Questions on COVID-19 Brain Changes | Dinosaur Swim Debate

ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE ■ APRIL 23, 2022

Particle Vision

Muons, born from cosmic rays, are helping researchers see inside volcanoes, pyramids and more

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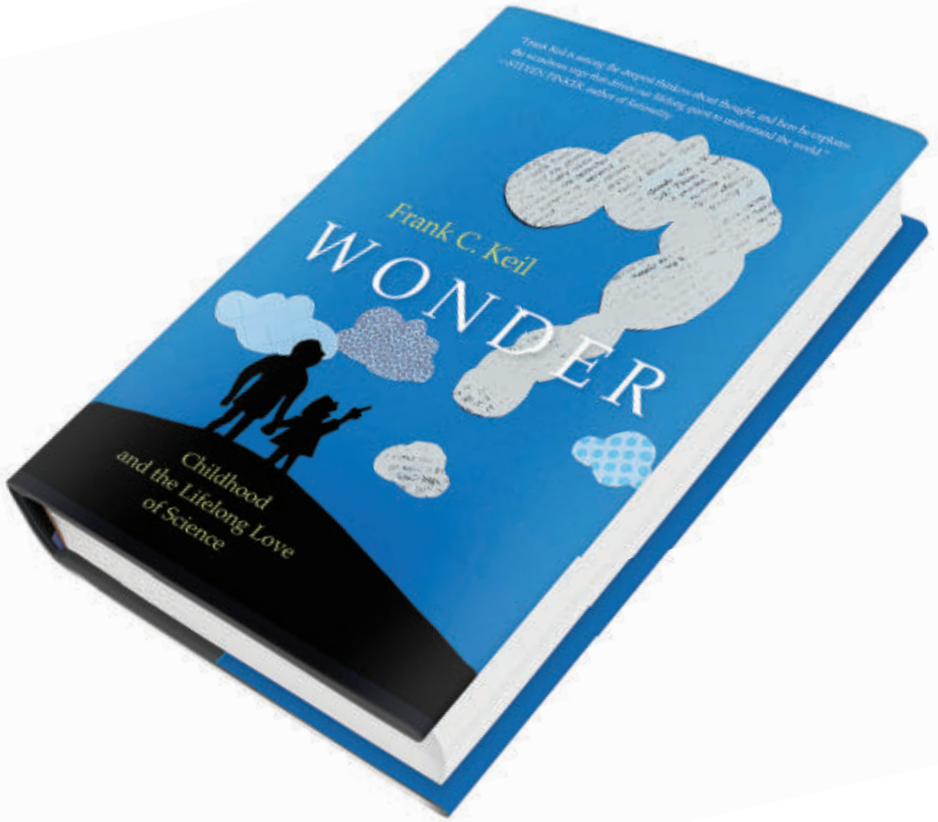

Why do balloons float? How do plants grow from seeds? Why do birds have feathers?

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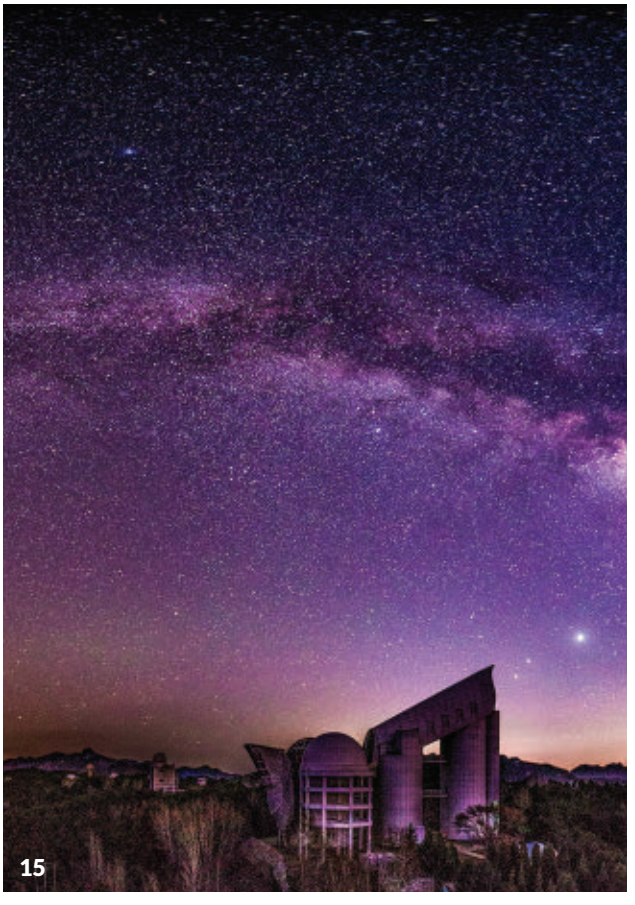
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COVER Muons form when cosmic rays hit Earth's atmosphere. The particles have become a tool for scientists. *Nicolle R. Fuller/SayoStudio*

FROM TOP: KYLE DYKES/UC SAN DIEGO HEALTH; SAN DIEGO NATURAL HISTORY MUSEUM; YINGWEI CHEN

To solve mysteries, scientists look to muons

I don't usually sit at my desk thinking, "Hmm, a muon just flew through my thumbnail." But now I know that these subatomic particles from the upper atmosphere do just that.

And thanks to this issue's cover story, I also know that muons are so good at tunneling through objects that scientists are using them to make discoveries on Earth (Page 22).

Muons aren't a big deal in everyday life. These "awkward cousins of electrons," as physics senior writer Emily Conover describes them, don't play a key role in making atoms. But by tracking muons as they barge ahead, researchers can detect what's inside otherwise impenetrable objects. The process, known as muography, is a bit like taking an X-ray or a CT scan, but with naturally occurring subatomic particles. Conover explains how tracking muons' paths has revealed a secret chamber in the Great Pyramid of Giza and the plumbing of some volcanoes. Researchers hope these new pictures of volcanoes will help them more accurately predict eruptions.

As journalists, we tend to pay more attention to big scientific discoveries, so I was curious as to how Conover decided that it was time *Science News* paid attention to these arcane particles. Like all our reporters, she spends a lot of time digging through research journals to learn what's new and sniff out trends. "If you see one paper in a journal you say, 'Huh, there's something cool happening in muography.' Then you see another one and think, maybe this is the right time to write about it."

Physicists are increasingly interested in studying muons, but what really grabbed Conover's attention is how researchers are using muons as tools in other fields of science, including geology and archaeology. Muons are even being tested to see if they can help customs officials detect smuggled goods. "It's so fun and interesting to learn about," Conover says.

She is no stranger to subatomic particles, having studied neutrinos for her Ph.D. in particle physics. "For a lot of physics experiments, muons are kind of a pesky nuisance," Conover says. "If you're looking for something that's rare or difficult to spot, muons can get in the way." Her research involved building a muon detector to filter out the pesky particles. And many physics experiments are built deep underground, where the ground above muffles muons.

Rather than shunning muons as annoying uninvited guests, scientists are beginning to appreciate their humble virtues. Conover is one of them. "I'm personally familiar with muons being a nuisance, but it didn't make me dislike them," she says. "It made me respect them. They're everywhere. And you can learn something from all the different particles, whatever they may be."

This issue also marks a major scientific milestone: the first complete scan of a human genome (Page 6). You may be wondering, wasn't this announced back in 2003, when the Human Genome Project wrapped up? Yes, kinda. That epic project had to skip some key bits of DNA due to technological limitations. Better technology now means 3,604 more genes to explore, some of which play key roles in assembling the human brain and may help reveal how we evolved differently than other apes. —*Nancy Shute, Editor in Chief*

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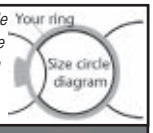

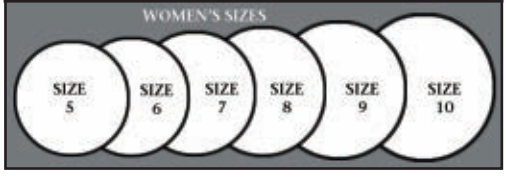

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Excerpt from the April 29, 1972 issue of *Science News*

50 YEARS AGO

Cyclic AMP and psoriasis

[A team of dermatologists] discovered that cyclic AMP levels in psoriasis lesions are significantly lower than in healthy skin.... [The team] is now trying to find out if the cyclic AMP deficiency causes psoriasis and to develop a medication to increase cyclic AMP levels in psoriasis lesions.

UPDATE: Psoriasis, which affects 2 to 3 percent of the global population, is an inflammatory skin disease marked by red, scaly patches that itch or burn. Low levels of cyclic AMP — a chemical messenger key to cellular communication — haven't been found to cause the disease. Psoriasis stems from an overactive immune response. Cyclic AMP is just one player alongside other chemical messengers and immune cells, and certain gene variants can make a person more susceptible. The choice among a range of treatment options today depends in part on the severity of the disease and the areas of the body affected. One drug, called apremilast, approved by the U.S. Food and Drug Administration in 2014, increases levels of cyclic AMP, among other actions.

Castleton Tower (right), near Moab, Utah, is a popular climbing destination. Researchers have enlisted rock climbers to help assess the natural vibrations of Castleton and similar structures.

THE SCIENCE LIFE

Climbers help scientists vibe with Utah's rocks

As Kathryn Vollinger prepared to climb Castleton Tower, a 120-meter-tall sandstone formation in the desert near Moab, Utah, the outdoor guide assessed her gear. Ropes? Check. Helmet and harnesses? Check. Climbing rack? Check. That day in March 2018, Vollinger's checklist also included an unusual piece of equipment: a seismometer. The excursion wasn't solely for pleasure; it was also for science.

Castleton Tower may appear still. But it and other soaring geologic structures are in constant motion, vibrating in response to earthquakes, human activity and even distant ocean waves. The same goes for fins — formations that are irregularly shaped instead of cylindrical or rectangular like towers, says geophysicist Riley Finnegan of the University of Utah in Salt Lake City.

The seismometers measure how much

INTRODUCING

This saber-toothed mammal was built to eat meat

Nearly 42 million years ago, a fearsome bobcat-sized creature prowled the forests of what is now San Diego County. Unlike most mammals at the time, it was a hypercarnivore, built to eat meat and almost only meat. Meet *Diegoaelurus vanvalkenburghae* — a newly identified species of the mysterious and now-extinct Machaeroidinae group. These were thought to be the first mammals with saberlike fangs and sharp slicing teeth, and preceded the better-known saber-toothed cats by tens of millions of years.

Until now, only about a dozen other machaeroidine fossils have been described, most from Wyoming but a few from Utah and Asia. Paleontologists identified this new predator, described March 15 in *PeerJ*, thanks to a 71.5-millimeter-long lower jawbone with teeth. Though the saberlike fangs weren't recovered, the bony chin is downturned to protect fangs, and there is a gap in the lower teeth to fit them, says Ashley Poust, a paleontologist at the San Diego Natural History Museum. The fossil "helps us understand what the whole food web would've looked like," Poust says. "There might have been this crazy saber-toothed animal stalking primates in the branches or maybe stalking the tapirs in the leaves below."

Today's hypercarnivore mammals range from polar bears to house cats. But that lifestyle was uncommon in the Eocene Epoch, which ended around 34 million years ago. — *Sofia Quaglia*

A bobcat-sized species with an appetite for almost only meat — and sharp slicing teeth to go after its meal — roamed what's now San Diego County some 42 million years ago, as depicted in this illustration.

FROM TOP: CRYSTAL/FLICKR (CC BY 2.0); SAN DIEGO NATURAL HISTORY MUSEUM

the towers and fins naturally vibrate. Those data are key to assessing the formations' stability and could help reveal possible signs of seismic activity in the distant past.

Such insights are important not just to scientists, but also to Native Americans, including the Eastern Shoshone, Hopi, Navajo, Southern Paiute, Ute and Zuni peoples. Many of the landforms, which are located on the traditional lands of these groups, hold cultural and religious significance, Finnegan says.

Finnegan's team has been working with Vollinger for nearly five years to assemble the first dataset on the dynamic physical properties of 14 towers and fins, reported February 16 in *Seismological Research Letters*. Without experienced climbers like Vollinger on board, the project wouldn't have been possible, Finnegan says.

Collecting the data was a tremendous challenge. Safely scaling the trickiest formations requires climbing chops,

Outdoor guide Kathryn Vollinger has been helping geophysicists study Utah's red rock tower formations for nearly five years.

strength, endurance and a sizable dose of planning. "There's only so much risk I'm willing to take for getting those seismometers up," Vollinger says. "When you're hauling extra gear, that adds another element to it."

Vollinger and her climbing partner and husband, Nathan Richman, had to ensure that the rock faces were vertical enough to avoid dragging the equipment, which would "likely knock loose rock off," she says. Once at the top—after anywhere from one to six hours of climbing—she read books or chatted with Richman while a seismometer collected data.

Back at the University of Utah, Finnegan and colleagues analyzed the data, finding that the structures' lowest natural frequencies—called fundamental frequencies—range from 0.8 to nearly 15 hertz. In other words, the towers sway roughly one to 15 times per second.

The team also used computer models for a more complete picture of how physics influences the behavior of towers and fins, Finnegan says. Inputting the height, density, cross-sectional area and other material properties into the model allowed the team to predict the fundamental frequencies.

Finnegan and her colleagues have proved that "the geometry is sufficient to really talk about the dominant frequencies for the behavior of the pillars," says Ramon Arrowsmith, a geologist at Arizona State University in Tempe.

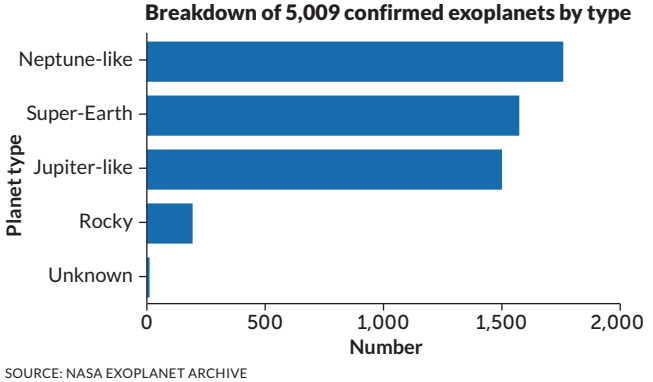
Eventually, Arrowsmith envisions robots putting seismometers in place and drones flying by to collect data. But for now, Vollinger will continue scaling these rocks for science. —*Rachel Crowell*

SCIENCE STATS

NASA's exoplanet count tops 5,000

The number of planets known beyond our solar system has just passed 5,000. Sixty-nine exoplanets found by four separate telescopes were confirmed with new observations, researchers report in multiple studies in March. Those planets put NASA's official tally as of March 31 at 5,009.

"We've really started to be able to fill out the diversity of exoplanets," says astronomer Aurora Kesseli of Caltech. So far, planets the size of Neptune are the most common (see below), and "super-Earths," larger than our solar system's rocky planets, are also abundant. There are roughly 200 small rocky worlds, some of which may resemble our own. —*Liz Kruesi*



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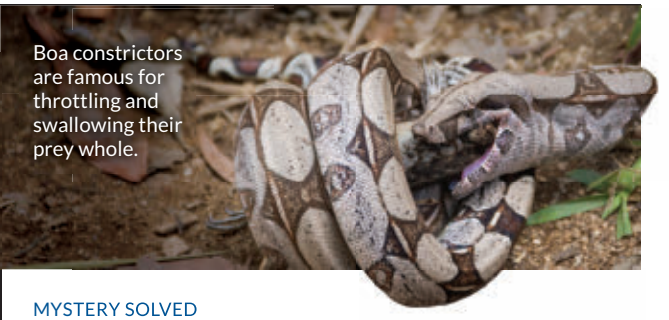


Boa constrictors are famous for throttling and swallowing their prey whole.

MYSTERY SOLVED

How dining boas avoid suffocation

The boa constrictor's choke hold is an iconic animal attack. A coiling snake can squeeze its prey's life out before gulping it down whole (SN: 8/22/15, p. 4). But it's been unclear how the snake gets dinner without suffocating itself.

Now, experiments using implanted metal markers, blood pressure cuffs and X-ray videos to map rib motions in three boa constrictors have revealed the trick. When one part of the rib cage is compressed—stopping the part of the lungs there from drawing in air—the snake can move another section of its rib cage to inflate its lungs there. "They can basically just breathe wherever they want," says biologist John Capano of Brown University in Providence, R.I.

Boas and other snakes probably couldn't have started throttling and swallowing large prey without this ability, Capano and colleagues report March 24 in the *Journal of Experimental Biology*. —*Maria Temming*

FROM TOP: N. RICHMAN; CAVAN IMAGES/GETTY IMAGES PLUS; E. OTWELL

GENES & CELLS

Human genome is finally complete

New technologies enabled scientists to read all our DNA

BY TINA HESMAN SAEY

Researchers have finally deciphered a complete human genetic instruction book from cover to cover.

The completion of the human genome has been announced a couple of times before, but those were actually incomplete drafts. "We really mean it this time," says human geneticist Evan Eichler, a Howard Hughes Medical Institute investigator at the University of Washington in Seattle.

The completed genome is presented in a series of papers published in the April 1 *Science* and March 31 in *Nature Methods*.

An international team of researchers, including Eichler, used new DNA sequencing technology to untangle repetitive stretches of DNA that were unknown from an earlier version of the genome, widely used as a reference for guiding biomedical research.

Deciphering those tricky stretches adds about 200 million DNA bases, about 8 percent of the full genome, to the instruction book. That's essentially an entire chapter. And it's a juicy one, containing the first looks at the short arms of some chromosomes, long-lost genes and important parts of chromosomes called centromeres, where machinery responsible for divvying up DNA grips the chromosome.

"Some of the regions that were missing actually turn out to be the most interesting," says Rajiv McCoy, a human geneticist at Johns Hopkins University, who was part of the Telomere-to-Telomere, or T2T, Consortium that completed the genome. "It's exciting because we get to take the first look inside these regions and see what we can find." Telomeres are repetitive stretches of DNA found at the ends of chromosomes. Like aglets on shoelaces, they may help keep chromosomes from unraveling.

Data from the effort are available for other researchers to explore. And some, like geneticist Ting Wang of Washington University School of Medicine in St. Louis, have already delved in. "Having a complete genome reference definitely improves biomedical studies," he says. "There's no question that this is an important achievement."

A Herculean task

Eichler is careful to point out that "this is the completion of *a* human genome. There is no such thing as *the* human genome." Any two people will have large portions of their genomes that range from very similar to virtually identical and "smaller portions that are wildly different," he says. A reference genome can help researchers see where people differ, which can point to genes that may be involved in diseases. Having a view of the entire genome, with no gaps or hidden DNA, may give scientists a better understanding of human health and evolution.

Although the new genome has no gaps, it still has limitations, Wang says. The old reference genome is a conglomerate of more than 60 people's DNA (*SN: 3/13/21, p. 24*). "Not a single individual, or single cell on this planet, has that genome." That goes for the new genome too. "It's a quote-unquote fake genome," Wang says.

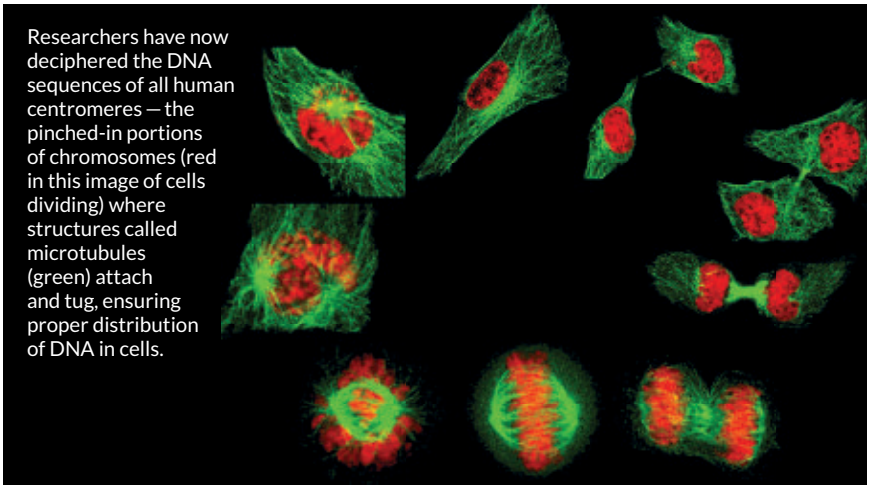
The new genome doesn't come entirely from a person either. It's the genome of what's called a complete hydatidiform mole, a tumor that arises when a sperm fertilizes an empty egg and the father's chromosomes are duplicated. The team chose to decipher the genome from a cell line called CHM13 made from one of these tumors.

That decision was made for a technical reason, says geneticist Karen Miga of the University of California, Santa Cruz. Usually, people get one set of chromosomes from mom and another from dad. "We all have two genomes in every cell," Miga says.

Putting together a genome is like assembling a puzzle, so "you essentially have two puzzles in the same box that look very similar to each other," says Miga, borrowing an analogy from a colleague. Researchers would have to sort the two puzzles before piecing them together. "Genomes from hydatidiform moles don't present that same challenge," she says. "It's just one puzzle in the box."

The researchers did have to add the Y chromosome from another person, because the sperm that created the hydatidiform mole carried an X chromosome.

Even putting one puzzle together is a Herculean task. But new technologies that allow researchers to put DNA bases — represented by the letters A, T, C and G — in order can spit out stretches up to more than 100,000 bases long. Just as children's puzzles are easier to solve because of larger and fewer pieces, these "long reads" made assembling the bits of the genome easier, especially in repetitive parts where just a few bases might distinguish one



Researchers have now deciphered the DNA sequences of all human centromeres — the pinched-in portions of chromosomes (red in this image of cells dividing) where structures called microtubules (green) attach and tug, ensuring proper distribution of DNA in cells.

MATTHEW DANIELS/WELLCOME COLLECTION (CC BY 4.0)

copy from another. The bigger pieces also allowed researchers to correct some mistakes in the old reference genome.

DNA discoveries

The newly deciphered DNA contains the short arms of chromosomes 13, 14, 15, 21 and 22. These "acrocentric chromosomes" don't resemble nice, neat X's the way the rest of the chromosomes do. Instead, they have a set of long arms and a set of nubby short arms.

The length of the short arms belies their importance. These arms are home to rDNA genes, which encode rRNAs, key components of complex molecular machines called ribosomes. Ribosomes read genetic instructions and build all the proteins needed to make cells and bodies work. There are hundreds of copies of rDNA regions in every person's genome, an average of 315, but some people have more and some fewer. Those copies are important for making sure cells have protein-building factories at the ready.

"We didn't know what to expect in these regions," Miga says. "We found that every acrocentric chromosome, and every rDNA [gene] on that acrocentric chromosome, had variants, changes to the repeat unit that was private to that particular chromosome."

By using fluorescent tags, Eichler and colleagues discovered that repetitive DNA next to the rDNA regions — and perhaps the rDNA too — sometimes switches places to land on another chromosome. "It's like musical chairs," he says. Why and how that happens is still a mystery.

The new genome also has 3,604 genes, including 140 that encode proteins, that weren't present in the old genome. Many of those genes are slightly different copies of previously known genes, including some that have been implicated in brain evolution and development, autism, immune responses, cancer and cardiovascular disease. Having a map of where these genes lie may lead to a better understanding of what they do, and perhaps even of what makes humans human.

One of the biggest finds may be the sequences of all of the human centromeres. Centromeres, the pinched portions that give most chromosomes their characteristic X shape, are the assembly points for kinetochores, the cellular machinery that divvies up DNA during cell division. That's one of the most important jobs in a cell. When it goes wrong, birth defects, cancer or death can result. Researchers had already deciphered the centromeres of fruit flies and the human 8, X and Y chromosomes, but this is the first time that researchers have gotten a glimpse of the rest of the human centromeres.

The sequences are mostly head-to-tail repeats of about 171 base pairs of DNA known as alpha satellites. But those repeats are nestled within other repeats, creating complex patterns that distinguish each chromosome's individual centromere. Knowing the sequences will help scientists learn more about how chromosomes are divvied up and what can throw off the process.

8 percent
Fraction of the human genome deciphered for the first time

Researchers also now have a more complete map of epigenetic marks — chemical tags on DNA or associated proteins that may change how genes are regulated. One type of epigenetic mark, known as DNA methylation, is fairly abundant across the centromeres, except for one spot in each chromosome called the centromeric dip region, Winston Timp, a biomedical engineer at Johns Hopkins University, and colleagues report.

Those dips are where kinetochores grab the DNA, the team discovered. But it's not yet clear whether the dip in methylation causes the cellular machinery to assemble in that spot or if assembly of the machinery leads to lower levels of methylation. Examining DNA methylation patterns in multiple people's DNA and comparing them with the new reference genome revealed that the dips occur at different spots in each person's centromeres, though the consequences of that aren't known.

About half of genes implicated in the evolution of humans' large, wrinkly brains are found in multiple copies in the newly uncovered repetitive parts of the genome (*SN: 3/21/15, p. 16*). Overlaying the epigenetic maps on the reference genome allowed researchers to figure out which of many copies of those genes were turned on and off, says geneticist Ariel Gershman of the Johns Hopkins School of Medicine.

"That gives us a little bit more insight into which of them are actually important and playing a functional role in the development of the human brain," Gershman says. "That was exciting for us, because there's never been a reference that was accurate enough in these [repetitive] regions to tell which gene was which, and which ones are turned on or off."

What's next?

One criticism of genetics research is that it relies too heavily on DNA from people of European descent. CHM13 also has European heritage. But researchers have used the complete reference genome to discover new patterns of genetic diversity. Using DNA data collected from thousands of people from a variety of backgrounds who participated in earlier research projects compared with the T2T reference, researchers more easily and accurately found places where people differ, McCoy and colleagues report.

The T2T Consortium has now teamed up with Wang and colleagues to decipher complete genomes of 350 people from various backgrounds (*SN: 3/27/21, p. 10*). Known as the pangenome project, that effort is expected to reveal some of its first findings later this year, Wang says.

The quest to complete the human genome also brings benefits to researchers studying other organisms, says Amanda Larracuente, an evolutionary geneticist at the University of Rochester in New York. "What I'm excited about is the techniques and tools this team has developed, and being able to apply those to study other species."

Eichler and others already have plans to decipher complete genomes of chimpanzees, bonobos and other great apes to learn more about how humans evolved differently than other apes did.

"No one should see this as the end," Eichler says, "but a transformation, not only for genomic research but for clinical medicine, though that will take years to achieve." ■

BODY & BRAIN

COVID-19 can change a person's brain

But the consequences are unclear, a *Science News* writer explains

BY LAURA SANDERS

Like all writers, I spend large chunks of my time looking for words. When it comes to the ultracomplicated and mysterious brain, I need words that capture nuance and uncertainty. The right words confront and address hard questions about exactly what new scientific findings mean and why they matter.

The search for the right words is on my mind because of recent research on COVID-19. As part of a brain-scanning study, researchers in the United Kingdom found that infections with SARS-CoV-2, the virus that causes COVID-19, were linked with less gray matter.

The results, published March 7 in *Nature*, prompted headlines about COVID-19 causing brain damage and shrinkage. That coverage prompted alarmed posts on social media, including mentions of early onset dementia and brain rotting.

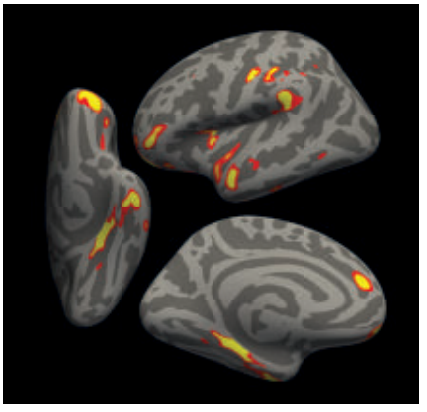
As someone who has reported on brain research for more than a decade, I can say those alarming words are not the ones that I would have chosen.

The study is one of the first to look at structural brain changes before and after a SARS-CoV-2 infection. As part of the project, 785 participants underwent two MRI scans. Between those scans, 401 people had COVID-19 and 384 people did not.

After a bout of COVID-19, people had, on average, less gray matter in parts of the brain that help handle the sense of smell. That's an interesting finding, especially given the virus's ability to steal people's sense of smell (SN: 2/12/22, p. 14). But it's also not surprising, given what we know about the brain's propensity to change.

I can rattle off a long list of things that change the brain, including learning new things, sleeping and using a smartphone (SN: 4/1/17, p. 18). The events of our lives are reflected in the size, shape and behavior of our constantly changing brains.

Growing up is one of those brain-changing events. As a toddler, you had the most nerve cell connections in some parts of your brain that you'll ever have. Those overabundant connections were then pruned and refined. In early adolescence, some parts of your brain were the largest they will be, by volume. Over your teenage years, parts of your brain got smaller, a trend that continues as you grow older (SN: 10/31/15, p. 8).



In a study of hundreds of people, certain brain regions linked to the sense of smell (red and yellow, shown in three views of the brain's left side) were smaller after a bout of COVID-19.

"The brain is dynamic," says neuroscientist Emily Jacobs of the University of California, Santa Barbara. "Less doesn't mean worse necessarily, and more doesn't mean better."

For instance, Jacobs and colleagues have found that a woman's brain areas grow and shrink over the course of days, changes that are tethered to hormone levels across the menstrual cycle. This change, found in the hippocampus, a brain structure tied to learning and memory, and nearby areas, "belies the notion that the brain is static," Jacobs says.

Pregnancy, and its ensuing hormone shifts, can also change the brain. In 2016, I reported on a study about pregnancy-related reductions in gray matter (SN: 2/4/17, p. 7). That story raised the same sticky question about word choice as the COVID-19 brain study. In the pregnancy study, was the brain change shrinkage or damage? Or, to cast it in a more positive light, was it maturing or sculpting? Study coauthor Elseline Hoekzema, a neuroscientist at Leiden University in the Netherlands, told me back then that to her, the process seemed like a second stage of brain maturing, akin to the refinements that happen during adolescence.

Jacobs also works on menopause, another big hormonal shift that affects the brain. And she has preliminary evidence that men's brains change day to day too. Like me, Jacobs grapples with language when describing some of these changes. Words matter quite a bit, she says. "You can paint [research findings] as a good thing or as a horror story."

So which scenario best captures the COVID-19 results? It's probably safe to assume that a viral infection isn't a good thing. But is it bad for the brain, and if so, how bad? The answer, frustrating though it may be, is that we don't yet know. "We were quite surprised to see clear differences in the brain, even with mild infection," says neuroscientist Gwenaëlle Douaud of the University of Oxford. "The concern is that these damages will last and make infected people more vulnerable to brain diseases in the future."

But these differences may not last, Douaud says. The brain can "reorganize and heal itself to some extent, even in older people," she notes. It's also possible that the observed changes are due to a lack of smell input. Other research has shown that stuffy noses can lead to brain changes, some of which are similar to those found in the COVID-19 brain-scanning study. Brain changes may reverse once a person's sense of smell returns.

Scanning the COVID-19 participants again in a few years will help answer the question of permanence. But for now, it's unclear whether these brain changes will linger — and what they mean for a healthy brain. "We haven't distinguished between what are normal changes and what are not," Jacobs says.

Until scientists figure out more about the brain, including whether changes are normal, reversible or inconsequential, we can't possibly know what's worrisome. So for now, the right words are, "We don't know." ■

G. DOUAUD, IN COLLABORATION WITH ANDERSON WINKLER, SAAD JBABDI, UNIV. OF OXFORD, NIH

EARTH & ENVIRONMENT

Forests cool Earth in multiple ways

Trees do more than capture carbon to curb global warming

BY NIKK OGASA

When it comes to cooling the planet, forests have more than one trick up their trees.

Tropical forests help cool the average global temperature by about 1.5 degrees Celsius, a new study finds. The effect stems largely from forests' capacity to capture and store atmospheric carbon. But about one-third of that tropical cooling effect comes from several other processes, such as the release of water vapor and aerosols, researchers report March 24 in *Frontiers in Forests and Global Change*.

"We tend to focus on carbon dioxide and other greenhouse gases, but forests are not just carbon sponges," says Deborah Lawrence, an environmental scientist at the University of Virginia in Charlottesville. "It's time to think about what else forests are doing for us besides just absorbing carbon dioxide."

Researchers already knew that forests influence their local climates through various physical and chemical processes. Trees release water vapor through pores in their leaves — a process called evapotranspiration — and, like human sweating, this cools the trees and their surroundings. Uneven forest canopies can also have a cooling effect, as they provide an undulating surface that can bump hot, overpassing fronts of air upward and away. What's more, trees generate aerosols that can lower temperatures by reflecting sunlight and seeding clouds.

But on a global scale, it wasn't clear how these other cooling benefits compared with the cooling provided by forests' capturing of carbon dioxide, Lawrence says.

So she and colleagues analyzed how the complete deforestation of different regions would impact global temperatures, using data gathered from other studies. For instance, the team used forest biomass data to determine how much the release of carbon stored by those forests would raise the global temperature. The team then compared those results with other studies' estimates of how much the loss of other aspects of forests — such as evapotranspiration, uneven canopies and aerosol production — affected regional and global temperatures.

In forests at latitudes from about 50° N of the equator to 50° S, the primary way that forests influenced the global average temperature was through carbon sequestration, the researchers found.

But other cooling factors still played large roles. Tropical forests, located from 30° N to 30° S, provided alternative benefits that cool the planet by about 0.5 degrees, about half as much cooling as carbon sequestration provided. About 0.2 degrees of that cooling came from forests in the core of the tropics (within 10° of the equator). Canopy topography generally provided the greatest cooling, followed by evapotranspiration and then aerosols.

Forests in the far north, beyond 50° N, however, appear to have a net warming effect. Clearing the boreal forests in Canada, Alaska, Russia and Scandinavia would expose more snow cover during winter. This would decrease ground-level temperatures because snow reflects much of the incoming sunlight back into the sky. Still, looking at the world's forests collectively, their net effect is to cool the global average temperature by about 0.5 degrees.

The research shows that clearing tropical forests robs us of cooling benefits, says Gabriel de Oliveira, a geographer at the University of South Alabama in Mobile. But deforestation isn't the only concern. Forests damaged by fires or selective logging may be less able to help with cooling. It would be useful to consider how such degradation, in addition to deforestation, impacts climate, de Oliveira says, to assess the impact of restoring and protecting forests. "It's cool to see beyond carbon dioxide, but it's also very important to see beyond deforestation." ■

EARTH & ENVIRONMENT

Australian fires damaged the ozone layer

Towers of smoke rose up into the stratosphere during Australia's "Black Summer" fires in 2019 and 2020 (as shown in New South Wales in December 2019). That smoke destroyed some of Earth's protective ozone layer, researchers report in the March 18 *Science*. Satellite data reveal that the smoke particles contained organic molecules that kicked off a series of chemical reactions that altered the balance of gases in the stratosphere to a degree never before observed in 15 years of satellite measurements. That shuffle boosted levels of chlorine-containing molecules that ultimately ate up ozone. Ozone concentrations initially increased from January to March 2020. But then from April to December 2020, ozone levels not only fell, but sank below the 2005–2019 average concentration. The hole in the ozone layer had been on the mend, but the increasing frequency of large wildfires due to climate change threatens that recovery, the researchers say. — *Carolyn Gramling*

The loss of certain genes may underpin physiological and behavioral adaptations that allow vampire bats to consume a blood-only diet.

LIFE & EVOLUTION

How vampire bats survive on blood

Loss of genes may help explain the evolution of a unique diet

BY RICHARD KEMENY

Surviving on blood alone is no picnic. But a handful of genetic tweaks may have helped vampire bats become the only mammals known to feed exclusively on the stuff.

These bats evolved a range of physiological and behavioral strategies to exist on a blood diet. The genetic picture behind this behavior is still blurry. But the loss of 13 genes over time may have helped the bats manage the diet, researchers report March 25 in *Science Advances*.

"Sometimes losing genes in evolutionary time frames can actually be adaptive or beneficial," says Michael Hiller, a genomicist at the Senckenberg Society for Nature Research in Frankfurt.

Hiller and colleagues pieced together the genetic instruction book of the common vampire bat (*Desmodus rotundus*) and compared it with the genomes of 26 other bat species. The team searched for genes that *D. rotundus* had either lost entirely or were inactivated through mutations.

Of the 13 missing genes, three had been previously reported. In other animals, these genes are associated with sweet and bitter taste receptors. So vampire bats probably have a diminished sense of taste—all the better for drinking blood.

For the 10 newly identified lost genes, the team proposes several ideas for how the absences may support a blood diet.

Some of the lost genes help raise insulin levels and convert ingested sugar into a storable form. Given blood's low sugar content, this system may have broken down and the genes probably aren't that useful anymore. Another gene, linked to gastric acid production, which helps break down solid food, may have been lost as the vampire bat stomach evolved to mostly store and absorb fluid.

Another lost gene inhibits the uptake of iron in gastrointestinal cells. Because blood is low in calories, vampire bats must drink up to 1.4 times their own weight during each feed. In doing so, they ingest a lot of iron. Gastrointestinal cells are regularly shed in vampire bats. So by losing that gene, the cells may be able to absorb a lot of iron, and the bats avoid iron overload because the cells are quickly excreted.

One lost gene may even be linked to vampire bats' thinking abilities. Susceptible to starvation, these bats share regurgitated blood and are more likely to do so with bats that have previously shared blood with them. In other animals, the gene breaks down a compound in the brain thought to aid learning and memory. Without this gene, vampire bats probably have more of this memory-related compound. These bats probably rely on memory to track social ties.

"There are some compelling hypotheses there," says David Liberles, an evolutionary genomicist at Temple University in Philadelphia.

Whether the diet caused these genetic changes, or vice versa, isn't known. Either way, it was probably a gradual process over millions of years, Hiller says. "Maybe they started drinking more and more blood, and then you have time to better adapt to this very challenging diet." ■

LIFE & EVOLUTION

Virus hijacks caterpillar vision

Genetic trickery forces zombie insects to climb to their deaths

BY JAKE BUEHLER

Higher and higher still, the cotton bollworm climbs, the caterpillar's tiny body ceaselessly passing leaf after leaf. Reaching the top of a plant, it will die, facilitating the spread of the virus that steered the insect there.

One particular virus behind this ascent manipulates genes associated with caterpillar vision, causing the insects to be more attracted to sunlight than usual, researchers report March 8 in *Molecular Ecology*.

The virus is a type of baculovirus. Baculoviruses can infect more than 800 insect species, mostly the caterpillars of moths and butterflies. Once infected, the hosts exhibit "treetop disease," compelled to climb before dying and leaving their bodies for scavengers to feast upon.

The clever trick of these viruses has been known for more than a century, says Xiaoxia Liu, an entomologist at China Agricultural University in Beijing. But how they turn caterpillars into zombies doomed to ascend to their own deaths wasn't understood.

Previous research suggested that infected caterpillars climb in response to light. Using cotton bollworm caterpillars (*Helicoverpa armigera*) and a baculovirus called HearNPV, Liu and her colleagues confirmed that infected caterpillars exhibit greater "photoaxis," an attraction to light, than uninfected insects.

The researchers compared infected and uninfected caterpillars' positions in glass tubes surrounding a climbing mesh under an LED light. Uninfected caterpillars wandered up and down the mesh, but returned to the bottom before pupating. That behavior makes sense because in the wild, these caterpillars develop into adults underground. But infected hosts ended up dead at the top of the mesh. The higher the source of light, the higher host caterpillars climbed.

SHERRI AND BROCK FENTON

Cotton bollworm caterpillars travel skyward when infected with a gene-manipulating virus that turns the insects into zombies and increases their attraction to sunlight.

The team moved to the horizontal plane to confirm that the hosts were responding to light rather than gravity, placing caterpillars in a hexagonal box with one of the side panels illuminated. By the second day after infection, host caterpillars crawled to the light about four times as often as the uninfected.

When the team surgically removed infected caterpillars' eyes and put the insects in the box, the blinded insects were attracted to the light a quarter as often as unaltered infected hosts. That suggested that the virus manipulates vision.

The team then compared how active certain genes are in various caterpillar body parts in infected and uninfected larvae. Detected mostly in the eyes, two genes for opsins, the light-sensitive proteins fundamental for vision, were more active after an infection. And so was another gene associated with vision called *TRPL*, which encodes for a channel in cell membranes involved in the conversion of light into electrical signals.

When the team used the gene-editing tool CRISPR/Cas9 to shut off the opsin genes and *TRPL* in infected caterpillars, the number of hosts attracted to the light in the box was cut roughly in half. Their height at death on the mesh was also reduced. But because some degree of phototaxis still occurred, other genes may also be involved in driving infected insects toward light.

Baculoviruses appear capable of commandeering the genetic architecture of caterpillar vision, exploiting an ancient importance of light, Liu says. Light can cue crucial biological processes in insects, from directing developmental timing to setting migration routes.

These viruses were already known to be master manipulators in other ways, tweaking their hosts' sense of smell, molting patterns and the programmed death of cells, says Lorena Passarelli, a virologist at Kansas State University in Manhattan. The new research shows that the viruses manipulate "yet another physiological host process: visual perception."

There's still a lot to learn about this visual hijacking, Passarelli says. It's unknown, for instance, which of the virus's genes turn caterpillars into light-chasing zombies in the first place. ■

DAVID MCCLENAGHAN/CSIRO (CC BY 3.0)

The dense bones of *Spinosaurus* (illustrated) may have helped keep it submerged, allowing the dinosaur to hunt prey such as ancient sawfish, some researchers argue.

DAVIDE BONADONNA

LIFE & EVOLUTION

Did *Spinosaurus* and its kin swim?

Bone study rekindles debate over aquatic dinosaurs

BY CAROLYN GRAMLING

A fierce group of predatory dinosaurs may have been swimmers that hunted underwater.

An analysis of bone density suggests that *Spinosaurus* and some of its relatives were predominantly aquatic, researchers report in the March 31 *Nature*.

That finding is the latest salvo in an ongoing challenge to the prevailing view that all dinosaurs were land-based animals that left the realms of water and air to other reptiles. But, other researchers say, the results still don't prove that *Spinosaurus* and its kin actually swam.

In 2014, Nizar Ibrahim, a vertebrate paleontologist now at the University of Portsmouth in England, and colleagues pieced together the fossilized skeleton of a 15-meter-long *Spinosaurus* found in 95-million-year-old rocks in Morocco. The dinosaur's odd collection of features — a massive sail-like structure on its back, short and muscular legs, nostrils set well back from the tip of the snout, and needlelike teeth seemingly designed for snagging fish — hinted that the predator might have been a swimmer (SN: 10/18/14, *p.* 10). In particular, it had very dense leg bones, a feature of some aquatic creatures like manatees that need the bones for ballast to stay submerged.

In the new study, Ibrahim and his team returned to the issue of bone density to assess whether it's a reliable proxy for how much time an animal spends in the water. The team assembled a dataset of femur and dorsal rib bone densities from "an incredible menagerie of extinct and living animals, reaching out to museum curators all around the world," Ibrahim says.

That menagerie included *Spinosaurus*, as well as its equally sharp-toothed cousins *Baryonyx* and *Suchomimus*. It also included other groups of dinosaurs, extinct marine reptiles, pterosaurs, birds, modern alligators and marine mammals.

The team then compared these bone analyses with the water-dwelling habits of the various creatures. That work confirms that density is "an excellent indicator" for species in the early stages of an evolutionary transition from land-dwelling to water-dwelling, the team reports. Those compact bones can help transitional creatures, which might not yet have fins or flippers, maneuver in the water more easily while hunting underwater — what Ibrahim's team calls "subaqueous foraging."

The analyses also show that not only did *Spinosaurus* have very dense bones, but *Baryonyx* did too. Both of these dinosaurs were subaqueous foragers, the team suggests. That idea builds on previous work by Ibrahim and colleagues that proposed that *Spinosaurus* didn't just spend much of its time in the water, but could actually swim in pursuit of prey, thanks to its odd, paddle-shaped tail (SN: 6/6/20, *p.* 13).

The idea of a swimming *Spinosaurus* hasn't been convincing to all. In 2021, a study in *Palaeontologia Electronica* examined *Spinosaurus*' anatomy and concluded that the dinosaur was not a highly specialized aquatic predator. David Hone, a zoologist and paleobiologist at Queen Mary University of London, and Thomas Holtz Jr., a vertebrate paleontologist at the University of Maryland in College Park, argued instead that *Spinosaurus* may have just waded in the shallows to fish, like a heron does today.

The new study has not convinced those skeptics. *Spinosaurus* has "clearly got very dense bones. This is really good evidence that they're hanging around in water — but we kind of knew that," Hone says. "It's not clear what they're doing in the water. That's the contentious part."

Take hippos, which spend much of their time mostly submerged, Hone says. "Hippos have bone densities entirely comparable to *Spinosaurus* and *Baryonyx*, but they don't eat in the water" and they don't swim, he says.

"Everyone has been in agreement that *Spinosaurus* was more aquatic than other big theropods" like *Tyrannosaurus rex*, Holtz adds. That *Baryonyx* also had dense bones was a bit of an interesting surprise, he says.

But dense bones or not, Holtz says, "it still doesn't turn them into aquatic hunters." He describes several anatomical features that point more to *Spinosaurus* hunting from above the water surface rather than chasing prey underwater. Those features include a long, slender neck, a tilted head and an arrangement of neck muscles hinting at a downward striking motion.

Kiersten Formoso, a vertebrate paleobiologist at the University of Southern California in Los Angeles, says that the new comparison of bone densities among a wide variety of creatures is a valuable resource, one that she anticipates referring to in her own work on how ancient creatures transitioned from land to water. But she is also not convinced that the study proves that *Spinosaurus* and *Baryonyx* could actually swim.

"I would never detach *Spinosaurus* from the water," Formoso says. But, she adds, more work is needed on how the dinosaur might have moved to understand how adroitly aquatic it might have been. ■

HUMANS & SOCIETY

Phoenician pool tracked the stars

The ancient basin was not a harbor, as once thought

BY BRUCE BOWER

On a tiny island off Sicily's west coast, a huge pool long ago displayed the star-studded reflections of the gods.

Scientists have long thought that a rectangular basin on the island of Motya served as an artificial inner harbor, or perhaps a dry dock, for Phoenician mariners about 2,550 years ago. Instead, the water-filled structure is the largest known sacred pool from the ancient Mediterranean world, says archaeologist Lorenzo Nigro of Sapienza University of Rome.

Phoenicians, who on their sea travels adopted cultural influences from many Mediterranean societies, put the pool at the center of a religious compound in a port city also dubbed Motya, Nigro reports March 17 in *Antiquity*.

The pool and three nearby temples were aligned with the positions of specific stars and constellations on key days of the year, such as the summer and winter solstices, Nigro found. Each of those celestial bodies was associated with a particular Phoenician god.

At night, the reflecting surface of the pool, which was longer and wider than an Olympic-sized swimming pool, was used to make astronomical observations by marking star positions with poles in the water, Nigro suspects. Discoveries of a navigation instrument's pointer in one temple and the worn statue of an Egyptian god associated with astronomy found in a corner of the pool support that possibility.

A block with a sculpted foot, found on the edge of a sacred pool, may have been part of a statue of a Phoenician god.

An archaeologist who explored Motya around a century ago first described the large pool as a harbor that connected to the sea by a channel. A similar harbor had previously been discovered at Carthage, a Phoenician city on North Africa's coast.

But excavations and radiocarbon dating conducted at Motya since 2002 by Nigro, working with the Superintendence of Trapani in Sicily and the G. Whitaker Foundation in Palermo, have overturned that view.

"The pool could not have served as a harbor, as it was not connected to the sea," Nigro says. His team temporarily drained the basin, showing that it is instead fed by natural springs. Only after Greek invaders conquered Motya in a battle that ended in 396 B.C. was a channel dug from the pool to a nearby lagoon, Nigro's group found.

Phoenicians settled on Motya between 800 B.C. and 750 B.C. The sacred pool, including a pedestal in the center that supported a statue of the Phoenician god Ba'al, was built between 550 B.C. and 520 B.C., Nigro says. Two clues suggested that the pedestal had once held a statue of Ba'al. First, after draining the pool, Nigro's team found a stone block with the remnants of a large, sculpted foot at the basin's edge. And an inscription in a small pit at one corner of the pool includes a dedication to Ba'al.

Gods worshipped by Phoenicians at Motya and elsewhere were adopted and adapted from gods of other Mediterranean societies. Ba'al was a close counterpart of the divine hero Hercules in Greek mythology.

An ability to incorporate other people's deities into their own religion "was probably one of the keys to Phoenicians' success throughout the Mediterranean," says archaeologist Susan Sherratt of the University of Sheffield in England.

Seafaring traders now called Phoenicians lived in eastern Mediterranean cities founded more than 3,000 years ago (*SN: 1/28/06, p. 52*). Phoenicians established settlements from Cyprus to Spain's Atlantic coast. Some researchers suspect that Phoenicians lacked a unifying cultural or ethnic identity.

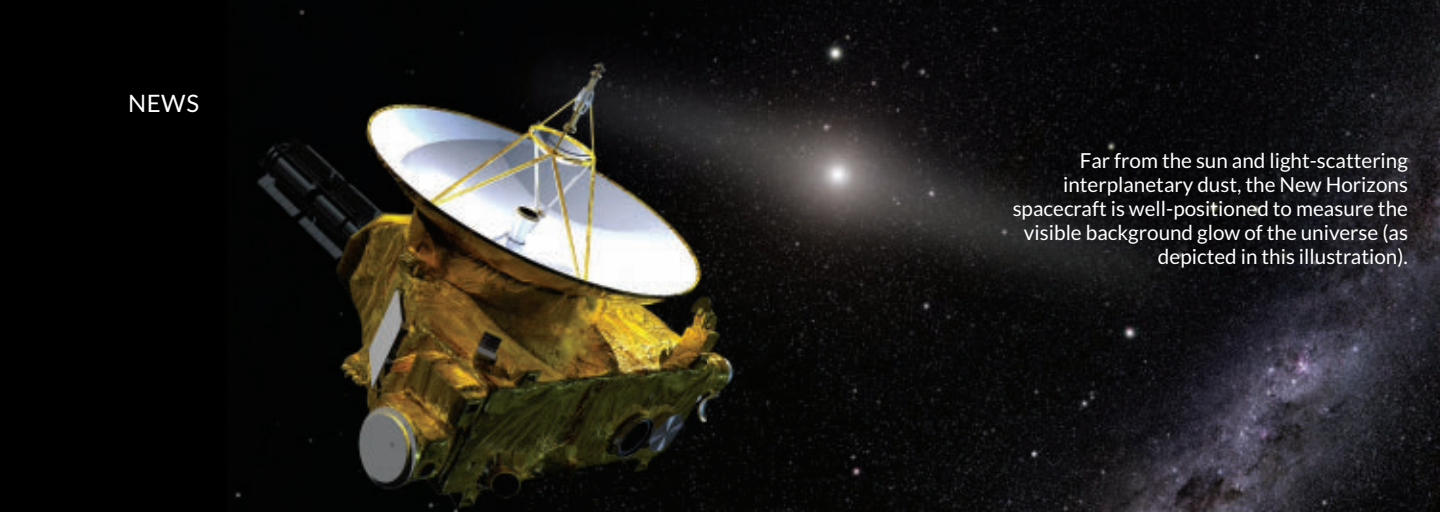
Nigro disagrees. Phoenicians developed an influential writing system and spoke a common Semitic language, key markers of a common eastern Mediterranean culture, he contends. As these seafarers settled islands and coastal regions stretching west across the Mediterranean, they created hybrid cultures with native groups, Nigro suspects.

Excavations at Motya indicate that Phoenician newcomers created a distinctive West Phoenician culture via interactions with people already living there. Pottery and other artifacts indicate that groups from Greece, Crete and other Mediterranean regions periodically settled on the island starting as early as about 4,000 years ago. Metal objects and other cultural remains from various stages of Motya's development display influences from all corners of the Mediterranean.

Though much remains unknown about political and social life at Motya, the Phoenicians oversaw an experiment in cultural tolerance that lasted around 400 years, Nigro says. ■

Researchers excavated a sacred pool built by the Phoenicians around 2,550 years ago on the tiny Mediterranean island of Motya. The pool is shown here with a replica of a statue of the god Ba'al.

FROM TOP: © MUSEO ARCHEOLOGICO REGIONALE A. SALINAS, PALERMO AND L. NIGRO/*ANTIQUITY* 2022; SAPIENZA UNIVERSITY OF ROME EXPEDITION TO MOTYA



Far from the sun and light-scattering interplanetary dust, the New Horizons spacecraft is well-positioned to measure the visible background glow of the universe (as depicted in this illustration).

NASA, JOSEPH OLMSTED/STSCI

ATOM & COSMOS

Excess light stumps astronomers

The universe's background glow is brighter than expected

BY LIZ KRUESI

Even if you remove the bright stars, the glowing dust and other nearby points of light from the inky, dark sky, a background glow remains. That glow comes from the cosmic sea of distant galaxies, the first stars that burned, faraway coalescing gas — and, it seems, something else in the mix that's evading researchers.

Astronomers estimated the amount of visible light pervading the cosmos by training the New Horizons spacecraft, which flew past Pluto in 2015, on a spot on the sky mostly devoid of nearby stars and galaxies. That estimate should match calculations of the total amount of light coming from galaxies across the history of the universe. But it doesn't, researchers report in the March 1 *Astrophysical Journal Letters*.

"It turns out that the galaxies that we know about can account for about half of the level we see," says Tod Lauer, an astronomer at the National Science Foundation's NOIRLab in Tucson.

For decades, astronomers have measured the extragalactic background light in different wavelengths, from radio waves to gamma rays (SN: 9/7/13, *p.* 22). These measurements provide a census of the universe and give researchers hints about the processes that emit those types of light.

But the background visible light — dubbed the cosmic optical background, or COB — is challenging to measure from the inner solar system. Lots of interplanetary dust scatters sunlight, washing out the much fainter COB. The New Horizons spacecraft, however, is far enough from the sun that scattered sunlight doesn't flood the spacecraft's images.

In September 2021, Lauer and colleagues pointed the spacecraft's LORRI camera toward a patch of sky and took a bunch of pictures. The team digitally removed all known sources of light — individual stars, nearby galaxies, even heat from the spacecraft's nuclear power source — and measured what was left to estimate the COB.

Then the researchers used large archives of galaxy observations, like those from the Hubble Space Telescope, to calculate the light emitted by all the galaxies in the universe. The measured COB is roughly twice as bright as that calculation.

While Lauer's group previously noted a discrepancy, this new measurement reveals a wider difference, and with smaller uncertainty. "There's clearly an anomaly. Now we need to try to understand it and explain it," says coauthor Marc Postman, an astronomer at the Space Telescope Science Institute in Baltimore.

There are several possible astronomical explanations for the discrepancy. Perhaps, Postman says, rogue stars stripped from galaxies linger in intergalactic space. Or maybe, he says, there is "a very faint population of very compact galaxies that are just below the detection limits" of Hubble and other existing telescopes. If it's the latter case, astronomers should know in the next couple years because NASA's recently launched James Webb Space Telescope will see these even-fainter galaxies.

Another possibility is the researchers missed something in their analysis. "I'm glad it got done. It's absolutely a necessary measurement," says Michael Zemcov, an astrophysicist at the Rochester Institute of Technology in New York. But perhaps the researchers are missing some additional glow from the New Horizons spacecraft and its LORRI instrument, or they didn't factor in some additional foreground light, Zemcov says. "I think there's a conversation there about details."

An example of that foreground light is the light that reflects off the Milky Way's dust, which is "a very subtle beast," Zemcov says, "and our uncertainties likely get dominated by it at some point, just because it's not very well understood." Several projects in the next few years, such as the CIBER-2 experiment and the space mission SPHEREx, could help astronomers understand this pesky dust-scattered light, says Zemcov, who is involved in both of those projects.

In addition, he and astrophysicist Teresa Symons, also at the Rochester Institute of Technology, are poring through hundreds of old LORRI images of dark sky and running their own analyses. Meanwhile, Lauer and his colleagues will take more pictures of other patches of sky with LORRI to strengthen the confidence in the measurement of the background light and to better understand intrusions from the spacecraft itself.

"There is something going on that we weren't expecting," Zemcov says, "which is where the fun part of science kicks in." ■

ATOM & COSMOS

Milky Way timing pinned down

Astronomers put precise dates on our galaxy's big events

BY KEN CROSWELL

A new analysis of nearly a quarter million stars puts firm ages on the most momentous events from our galaxy's life story.

Far grander than most of its neighbors, the Milky Way arose long ago, as lesser galaxies smashed together. Its thick disk — a pancake-shaped population of old stars — originated remarkably soon after the Big Bang and well before most of the stellar halo that envelops the disk, astronomers report in the March 24 *Nature*.

"We are now able to provide a very clear timeline of what happened in the earliest time of our Milky Way," says astronomer Maosheng Xiang.

Xiang and Hans-Walter Rix, both at the Max Planck Institute for Astronomy in Heidelberg, Germany, studied almost 250,000 subgiants, stars that are growing larger and cooler after using up the hydrogen fuel at their centers. The temperatures and luminosities of these stars reveal their ages, letting the researchers track how different epochs in galactic history spawned stars with different chemical compositions and orbits around the Milky Way's center.

"There's just an incredible amount of information here," says Rosemary Wyse, an astrophysicist at Johns Hopkins University. "We really want to understand how our galaxy came to be the way it is," she says. "When were the chemical elements of which we are made created?"

Xiang and Rix discovered that the Milky Way's thick disk got its start about 13 billion years ago. That's just 800 million years after the universe's birth. The thick disk, which measures 6,000 light-years from top to bottom in the sun's vicinity, kept forming stars for a long time, until about 8 billion years ago.

During this period, the thick disk's iron content shot up 30-fold as exploding stars enriched the disk's star-forming gas, the team found. At the dawn of the thick disk era, a newborn star had only a tenth as much iron, relative to hydrogen, as the sun. By the end, 5 billion years later, a thick disk star was three times as rich in iron as the sun.

Xiang and Rix also found a tight relationship between a thick disk star's age and iron content. This means gas was thoroughly mixed throughout the thick disk: As time went on, newborn stars inherited steadily higher amounts of iron, no matter whether the stars formed close to or far from the galactic center.

But that's not all that was happening. As other researchers reported in 2018, another galaxy once hit our own, giving the Milky Way most of the stars in its halo, which engulfs the disk (SN: 11/24/18, p. 8). Halo stars have little iron.

The new work revises the date of this great galactic encounter: "We found that the merger happened 11 billion years ago," Xiang says, a billion years earlier than thought. As the intruder's gas crashed into the Milky Way's gas, it triggered the creation of so many new stars that our galaxy's star formation rate reached a record high.

The merger also splashed some stars from the thick disk up into the halo, which Xiang and Rix identified from the stars' higher iron abundances. These "splash" stars, the researchers found, are at least 11 billion years old, confirming the date of the merger.

The thick disk ran out of gas 8 billion years ago and stopped making stars. Fresh gas around the Milky Way then settled into a thinner disk, which has given birth to stars ever since — including the 4.6-billion-year-old sun and most of its stellar neighbors. The thin disk is about 2,000 light-years thick in our part of the galaxy and has younger stars than the thick disk.

"The Milky Way has been quite quiet for the last 8 billion years," Xiang says. Our galaxy has experienced no further encounters with big galaxies. That makes it different from most of its peers.

If the thick disk really existed 13 billion years ago, Xiang says, then the new James Webb Space Telescope may discern similar disks in galaxies 13 billion light-years from Earth — portraits of the Milky Way as a young galaxy. ■

YINGWEI CHEN

The Milky Way arches over China's Large Sky Area Multi-Object Fiber Spectroscopic Telescope. This observatory and others collected data that revealed that our galaxy began forming a disk of stars surprisingly early, just 800 million years after the Big Bang.

THE PREGNANT PAUSE

Pregnant people are barred from most clinical trials, leading to a scarcity of data on the safety and effectiveness of medications used during pregnancy.

Why excluding pregnant people from medical research is a problem **By Erika Engelhaupt**

Obstetrician Cynthia Gyamfi-Bannerman was treating patients in New York City when the COVID-19 pandemic swept in. Hospitals began filling up. Some of her pregnant patients were among the sick.

It was a terrifying time. Little was known about the virus called SARS-CoV-2 to begin with, much less how it might affect a pregnancy, so doctors had to make tough calls. Gyamfi-Bannerman remembers doctors getting waivers to administer the antiviral drug remdesivir to pregnant COVID-19 patients, for instance, even though the drug hadn't been tested during pregnancy.

"Our goal is to help the mom," she says. "If we had something that might save her life — or she might die — we were 100 percent using all of those medications."

These life-or-death decisions were very familiar to obstetricians even before the pandemic. Pregnant women have long been excluded from most drug testing to avoid risk to the fetus. As a result, there's little data on whether many medications are safe to take while pregnant. This means tough choices for the roughly 80 percent of women who will take at least one medication during pregnancy. Some have serious conditions that can be dangerous for both mother and fetus if left untreated, like high blood pressure or diabetes.

"Pregnant women are essentially like everybody else," Gyamfi-Bannerman says. They have the same underlying conditions, requiring the same drugs. In a 2013 study, the top 20 prescriptions taken during the first trimester included antibiotics, asthma and allergy drugs, metformin for diabetes, and antidepressants. Yet even for common drugs, the only advice available if you're pregnant is "talk to your doctor." With no data, doctors don't have the answers either.

What's frustrating to many doctors and researchers is that this lack of information is by design. Even the later stages of most clinical trials, which test a new drug's safety and efficacy in people, specifically exclude pregnant people to avoid risk to the fetus. But in the wake of a pandemic that disproportionately harmed the pregnant population, researchers are questioning more than ever whether this is the best approach.

Typically, researchers have to justify excluding certain groups, such as older adults, from clinical trials in which they might benefit. "You never have to justify why you're excluding pregnant people," says Gyamfi-Bannerman, who now heads the obstetrics, gynecology and reproductive science department at the University of California, San Diego. "You can just go ahead and exclude them.

"The exclusion of pregnant people in clinical trials is a huge, historic problem," she says, "and it really came to light with COVID."

Pregnant in a crisis

Teresa Mathews was 43 years old when she found out she was pregnant in June 2020, just as the pandemic was tearing across the United States. "I was really worried," she says. In addition to her age as a risk factor, Mathews has sickle cell trait, meaning she carries one defective gene copy that makes her prone to anemia and shortness of breath. COVID-19 also causes shortness of breath, so Mathews feared her unborn child could starve for oxygen if she caught the virus.

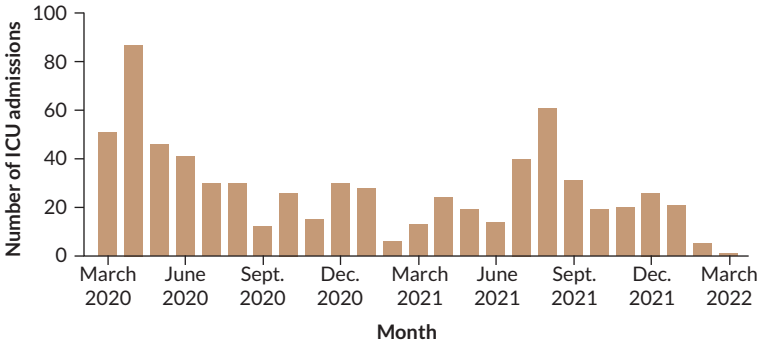
What's more, the baby would be her first. "I don't want to say it melodramatically, but it was my last chance of having a baby, right? So I didn't really want to take chances." She went into full lockdown for the rest of her pregnancy.

For good reason. A study during the pandemic's first year in England found that pregnant women who got the virus were about twice as likely to have a stillbirth or early birth. And the U.S. Centers for Disease Control and Prevention reported in November 2020 that pregnant women are about three times as likely as other women to land in intensive care with COVID-19, and 70 percent more likely to die from the infection (*SN Online*: 2/7/22).

Obstetrician Cynthia Gyamfi-Bannerman (left) has conducted clinical trials to learn the effects of medications taken during pregnancy and advocates for more research involving pregnant people.

OPPOSITE PAGE: LJUBAPHOTO/E+/GETTY IMAGES PLUS; THIS PAGE: KYLE DYKES/UC SAN DIEGO HEALTH

Intensive care unit admissions among U.S. pregnant women with COVID-19, March 2020–March 2022



Heightened risk Shown are admissions to hospital intensive care units during the pandemic. Unvaccinated pregnant women are about three times as likely as pregnant women who've been vaccinated to require intensive care for COVID-19. SOURCE: CDC

So when the race for a vaccine began, many doctors and officials hoped that vaccines would be tested in pregnant women and shown to be safe. There were promising signs: The U.S. Food and Drug Administration encouraged vaccine developers to include pregnant women in their trials. A large body of previous research suggested that risks would be low for vaccines like those for COVID-19, which do not contain live viruses.

But ultimately the three vaccines that the FDA cleared for use in the United States, from Pfizer/BioNTech, Moderna and Johnson & Johnson, excluded pregnant people from their initial clinical trials. After its vaccine was authorized for emergency use in December 2020, Pfizer began enrolling pregnant women for a clinical trial but called it off when federal officials recommended that all pregnant women get vaccinated. The company cited challenges with enrolling enough women for the trial, as well as ethical considerations in giving a placebo to pregnant individuals once the vaccine was recommended.

31,211
Number of U.S. pregnant women hospitalized with COVID-19, January 2020–March 2022
SOURCE: CDC

When pregnant people were excluded from vaccine trials, doctors knew it would be difficult to convince pregnant patients to take a vaccine that hadn't been tested during pregnancy.

Mathews says she would have been willing to get vaccinated while pregnant if there had been data to support the decision. But the choice was made for her. Her daughter, Eulalia, was born healthy in February 2021, shortly before the vaccines became available to all adults in Mathews' hometown of Knoxville, Tenn. At that point, there was still no clear guidance on whether to get vaccinated while pregnant or nursing.

Officials at the National Institutes of Health in Bethesda, Md., were worried about that lack of direction. Diana Bianchi, director of the National Institute of Child Health and Human Development, called for more COVID-19 vaccine research in the pregnant population in a February 2021 commentary in JAMA. She wrote, "Pregnant people and their clinicians must make real-time decisions based on little or no scientific evidence."

Meanwhile, social media and pregnancy websites filled the void with conspiracy theories and scary stories about vaccines causing infertility or miscarriages. Alarmed, the American College of Obstetricians and Gynecologists warned last October that "the spread of misinformation and mistrust in doctors and science is contributing to staggeringly low vaccination rates among pregnant people."

Indeed, the CDC had issued an urgent health advisory the month before warning that only 31 percent of pregnant people were fully vaccinated, compared with about 56 percent of the general population. (CDC and many experts favor "pregnant people" as a general term. *Science News* is following the language used by sources, and refers to pregnant women when a study population was designated as such.)

"Every week, I look at the number of pregnant people who have died due to COVID. Right now, the most recent statistic is 257 deaths," Bianchi said in January. "I look at that and I say, that was a preventable statistic."

After the vaccines received emergency use authorization, the CDC analyzed the outcomes for nearly 2,500 vaccinated pregnant people and found no safety concerns related to pregnancy. The agency recommended vaccination for anyone who is pregnant, lactating or considering becoming pregnant. But that recommendation arrived more than six months after the first vaccine became available.

Since then, the vaccines have also proved to be highly effective in pregnancy. More than 98 percent of COVID-19 critical care admissions in a group of more than 130,000 pregnant women in Scotland were unvaccinated, researchers reported in January in *Nature Medicine*. And all of the infants who died had unvaccinated moms.

"The story of COVID is yet another cautionary tale," says Anne Lyerly, a bioethicist at the University of North Carolina at Chapel Hill who trained as an obstetrician and gynecologist. "It highlighted what we're up against." Researchers have an ethical duty, she says, not only to protect fetuses from the potential risks of research, but also to ensure that "the drugs that go on the market are safe and effective for all the people who will take them."

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Good intentions

Increasingly, scientists are questioning what Gyamfi-Bannerman calls a "knee-jerk" tendency to exclude pregnant individuals from clinical trials. In 2009, Lyerly and colleagues formed the Second Wave Initiative to promote ethical ways to include pregnant women in research. As their ideas have spread, more researchers — mostly women — have held conferences and spearheaded research. Collectively, they're pushing back on the prevailing culture "that pregnant people need to be protected *from* research instead of protected *through* research," Bianchi says.

"We got here with good intentions," says Brookie Best, a clinical pharmacologist at UC San Diego who studies medication use among pregnant people. "There were some terrible, terrible tragedies of pregnant people taking a drug and having bad outcomes."

The most famous of these was thalidomide. Starting in the late 1950s, the drug was prescribed for morning sickness, but it had never been tested in pregnant people. By the early 1960s, it became clear that it caused birth defects including missing or malformed limbs (SN: 7/14/62, *p.* 22). Afterward, drug companies were reluctant to take on the risk, or legal liability, of potential birth defects. While the FDA enacted new safety rules in response to the thalidomide disaster, the agency did not require testing during pregnancy before drugs went to market.

In 1977, the FDA recommended the exclusion of all women of childbearing age from the first two phases of clinical trials. When the U.S. Congress passed a bill in 1993 requiring that women and minorities be included in clinical research, the requirement did not extend to pregnant women.

Some scientists still see plenty of good reasons not to include pregnant women in clinical trials. For example, reproductive epidemiologist Shanna Swan has seen unexpected health effects crop up long after substances were deemed safe. With that in mind, Swan, of the Icahn School of Medicine at Mount Sinai in New York City, says that observational studies that follow women and their children after a drug has been approved remain the best approach. These studies are "expensive, and very slow," she admits, but safer.

For decades, that level of precaution has extended to essentially all medications. As a result, the reproductive effects of a medicine aren't usually discovered until long after a drug enters the market. Even then, such research is not required for most new drugs, so doctors and researchers must take the initiative. Typically, this happens through pregnancy registries, which enroll pregnant volunteers who are taking a particular drug and follow them throughout pregnancy or beyond.

But voluntary registries leave huge data gaps. A 2011 review of 172 drugs approved by the FDA in the preceding decade found that the risk of harm to fetal development was "undetermined" for 98 percent of them, and for 73 percent there was no safety data during pregnancy at all.

That doesn't mean all those drugs are dangerous. Relatively few drugs cause major birth defects, and many of those fall into known classes. For example, ACE inhibitors used to control blood pressure have been linked to a range of issues, including kidney and cardiovascular problems in infants, when taken during pregnancy. But the potential for more subtle, long-term effects has been trickier to tease out.

For instance, several studies in the 2010s reported links between mothers taking antidepressants during pregnancy and their kids having developmental problems like attention-deficit/hyperactivity disorder and autism spectrum disorder. Some moms became afraid to treat their own depression. But in 2017, studies of siblings found no difference in these conditions among children who had been exposed to antidepressants in the womb and those who had not (SN: 5/13/17, *p.* 9). More likely, the problem was the depression the mom was experiencing, the studies suggested, not the drugs.

No legal requirement

How the contents of a pregnant woman's medicine cabinet might affect her child depends on a host of factors, including how the drug works and

PAUL FIEVEZ/BIPS/GETTY IMAGES

In the late 1950s and early 1960s, the drug thalidomide was prescribed to pregnant women for morning sickness without adequate testing. The drug resulted in birth defects, such as limb malformations, in thousands of children.

whether it crosses the placenta. The main way to gauge whether a drug may harm a fetus is through animal studies called developmental and reproductive toxicology, or DART, studies. But drug companies often don't begin these studies until they've already gotten clinical trials rolling.

This creates a catch-22, because clinical trials can't include pregnant people until DART studies suggest it's safe to do so. That's why Lyerly and others pushing for change say that pharmaceutical companies should start doing these studies earlier, before clinical trials begin.

In 2018, the FDA issued draft guidance to help the pharmaceutical industry decide how and when to include pregnant people in clinical trials (*SN Online*: 5/30/18). That guidance is an encouraging first step, Lyerly says, but it didn't change any of the stringent rules for when pregnant people could be included in research.

Plus, it's all completely voluntary, says Leyla Sahin, acting deputy director for safety in FDA's Division of Pediatric and Maternal Health. "We advise industry.... We tell them we recommend that you include pregnant women in your clinical trials," Sahin says. "But there's no requirement."

In fact, the FDA doesn't even have the legal authority to create a requirement. In that sense, Sahin says, "we're where pediatrics was 20 years ago." Until Congress passed the Pediatric Research Equity Act of 2003, children were routinely excluded from clinical trials just as pregnant women are now. The pediatric law required drug companies to gather data on the safety and effectiveness of medications in children and to provide FDA an appropriate plan for pediatric studies.

Congress could pass a similar law for pregnancy. And in 2020, a government task force recommended exactly that to the Department of Health and Human Services, which oversees FDA. But "it's almost like it's gone into this black hole," Sahin says. "We haven't heard from HHS. We haven't heard from Congress."

Too few drugs have pregnancy safety data

Efforts to protect pregnant people and fetuses have resulted in very little safety information available for them and their doctors.

80 percent
Proportion of U.S. pregnant people who take at least one medication during pregnancy

98 percent
Proportion of drugs approved by the FDA from 2000–2010 without data on fetal safety

Stocking the medicine cabinet

Until clinical trials during pregnancy become more routine, pregnant people face an untenable choice—take a drug without knowing its safety, or leave their medical conditions untreated.

Case in point: A group of 91 doctors and scientists published a consensus statement in September 2021 in *Nature Reviews Endocrinology* warning that acetaminophen, the most commonly used drug during pregnancy, may harm fetal development. Research suggests the drug disrupts hormones, with effects ranging from undescended testicles in male infants to an increased risk of ADHD and autism spectrum disorder in boys and girls.

But as is often the case with drugs and pregnancy, there's not exactly a consensus among doctors about what pregnant people should do. In response to the new paper, the American College of Obstetricians and Gynecologists issued a statement saying the evidence wasn't strong enough to suggest doctors should change their standard practice, which is to recommend acetaminophen be taken as needed and in moderation.

Acetaminophen is an active ingredient in more than 600 medications, including Tylenol, and is estimated to be used by up to 65 percent of pregnant people in the United States. It has long been the preferred pain medication and fever reducer during pregnancy because the FDA recommends against the anti-inflammatory drugs known as NSAIDs—such as ibuprofen and aspirin—in the second half of pregnancy. Those drugs have been linked to rare fetal kidney problems and low amniotic fluid levels.

While at the University of Copenhagen, clinical pharmacologist David Kristensen began studying acetaminophen's effects on fetal development after noticing that the drug is structurally similar to chemicals that disrupt hormones. In 2011, he and colleagues published animal and human studies linking acetaminophen use during pregnancy with concerning effects in infants, including undescended testicles.

"My ears perked up when I heard that," says Swan, the Mount Sinai reproductive epidemiologist and coauthor of the 2021 acetaminophen review. She had seen similar effects with maternal exposure to phthalates, chemicals used in plastics that are known to alter the activity of hormones needed to regulate fetal development.

She and colleagues surveyed 25 years of

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acetaminophen studies. The group found that five out of 11 relevant studies linked prenatal acetaminophen use to urogenital and reproductive tract abnormalities in children, and 26 out of 29 epidemiological studies linked fetal exposure to acetaminophen with neurodevelopmental and behavioral problems. The strength of these links varied, but were "generally modest," the authors wrote.

"We're looking at subtle effects here," Swan says, "but that doesn't mean that they're not important." With such widespread use, "there's a good chance that a fair number of offspring are affected."

Although Swan is wary of testing new drugs in pregnant women, she would like to see better research on medications during pregnancy. "There's a whole range of options short of doing human study," she says.

To start with, Swan says, scientists need better data on what medications pregnant women are taking, and how much. That means more studies should ask women to keep daily logs of every pill they take. Researchers can also do more studies of drugs' reproductive effects in animals, she notes, and even transplant human tissues such as brain, liver or gonads into animals to learn how they respond to drugs.

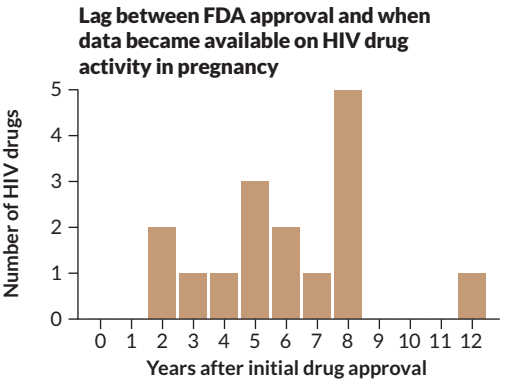
Not the same vulnerability

The cultural shift around pregnancy research may be gaining momentum.

Government-funded research is one key area for change. In 2016, the 21st Century Cures Act established an interagency task force on research specific to pregnant and lactating women. It included officials from NIH, CDC and FDA, as well as medical societies and industry. One of the task force's recommendations was acted upon in 2018: removing pregnant women as a "vulnerable" group in a federal regulation called the Common Rule, which governs federally funded research. Pregnant women had been listed along with children, prisoners and people with intellectual disabilities as vulnerable and thus requiring special protections if included in research.

Unlike the other groups in that list, pregnant people "don't have a diminished capacity to provide informed consent," says Lyerly, the bioethicist at the University of North Carolina. That rule change alone could help "change the culture of research."

Meanwhile, researchers are forging ahead with studies on many drugs used during pregnancy. HIV drugs are among the most studied, says Best of UC San Diego, in part because the virus can pass from pregnant women to their fetuses. "So right off the bat, everybody knew that we needed to treat these [pregnant] patients with medication," she says. Yet data on HIV drugs during pregnancy lagged as much as 12 years after FDA approval.



Waiting game
Even for HIV drugs, which are better studied during pregnancy than most drugs, it took an average of six years after U.S. Food and Drug Administration approval before the first data were published on a drug's activity during pregnancy.
SOURCE: A. COLBERS *ET AL/ CLINICAL INFECTIOUS DISEASES* 2019

Many pregnant women appear to be willing to participate in research. More than 18,000 pregnant people had enrolled in the COVID-19 vaccine pregnancy registry as of March, and every year many volunteer for other pregnancy registries.

Gyamfi-Bannerman says that in her experience, plenty of pregnant patients are willing to volunteer, even for experimental drugs, if there's potential to benefit from the drug and they will be monitored closely. At Columbia University, she helped lead a clinical trials network called the Maternal Fetal Medicine Units Network that specifically studies complications during pregnancy. "It's a very safe and protective environment," she says.

As for next steps, a few policy changes could make a big difference, Best says, like "getting those preclinical studies done earlier and allowing people who accidentally get pregnant while participating in a clinical trial to make the choice of whether or not to stay." Right now, "if you get pregnant, you're out. Boom, that's it," she says. "But they were already exposed to the risk, and now they're not getting the benefit. And so we don't think that's actually ethical."

Thalidomide was prescribed to pregnant women to treat morning sickness, without ever having been tested in pregnant women. "We took the wrong lesson from thalidomide," Lyerly says. "The first lesson of thalidomide is that we *should* do research, not that we shouldn't." ■

Explore more

- National Institute of Child Health and Human Development. "List of recommendations from the Task Force on Research Specific to Pregnant Women and Lactating Women." 2018. bit.ly/NICHD-pregnancystudies

C. CHANG

MUONS OPEN DOORS

Subatomic particles offer special access into pyramids, volcanoes and more

By Emily Conover

An invisible rain of the subatomic particles called muons pierces structures on Earth's surface, including the Great Pyramid of Giza. Those muons can help map out the chambers within the pyramid and have even revealed a mysterious hidden void.

Inside Egypt's Great Pyramid of Giza lies a mysterious cavity, its void unseen by any living human, its surface untouched by modern hands. But luckily, scientists are no longer limited by human senses.

To feel out the contours of the pyramid's unexplored interior, scientists followed the paths of tiny subatomic particles called muons. Those particles, born high in Earth's atmosphere, hurtled toward the surface and burrowed through the pyramid. Some of the particles imprinted hints of what they encountered on sensitive detectors in and around the pyramid. The particles' paths revealed the surprising presence of the hidden chamber, announced in 2017 (SN: 11/25/17, *p.* 6).

That stunning discovery sparked plans among physicists to use muons to explore other archaeological structures. And some researchers are using the technique, called muography, to map out volcanoes' plumbing. "You can see inside the volcano, really," says geophysicist Giovanni Leone of Universidad de Atacama in Copiapó, Chile. That internal view could give scientists more information about how and when a volcano is likely to erupt.

HIP INSTITUTE

Muons are everywhere on Earth's surface. They're produced when high-energy particles from space, known as cosmic rays, crash into Earth's atmosphere. Muons continuously shower down through the atmosphere at various angles. When they reach Earth's surface, the particles tickle the insides of large structures like pyramids. They penetrate smaller stuff too: Your thumbnail is pierced by a muon about once a minute. Measuring how many of the particles are absorbed as they pass through a structure can reveal the density of an object, and expose any hidden gaps within.

The technique is reminiscent of taking an enormous X-ray image, says Mariaelena D'Errico, a particle physicist at the National Institute for Nuclear Physics in Naples, Italy, who studies Mount Vesuvius with muons. But "instead of X-rays, we use … a natural source of particles," the Earth's very own, never-ending supply of muons.

Physicists have typically studied cosmic rays to better understand the universe from whence they came. But muography turns this tradition on its head, using these cosmic particles to learn more about previously unknowable parts of our world. For the most part, says particle physicist Hiroyuki Tanaka of the University of Tokyo, "particles arriving from the universe have not been applied to our regular lives." Tanaka and others are trying to change that.

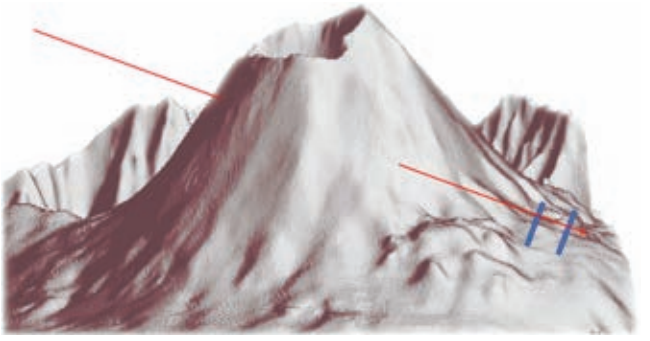
No particle like it

Awkward cousins of electrons, muons may seem like an unnecessary oddity of physics. When the particle's identity was first revealed, physicists wondered why the strange particle existed at all. While electrons play a crucial role in atoms, the heavier muons serve no such purpose.

But muons turn out to be ideal for making images of the interiors of large objects. A muon's mass is about 207 times as large as an electron's. That extra bulk means muons can traverse hundreds of meters of rock or more. The difference between an electron and a muon passing through matter is like the difference between a bullet and a cannonball, says particle physicist Cristina Cârloganu. A wall may stop a bullet, while a cannonball passes through.

Muons are plentiful, so there's no need to create artificial beams of radiation, as required for taking X-ray images of broken bones in the doctor's office, for example. Muons "are for free," says Cârloganu, of CNRS and the National Institute of Nuclear and Particle Physics in Aubière, France.

Another crucial upside of muons: "They're also very easy to detect," says nuclear physicist Richard Kouzes of the Pacific Northwest National Laboratory in Richland, Wash. A simple detector made of strips of plastic and light sensors will do the trick. Other muon detectors require little more than a specialized version of photographic film. There's no other particle like it, Kouzes says.



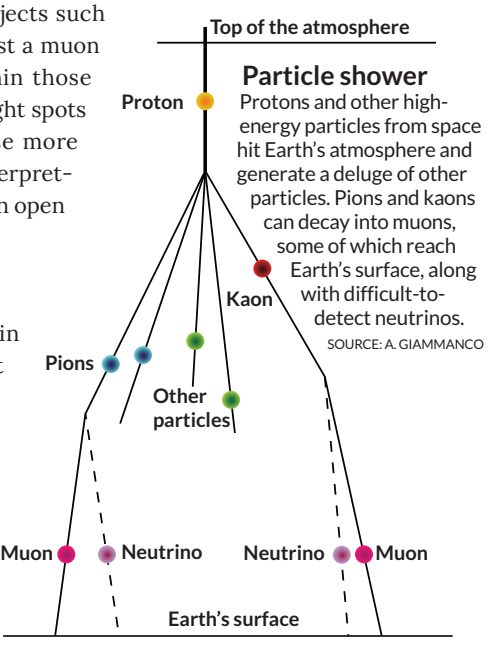
To visualize the inner workings of a volcano, scientists capture muons that pass through (one track illustrated in red) and onto particle detectors (blue). By determining where the muons pierced the volcano, scientists can map out the density of the material.

Muons have a negative electric charge, like an electron. Their antiparticles, antimuons, which also shower down on Earth, have a positive charge. Muon detectors capture tracks of both negatively and positively charged varieties. When these particles pass through material, they lose energy in various ways, for example, by colliding with electrons and knocking them loose from their atoms.

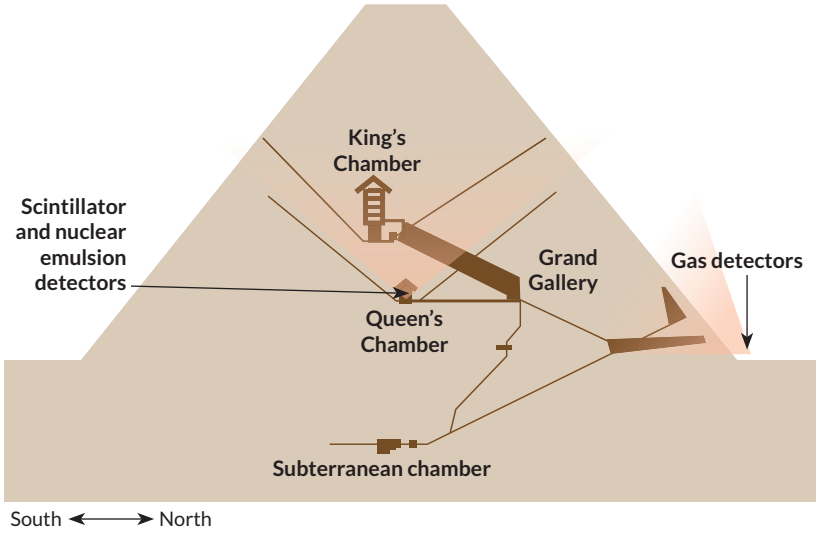
With that energy loss, muons slow down, sometimes enough to stop. The denser the material, the fewer muons will make it through to a detector placed underneath or to the side of the material. So large, dense objects such as volcanoes or pyramids cast a muon shadow. And any gaps within those structures will appear as bright spots within that shadow, because more muons can slip through. Interpreting such dappled shadows can open a vista into hidden worlds.

Probing pyramids

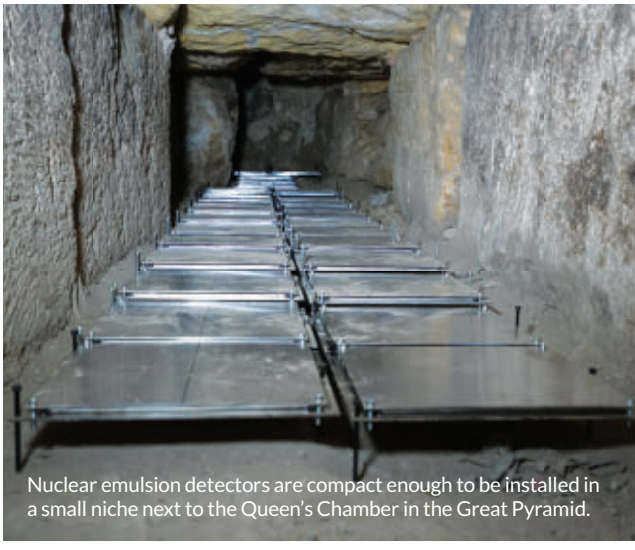
Muography proved itself in a pyramid. One of the first uses of the technique was in the 1960s, when physicist Luis Alvarez and colleagues looked for hidden chambers in Khafre's pyramid in Giza, a slightly smaller neighbor of the Great Pyramid. Detectors found no hint of



G. BONOMI ET AL./PROGRESS IN PARTICLE AND NUCLEAR PHYSICS 2020; T. TIBBITTS



A look inside
Scientists placed three different types of muon detectors in and around the Great Pyramid to map out the density of the structure and search for hidden chambers.
SOURCE: K. MORISHIMA *ET AL*/ *NATURE* 2017


Nuclear emulsion detectors are compact enough to be installed in a small niche next to the Queen's Chamber in the Great Pyramid.

unexpected rooms, but proved that the technique worked.

Still, the idea took time to take off, because muon detectors of the era tended to be bulky and worked best in well-controlled laboratory conditions. To spot the muons, Alvarez's team used detectors called spark chambers. Spark chambers are filled with gas and metal plates under high voltage, so that charged particles passing through create trails of sparks.

Now, thanks to advances in particle physics technologies, spark chambers have largely been replaced. "We can make very compact, very sturdy detectors," says nuclear physicist Edmundo Garcia-Solis of Chicago State University. Those detectors can be designed to work outside a carefully controlled lab.

One type of resilient detector is built with plastic containing a chemical called scintillator, which releases light when a muon or other charged particle passes through (SN *Online*: 8/5/21). The light is then captured and measured by electronics. Later this year, physicists will use these detectors to take another look at Khafre's pyramid, Kouzes and colleagues reported February 23 in the *Journal for Advanced Instrumentation in Science*. Compact enough to fit within two large carrying cases, the detector "can be carried into the pyramid and then operated with a laptop and that's all," Kouzes says.

A different but particularly low-maintenance type of detector, called a nuclear emulsion film, was crucial to uncovering the Great Pyramid's hidden void in 2017. Nuclear emulsions record particle tracks in a special type of photographic film. The detectors are left in place for a period of time, then brought back to a lab for analysis of the tracks imprinted in them.

Particle physicist Kunihiro Morishima of Nagoya University in Japan helped discover the secret chamber through work on an international project called ScanPyramids. "Nuclear emulsions are lightweight, compact and do not require a power supply," he explains. That meant that multiple detectors could be placed in prime viewing locations in one of the pyramid's rooms, the Queen's Chamber, and a small niche next to it. The detectors' measurements were supplemented with plastic scintillator detectors inside the Queen's Chamber, and gas-based detectors outside the pyramid.

Since the discovery of the void, Morishima and colleagues have been taking additional measurements to better sketch out its properties. The team placed emulsion detectors in 20 locations in the pyramid, as well as gas detectors in several different spots. Using their new array of instruments, the researchers determined that the void is over 40 meters long. Its purpose is still unknown.

A more extensive survey of the Great Pyramid, placing much larger detectors outside the pyramid, is being planned by another team of researchers. The detectors will be periodically moved to measure muons from multiple angles, the team reported March 6 in the *Journal for Advanced Instrumentation in Science*. The result, says coauthor and particle physicist Alan Bross of Fermilab in Batavia, Ill., will offer a 3-D view of what's inside.

Pyramids in other parts of the world are also getting closer scrutiny. Garcia-Solis and colleagues are now planning muography of the Maya pyramid known as El Castillo at Chichén Itzá in Mexico.

FROM LEFT: T. TIBBITTS; NAGOYA UNIV.

Morishima and colleagues, as well, are planning work on Maya pyramids.

Scientists hope such studies might reveal new chambers, or features not visible with other techniques for peering inside of objects. Ultrasound, ground-penetrating radar or X-rays, for example, can only penetrate a short distance from the surface, Bross explains. Muons, on the other hand, give an in-depth picture. For studying pyramids, Bross says, "muons really are ideal."

Peering inside a volcano

Vesuvius is a known menace in Naples and the surrounding municipalities that snuggle up against the volcano's flanks. Infamous for destroying the ancient city of Pompeii in A.D. 79, the volcano has been quiescent since 1944, when a major eruption destroyed several nearby villages (*SN: 2/29/20, p. 5*). But if it erupted, it would endanger the lives of roughly 600,000 people who live closest to it, and many others in the vicinity.

"Vesuvius always scared me," D'Errico says. "I was born and I live under this volcano." Now, as part of the Muon Radiography of Vesuvius experiment, or MURAVES, she seeks to better understand the volcano and its dangers.

Using muon detectors 1.5 kilometers from the volcano's crater, the team is mapping out muon densities—and thus rock densities—at the top of Vesuvius' cone. In a paper posted February 24 at arXiv.org, the researchers presented preliminary hints of density differences between the volcano's northwestern and southeastern halves. MURAVES is still collecting data; future observations should help scientists understand finer details of the volcano's internal structure, which is thought to be layered due to repeated eruptions.

Information about a volcano's structure can help scientists predict what hazards to expect in an eventual eruption, such as where landslides might occur. And that could help scientists know what steps to take to reduce risks to people living nearby, says Cârloganu, who studied the dormant volcano Puy de Dôme near Clermont-Ferrand, France, with muography and is now working to image the aptly named island of Vulcano in Italy.

When Mount St. Helens in Washington erupted in 1980, for example, an entire flank of the volcano collapsed. The disaster killed 57 people and caused widespread damage. Knowing where a volcano's structural weaknesses lie could help scientists better predict how an eruption might play out, and what areas sit inside the danger zone, Cârloganu says.

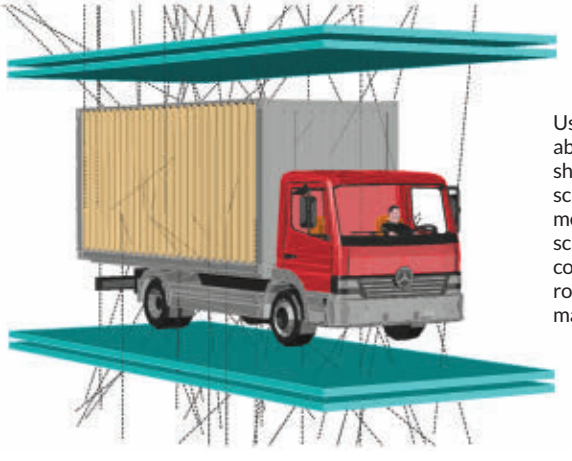
Contraband revealed

Superman's X-ray vision was impressive. But some scientists might prefer muon vision. For example, muons could help officials peer inside closed shipping containers "to see if there is something suspicious inside," says particle physicist Andrea Giammanco of the Université Catholique de Louvain in Belgium. A European Union–funded project called Silent Border aims to develop a method to uncover dangerous contraband at customs checkpoints without having to physically open and inspect every container that passes through.

The key to this technique is measuring how muons scatter. When muons pass through a material, some are absorbed and some scatter, changing direction. Using detectors above and below an object, scientists can observe how a muon's trajectory changes as it passes through the object. Since muons tend to scatter away at larger angles in materials made of heavier elements, this technique can reveal substances such as uranium.

Muon scattering measurements could also be useful for peering into nuclear waste storage containers to verify what's inside, ruling out any theft of dangerous substances or other funny business.

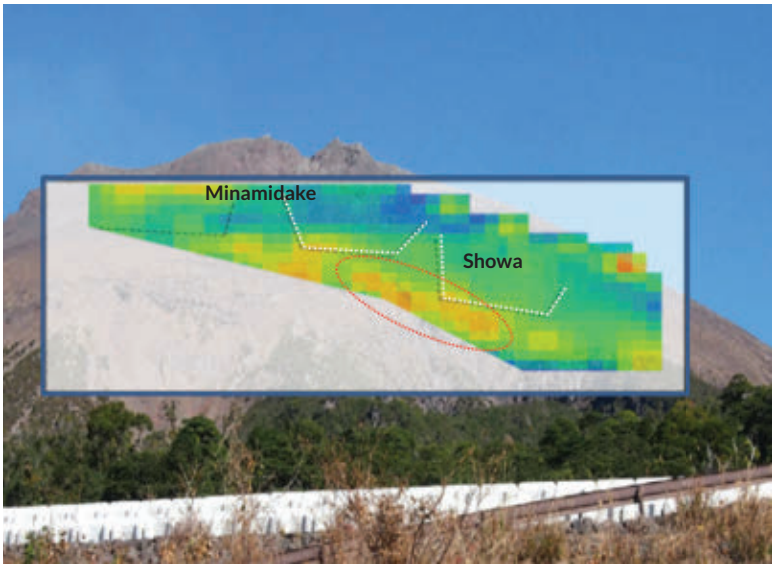
Separately, Giammanco and colleagues are studying muon scattering for measuring strong magnetic fields, which could be useful for monitoring certain technologies that rely on that magnetic might. That includes experimental nuclear fusion reactors that scientists hope could one day power the planet (*SN: 2/6/16, p. 18*). — *Emily Conover*



Using detectors above and below a shipping container, scientists could measure how muons scatter inside the container, as a way to root out dangerous materials.

L. BONECHI, R. D'ALESSANDRO AND A. GIAMMANCO/*REVIEWS IN PHYSICS* 2020

With Naples and several other communities in Italy dangerously close to Mount Vesuvius, scientists are using muography to try to predict the volcano's hazards.



Muography revealed a newly formed plug of denser material (red oval) below the Showa crater of the Sakurajima volcano in Japan. This muography image, made with data taken in 2018 and overlaid on a photo of the volcano, hinted at why the crater stopped erupting. Redder colors indicate denser material, while blue is less dense.

Cârloganu thinks muons will be useful for pointing out structural weaknesses, but not for giving a warning when the volcano is going to blow. Other researchers are more optimistic about muons' capability for giving timely forewarnings.

Muography is ripe for inclusion in volcano early-warning systems, Leone, Tanaka and colleagues wrote last November in *Proceedings of the Royal Society A*. But more work needs to be done to integrate muography with other established methods that help warn of an upcoming eruption, Leone says. These methods include seismic measurements, as well as observations of ground deformation and volcanic gas emissions.

Tanaka and colleagues are studying Sakurajima, one of the most active volcanoes in the world, near Kagoshima, Japan. One of the volcano's craters, the Showa crater, erupted frequently until 2017 when the activity abruptly shifted to another crater, Minamidake. Comparing muography data taken before and after this shift revealed that a new, dense region had formed below the Showa crater, Tanaka and colleagues reported in 2019 in *Geophysical Research Letters*. That hints at the reason Showa's eruptions stopped: It was clogged with a dense plug of solidified magma, Tanaka says.

These results suggest that scientists can use muography to help predict volcanic eruptions, Tanaka says. In fact, using deep learning techniques on the muography data from Sakurajima, Tanaka and colleagues reported in *Scientific Reports* in 2020 that they were able to predict whether the volcano would erupt the next day, by analyzing the previous week's data. The technique correctly predicted eruption days of the volcano more than 72 percent of the time, and correctly predicted non-eruption days more than 85 percent of the time.

Just as the discovery of X-rays unveiled a whole new way of seeing the world, harnessing muons could change our perspective on our surroundings. Attitudes toward a particle once thought to be unnecessary — unwanted and unloved by physicists — have been transformed. One day, perhaps, muons could save lives. ■

Explore more

- International Muography Research Organization, University of Tokyo: www.muographix.u-tokyo.ac.jp
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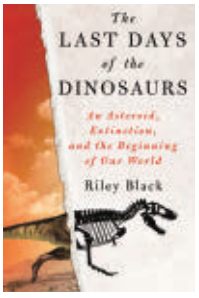

The Last Days of the Dinosaurs
Riley Black
ST. MARTIN'S PRESS, $28.99

BOOKSHELF

How life recovered after 'Earth's worst day'

Some 66 million years ago, give or take several millennia, a 10-kilometer-wide asteroid slammed into our planet. The impact blasted out an enormous crater and heaved large amounts of material into the atmosphere. Some of the sulfur-rich debris poisoned the sky, unleashing downpours of acid rain. Heat generated by ejecta falling back to Earth ignited wildfires worldwide that blazed for months, if not years. In the wake of the event, as many as 75 percent of all species were wiped out.

In *The Last Days of the Dinosaurs*, science writer Riley Black chronicles both the pre-apocalyptic idyll and the worldwide devastation that resulted from what some scientists have dubbed "Earth's worst day." The book is a compelling amalgamation of both new and old scientific information (and some science-based speculation).

Black begins her tale by exploring what happened in the Hell Creek area of today's Montana, whose rocks offer what is perhaps the best record of a dinosaur habitat. This ancient ecosystem and others worldwide included far more than apex predators, such as *Tyrannosaurus rex*, and their prey, of course; they also hosted a wealth of creatures, including lice and other parasites.

These ecosystems drastically changed once the space rock hit. Larger dinosaurs, as well as any smaller creatures unable to shelter in burrows, for example, couldn't escape the destruction (SN: 3/26/22, p. 8).

Despite the title, the largest part of Black's book recounts how life rebounded in the 1 million years after the impact. Forest floors served as natural seed banks to feed surviving insects, birds and small mammals. These seeds, some of which had previously evolved to withstand wildfires, were also the sources of forests that grew back. Those initial forests were stubby and dominated by ferns for years. Some ecosystems — especially freshwater lakes and rivers whose waters were chemically buffered from acid rain by dissolved carbonates derived from limestones — emerged relatively unscathed and so species persisted there.

Evolution is usually driven by gradual change, Black notes. But the dinosaur-killing impact was so abrupt and caused such extreme environmental changes that most species couldn't adapt. In fact, she notes, animals and plants that weren't already preadapted to the new state of affairs rapidly succumbed and thus left no descendants.

Yet in devastation lay opportunities: Ecological roles that had been occupied by dinosaurs for at least 100 million years were suddenly available, setting the stage for the slow but steady rise of mammals and the world we inhabit today (SN: 2/4/17, p. 22).

While engaging and approachable, *The Last Days of the Dinosaurs* is scrupulously rooted in information gathered by paleontologists, geologists, astronomers, physicists and ecologists. In vignettes at the end of each chapter, Black explores what was unfolding at locales far from Hell Creek. In an extensive appendix, she painstakingly helps readers sort through what's fact and what's speculation in those scenes. For example, the behaviors of burrowing mammals during the impact and its aftermath are presumed to be similar to those inferred from the fossils of similarly sized mammals that lived a few million years earlier. — *Sid Perkins*

The demise of nonavian dinosaurs 66 million years ago dramatically reshaped ecosystems as other animals, such as small mammals (illustrated), took over.

MARK GARLICK/SCIENCE SOURCE

The U.S. Mint Just Struck Morgan Silver Dollars for the First Time in 100 Years!

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It's been more than 100 years since the last Morgan Silver Dollar was struck for circulation. With a well-earned reputation as the coin that helped build the Wild West, preferred by cowboys, ranchers, outlaws as the "hard currency" they wanted in their saddle bags, the Morgan is one of the most revered, most-collected vintage U.S. Silver Dollars ever.

Struck in 90% silver from 1878 to 1904, then again in 1921, these silver dollars came to be known by the name of their designer, George T. Morgan. They were also nicknamed "cartwheels" because of their large weight and size.

Celebrating the 100th Anniversary with Legal Tender Morgans

Honoring the 100th anniversary of the last year the Morgan Silver Dollar was minted, the U.S. Mint struck five different versions in 2021, paying tribute to each of the mints that struck the coin. The coins here honor the historic New Orleans Mint, a U.S. Mint branch from 1838–1861 and again from 1879–1909. These coins, featuring an "O" privy mark, a small differentiating mark, were struck in Philadelphia since the New Orleans Mint no longer exists. These beautiful coins are different than the originals for two reasons. First, they're struck in 99.9% fine silver instead of the 90% silver/10% copper of the originals. And second, these Morgans were struck using modern technology, serving to highlight the details of the iconic design even more than the originals.

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BEST AND BRIGHTEST

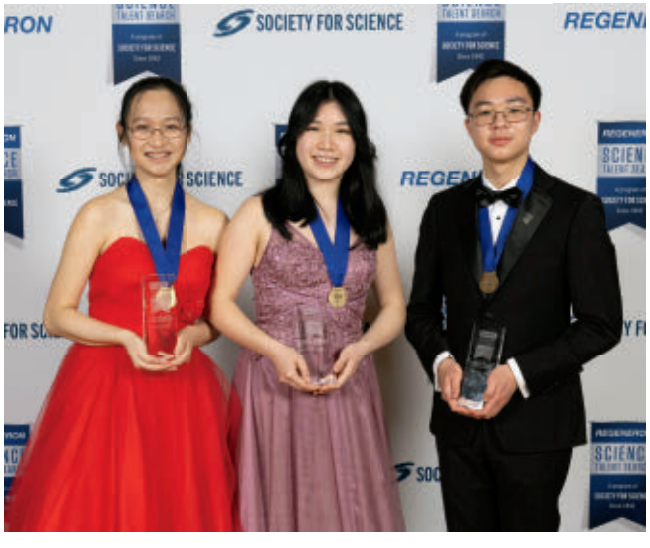
Congratulations to this year's Regeneron Science Talent Search top winners

On March 15, the Society for Science and Regeneron announced the top winners of the Regeneron Science Talent Search, the most prestigious science and math competition in the United States for high school seniors. Hosted in person in Washington, D.C., for the first time since 2019, the competition awarded more than $1.8 million to this year's finalists.

Christine Ye (pictured above), 18, of Sammamish, Wash., won the top award of $250,000 for analyzing the gravitational waves emitted from collisions between neutron stars and black holes and developed a novel method for modeling rapidly rotating neutron stars.

Victor Cai, 18, of Orefield, Pa., won second place and $175,000 for creating a low-cost, short-range, distance-sensing radar that is accurate to within 12 centimeters. The radar also operates at a narrower bandwidth than traditional radars.

Amber Luo, 18, of Stony Brook, N.Y., won third place and $150,000 for studying the process of protein expression and how ribosomes move along a cell's mRNA transcripts to produce proteins.



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TOP THREE REGENERON SCIENCE TALENT SEARCH WINNERS
Amber Luo, Christine Ye and Victor Cai (from left to right) are the top three winners of the 2022 Regeneron Science Talent Search. They were selected based on their projects' scientific rigor, their exceptional problem-solving abilities and their potential to become scientific leaders.

MARCH 12, 2022

SOCIAL MEDIA

Dino in the dumps

Fossilized lesions in the vertebrae of a 150-million-year-old juvenile sauropod (illustrated) may record the oldest known respiratory infection in a dinosaur, **Sid Perkins** reported in "Fossils reveal a case of the dino sniffles" (*SN: 3/12/22, p. 10*). The story inspired a chorus of puns on Twitter, including one by user **@agent_outside**: "Some 'Jurassick' facts for you…"

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Turning tides

*Gravitational interactions with nearby planets and stars can hurl giant exoplanets into orbits that bring them close to their suns, **Ken Croswell** reported in "Hot Jupiters may be kicked into place" (SN: 3/12/22, p. 13).*

Croswell wrote that a hot Jupiter gets put on a highly elliptical and inclined orbit that brings the planet close to its star. Over time, the star's gravity makes the planet's orbit smaller and rounder. Some readers wondered if atmospheric friction, not gravity, plays the main role in the orbit's transformation.

"Friction isn't what causes a close-in planet's orbit to change," **Croswell** says. Instead, gravity between the star and planet raises strong tides — similar to those formed from the gravitational interactions between Earth and its moon. It is those tides that rob the world of orbital energy, gradually shrinking and rounding the orbit, he says. "This process goes by various names, such as 'tidal circularization' and 'tidal damping.'"

It's shear science

*Computer simulations suggest that weird "superionic" matter, which behaves like a mash-up of solid and liquid, could explain the oddities of Earth's center, **Emily Conover** reported in "Earth's inner core may be 'superionic'" (SN: 3/12/22, p. 12).*

One simulation showed that a superionic inner core slows shear waves, seismic waves that jiggle the Earth perpendicular to their direction of travel, **Conover** wrote. The phenomenon may explain the unexpectedly low shear wave velocities previously measured in the inner core. Reader **Jeff Fisher** asked how shear waves could occur in the inner core when such waves aren't able to pass through liquids like Earth's outer core.

It's true that shear waves, also known as secondary or S waves, cannot travel through the liquid outer core, **Conover** says. But primary waves, or P waves, which compress and expand the Earth in a direction parallel to their travel, *can*. "When a P wave goes through the outer core and meets the inner core, it can create an S wave that will travel through the inner core," **Conover** says. "When that S wave meets the outer core again, it will create a P wave that will travel through the outer core and onward. Scientists can measure that P wave and draw conclusions about the S wave that traveled through the inner core."

A century of climate

*The last century and a half of climate science has strengthened our understanding of the roots and impacts of human-caused climate change, **Alexandra Witze** reported in "A planetary crisis" (SN: 3/12/22, p. 16).*

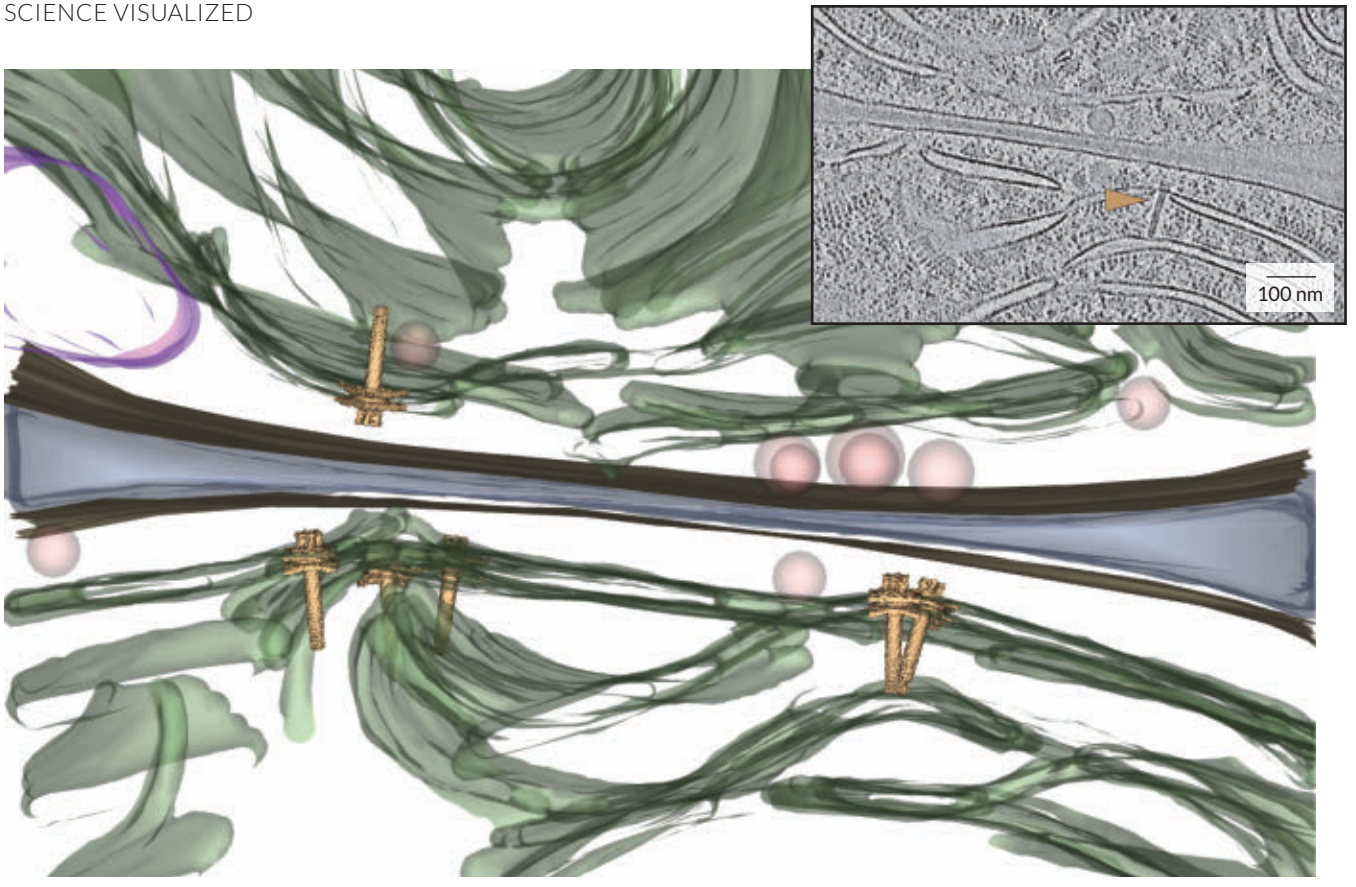
Reader **Connie Hellyer** lauded **Witze's** coverage as "masterful in its scope and clarity." The article "should be required reading for policy makers, voters and all confused by the shards of sometimes conflicting and out-of-context factoids coming from every direction."

Update

"A high-profile transplant milestone" described the first transplant of a genetically modified pig heart into a human (*SN: 3/12/22, p. 26*). David Bennett, the 57-year-old man who received the organ, died on March 8, two months after the surgery.

Correction

In "James Webb telescope gets in position" (*SN: 2/26/22, p. 10*), the definition of L2 wasn't quite right. L2, the telescope's home, is a relatively stable region where the sun's and Earth's gravity combine to provide the centripetal force needed to keep a smaller object on a curved path.



Zooming in on bacteria weaponry

Some bacteria carry tiny syringes filled with chemicals that may thin out competitors or incapacitate predators. Now, in two types of bacteria, researchers have gotten up-close views of these syringes — and found them in some unusual places.

Gregor Weiss, a cellular structural biologist at ETH Zurich, and colleagues examined bacterial syringes using cryo-electron microscopy, in which cells are flash frozen to capture cellular structures as they look in nature (*SN: 8/5/17, p. 12*). Previously, researchers have found syringes anchored in the outer membranes of bacteria. Some species shoot their injectors' payload into cells they bump into; others squirt their contents into the environment.

But in a cyanobacteria called *Anabaena*, the syringes are inside the cell, nestled in structures where the bacteria carry out photosynthesis, Weiss and colleagues report in the March *Nature Microbiology*. One such syringe can be seen in the image inset above (arrow); the above illustration shows several syringes (tan) piercing internal membranes (green). Buried inside the cells, "it's hard to imagine how [the syringes] could get out and interact with the target organism," Weiss says.

Each syringe consists of a molecular sheath stretched over an inner tube filled with chemicals, the team reports. Some signal, such as stress, causes a ring at the syringe's base (near the top of the visualization at right, where colors denote different proteins) to open, and the inner tube shoots out.

An *Anabaena* cell may use its syringes against itself to trigger cell death when under stress, the team suggests. In experiments, ultraviolet light or high salt levels triggered some syringes to dump their payload. That led to the death of some *Anabaena* cells in the long chains that the bacteria grow in, forming hollow "ghost cells." The ghost cells — which shed their outer wall and membrane, exposing any remaining yet-to-be-fired syringes to the outside world — may act like Trojan horses, delivering their deadly payload to predators or competitors, the team says.

In *Algoriphagus machipongonensis*, a type of marine bacteria, the syringes have a different architecture and float unmoored, molecular biologist Charles Ericson, also of ETH Zurich, and colleagues report in the same issue of *Nature Microbiology*. The injectors were also found in the liquid in which the bacteria were grown, but how the syringes get out of the cell is a mystery. Perhaps they are released when the bacteria die or, in the wild, get eaten by a predator, Ericson says.

Comparing syringes from various species, the two teams identified structures that are slightly different from species to species. Learning how those modifications change the way the injectors work may help scientists devise their own nanoinjectors that, for example, direct antibiotics against troublesome bacteria. "Now we have the general blueprint," Ericson says. "Can we re-engineer it?" — *Tina Hesman Saey*

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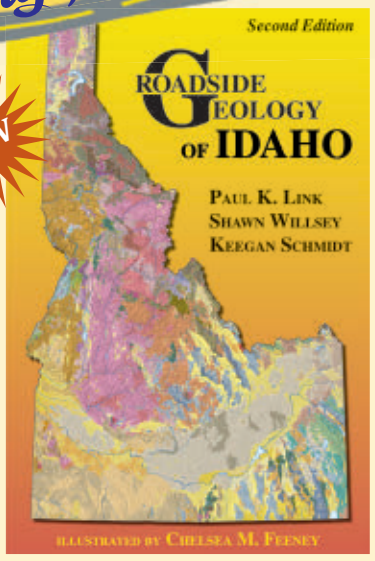

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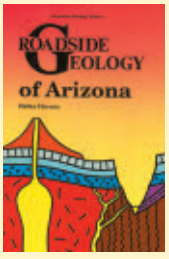

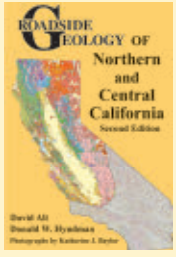

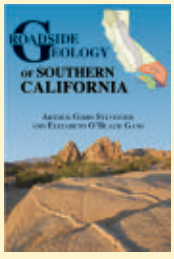

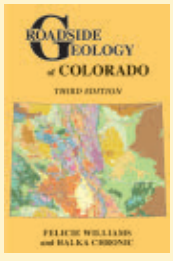

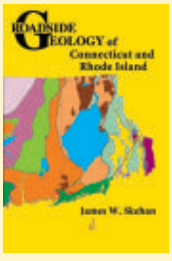

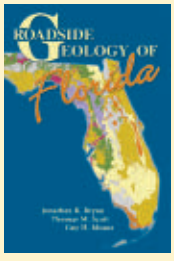

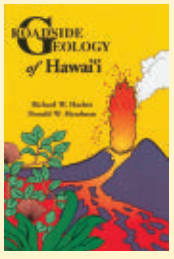

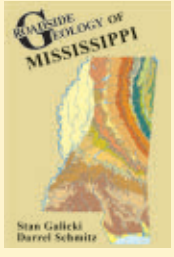

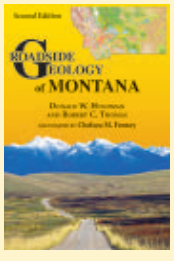

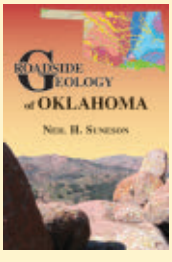

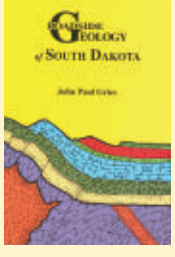

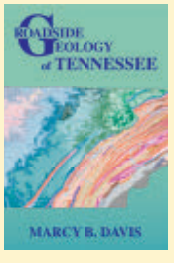

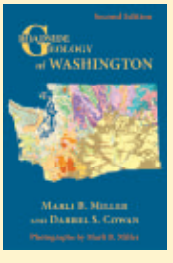

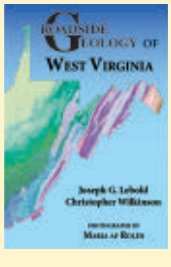

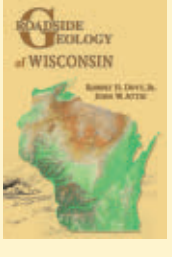

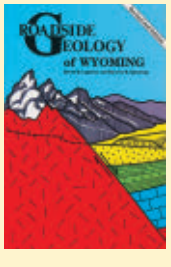

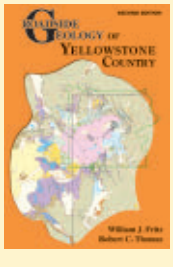

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