have stared long enough in its lifetime to catch one transiting, **Coughlin** says.

Corrections

In "Electric eel inspires new power source" (*SN: 1/20/18, p. 13*), voltage was incorrectly described as a measure of energy. Voltage is a measure of the difference in electric potential between two points.

Due to an editing error, "IUDs: approval of a renaissance" (*SN: 2/3/18, p. 4*), incorrectly stated that intrauterine devices block contraception. IUDs block conception.

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This ancient creature resembles a spider, but what's with the tail?

Fossils of what looks like a spider, but with a segmented rear and a long tail, have turned up in amber that's roughly 100 million years old.

About the size of a peppercorn (not including the tail, which stretches several times the body length), this newly described extinct species lived in forests in what's now Myanmar during the dinosaur-rich Cretaceous Period.

Spiders as their own distinctive group had evolved long before. But whether this tailed creature should be considered a true spider (of the group Araneae) is debatable, researchers acknowledge February 5 in two studies in *Nature Ecology & Evolution*. The fossils' chimeric mash-up of traits both spidery and nonspidery inspired Bo Wang of the Chinese Academy of Sciences in Nanjing and colleagues to name the species *Chimerarachne yingi* in one of the papers.

C. yingi has some anatomy that, among living animals, would be unique to spiders, says Gonzalo Giribet of Harvard University, a coauthor of the other paper. The fossils have what look like little structures called spinnerets that could have exuded spider silk, as well as distinctive male spider sex organs. Called pedipalps, these modified legs have no direct connection to a sperm-producing organ. Spiders must load these appendages before mating, for instance by ejaculating a sperm droplet and dipping the pedipalps in it.

But the abdomen-like end of a true spider's body isn't segmented and certainly doesn't have a tail. Giribet and his colleagues' analysis puts *C. yingi* in an ancient sister group of spiders. That's startling in itself, Giribet says, because researchers have speculated that this Uraraneida group went extinct much earlier. — *Susan Milius*

B. WANG ET AL/NATURE ECOLOGY & EVOLUTION 2018

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