

**SPECIAL
ISSUE**

THE STATE OF SCIENCE 2024

JANUARY/FEBRUARY 2024

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SCIENCE THAT MATTERS

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RETURN TO THE MOON

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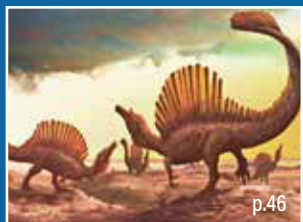


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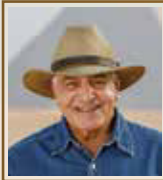
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Over 5,000 new abyssal species were recently announced, but these creatures and more are threatened by proposed deep-sea mining. p. 40

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AI, Artemis, & More

 **WELCOME ONCE** again, friends, to *Discover's* annual State of Science issue, where our editors and writers bring you the biggest and most intriguing science stories of the year.

While every story here deserves your attention, a few stood out for me as we were preparing this issue. Although it's still early days, I'm excited for the promise of the Artemis program (page 48). I grew up at the tail end of the Space Race, so I confess that I'm hopelessly besotted with the idea of humankind's return to the moon. My excitement is driven by more than nostalgia, though, just as NASA and its various Artemis partners are driven by so much more than the desire to repeat the triumphs of the Apollo landings of the 1960s and '70s. If the missions proceed as planned, I'm eager to see new science, new discoveries, and new lunar firsts, including the

What was the biggest science story of the year for you? Email me at editorial@discovermagazine.com and let me know.

Meanwhile, back on Earth, artificial intelligence definitely had more than a moment this year. You'll see that reflected in our coverage, chiefly with writer Stephen Ornes' overview of the year in AI (page 64). In the popular consciousness, much has been made of the potential and pitfalls of using (or abusing) AI in various fields. New



THE ARTEMIS CREW will take humanity back to the moon. Learn more about the crew and upcoming missions on page 48.

advances in science and technology do tend to raise various concerns and fears.

I try to be an optimist, though, and remind myself that, as a tool used well and wisely, AI has the power to change lives for the better. Perhaps nowhere in this issue is that better reflected than in Avery Hurt's story on page 62, which highlights an astounding merger of medicine and technology. Employing a "digital bridge" — an interface that uses AI to translate brain signals into electrical impulses — researchers enabled a man to stand and even walk again despite a major spinal-cord injury.

And those are just two of the dozens of stories you'll find in this issue. I hope you enjoy them all, and are just as fascinated by the current state of science as I am.



Stephen C. George, Editorial Director

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How to Win at Love

A classic tennis bracelet serves up over 10 carats of sparkle for a guaranteed win

It was the jewelry piece that made the world stop and take notice. In the middle of a long volley during the big American tennis tournament, the chic blonde athlete had to stop play because her delicate diamond bracelet had broken and she had to find it. The tennis star recovered her beloved bracelet, but the world would never be the same.

From that moment on, the tennis bracelet has been on the lips and on the wrists of women in the know. Once called eternity bracelets, these bands of diamonds were known from then on as tennis bracelets, and remain *the* hot ticket item with jewelers.

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REFRIGERATION INNOVATION

("Cold Comfort," Sep/Oct 2023)

Thank you for Amy Brady's excellent article about John Gorrie and building refrigeration. A shout-out is also needed to Frederick McKinley Jones (May 17, 1893–Feb. 21, 1961), an African American inventor. Jones innovated mobile refrigeration technology, which allowed for the transportation of food and blood during World War II. He received 61 patents, 40 for refrigeration technology. He also co-founded Thermo King; I started my engineering career at there in 1972 and worked with many brilliant managers, engineers, and workers.

Jim Holstein



(TELE)MEDICAL MYSTERIES

In each issue, your Vital Signs column focuses on patients [with medical mysteries who are] fortunate enough to have face-to-face medical consultation in which the doctor diagnoses based on visual examination. What's a person to do when their health plan consistently provides only email and video consultation?

Patrick Lofft

DR. TONY DAJER, A FREQUENT VITAL SIGNS CONTRIBUTOR, RESPONDS:

Post-pandemic, the U.S. health care system is still digging out from a backlog of unmet primary care needs. I added telemedicine to my practice in 2020; it is surprisingly effective for a range of acute and health-maintenance issues. Telemedicine doctors can order labs and X-rays, review results, and steer people to the correct facility for more serious illnesses. It is well-suited for continuity of care. You always have the right to appeal to your insurance carrier for the care you think is best. However, having gained critical experience during the pandemic, telemedicine has come into its own.

THEATER OF THE MIND

("Mind Games," Jul/Aug 2023)

I was very excited to read the part of the article about Adele Diamond and executive functions, but I was surprised that the author did not share all of the activities that Diamond found increased executive functions. Ultimately, she discovered that there were four: taekwondo and tai chi were both mentioned in the article, but theater training and learning through the arts were not. Yes, the author did include a section that acknowledged music education for children, but she did not include the rest of the arts, which also work to develop executive functions (EFs). Instead, the author of the article talked in general about hobbies like gardening, cooking, or volunteering. Those were not cited by Diamond as developing EFs.

Theater works on many different levels of EFs, from working memory to sequencing to cognitive flexibility (especially during improvisation) to emotional regulation to behavioral regulation. I feel like people are afraid to bring the arts — particularly theater — into science discussions because they think the arts aren't "scientific," or they think of the arts as "unnecessary frills." Yet the arts have been studied scientifically and have resulted in findings of improved

cognitive functioning. Currently, there are a number of ongoing studies about how the arts and the brain interact, and a number of books have recently come out about arts and the brain.

Sally Bailey
 Director, Drama Therapy Program
 Kansas State University

STORY EDITOR ALEX ORLANDO

RESPONDS: Thanks for your interest, Sally. You raise an excellent point that "Mind Games" doesn't explore all the activities found to increase EFs, including theater and the arts, in detail. Regarding the specific study we cite in the story —

a 2020 review by Diamond and Daphne S. Ling that looked at 179 studies — the authors indeed specify that theater might be an excellent activity for improving EFs, as it has been found to have a positive impact on psychological well-being, while also giving participants practice

in processing things deeply and staying in the present moment. This takeaway in particular stuck with me: "Further study of the potential EF benefits of theater with children, young adults, and elders would be most welcome, especially when training in generalizing the cognitive skills learned in theater to other contexts is provided."



THE LATEST NEWS AND NOTES

NEIL DEGRASSE TYSON Q&A • WHY WE FALL FOR SUNK COSTS • DEHORNING RHINOS
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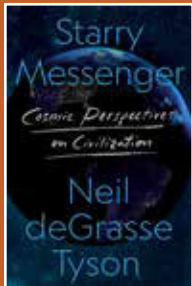


HIGH-FLYING LIZARD

Look, up in the sky! It's a bird!
It's a plane! It's a ... gecko?
Meet *Gekko mizoramensis*, the newest member of the Southeast Asian parachute gecko family, discovered in India and first described by scientists last May. Like its cousins, *G. mizoramensis*

is built for gliding, with skin flaps along its body to keep it aloft and a rudderlike tail to help the nocturnal aerial adventurer gracefully soar from tree to tree. Hidden in plain sight, this new gecko is a cryptic species — meaning that it looks incredibly similar to

other species, yet has different enough DNA to be considered distinct. The discovery points to a trove of biodiversity waiting to be cataloged by researchers in the region. — ANNA NORDSETH; IMAGE BY LAL MUANSANGA



TYSON'S 2022 book applies scientific reasoning to contemporary issues like race and politics.

THE ASTROPHYSICIST AND SCIENCE COMMUNICATOR REFLECTS ON HIS FAVORITE SCI-FI FLICK, HIS FIRST MEETING WITH CARL SAGAN, AND THE FUTURE OF SPACE TRAVEL.



NEIL DEGRASSE TYSON'S COSMIC RIDE



STARING UP at the moon through a pair of binoculars as a young child, Neil deGrasse Tyson found himself inspired by the cosmos that unfolded above him. “If you look at the moon through good binoculars or even through a simple telescope, oh my gosh,” says Tyson. “It’s not just this thing

in the sky. It’s a world with mountains and valleys and craters and shadows and gullies. And, all of a sudden,

the moon goes from this object that you ignored most of your life [to] a place [that makes you say], ‘Hey,

I want to visit that. I want to know more about what’s in the universe.’”

Later, at age 9, Tyson visited his local planetarium for the first time, another cosmic encounter that would send ripples far into the future. By age 11, he already knew that he wanted to become an astrophysicist.

Today, Tyson is one of the most renowned astrophysicists — and science communicators — in the world. His recent bestselling book, *Starry Messenger: Cosmic Perspectives on Civilization* (Henry Holt, 2022), analyzes real-world issues like race, gender, and politics through a scientific

lens. *Discover* caught up with Tyson to talk about bringing a cosmic perspective to contemporary problems, his biggest sci-fi influences, and what he learned from Carl Sagan.

Q Your role as a science communicator often touches on the intersection of science and science fiction. What sci-fi stories, either in books or movies or TV, had an impact on you growing up?

NDT: I was much more of a moviegoer. So many of my colleagues have these huge sci-fi libraries and they can point to bits and pieces and storylines that influence them. For me, it was all through movies. I'm old enough to remember *2001: A Space Odyssey* in its first run.

And to see it, to hear it, to feel it, that was when many of us said, 'Yeah! Space, of course. That's tomorrow. Let's do it. Let's do it now.' And that movie came out a year before we landed on the moon. Movies can have a way of setting a tone for subsequent conversations, subsequent dreams, even subsequent goals of a nation. That one, above all else, put my mind, body, and soul into the future of space.

Q Speaking of space, how excited were you about the announcement of the crew for NASA's Artemis II mission to the moon?

NDT: There's a limit to how excited I can get, given

that we should have been doing this 45 years ago. We were on the moon through 1972. And [then] we're not on the moon for 50 years, and now you want me to get excited?

So, I'm not excited. It's about damn time. Does that count as being excited? That's more happy frustration. How about that? I'm happily frustrated that we eventually are going back.

Q What do you think the near future of space travel would look like if more people invested in it or were compelled to go to outer space?

NDT: Well, not just people, but governments. People and companies generally don't do things that are expensive and dangerous with no return on the investment. But a government can do it; a government will do it for many reasons. They could do it for geopolitical reasons, for long-term security reasons, they could do it for long-term economic reasons. Countries can do that and have the motive to do it and the timeline to do it.

I would say to open our backyard — the solar system — to space exploration will require some combination of private enterprise and national motivation.

Q We're really big fans of Carl Sagan at *Discover*. What are some of the most insightful things you learned from him?

NDT: It's a great question

and oddly I've never been asked that. One of [the most] influential moments was my first time meeting him. He had written a letter to me to invite me to tour Cornell University to decide whether I wanted to attend. I did not know that the admissions office had sent my application to him for his comment, because my application was dripping with the universe.

And he hadn't done *Cosmos* yet, but he was already famous. He had a bestselling book and been on *The Tonight Show* — then a highly criticized step for a scientist, by the way. But why is he spending this much time with me? We just met. I'm 17. He's a full-grown, famous person. And I swore, after that encounter, that on any future occasion [where I had] to advise or to offer helpful comments to a student, that no matter how famous I became, I would give time to the student the way Carl Sagan gave time to me.

Q In your 2022 book, *Starry Messenger*, why did you feel that it was important to view real-world issues, like veganism, through a scientific lens?

NDT: Well, nobody else was. And I see it that way every day. I see people say things, do things, arrive at conclusions, dig their heels in with an opinion, and half the time I'm like the dog listening to a high-pitch whistle. I'm just like, huh? You really think that?

[Say] you're vegetarian because you don't want to kill animals. So, you trap mice in a humane mouse trap. That's very noble of you, but then you release it into the wild, where it'll be eaten within months by owls and all manner of woodland predators. You just cut short the life expectancy of that mouse. You know what the best thing to do is for that mouse? Leave it in your basement; it will live six years in the comfort of your basement.

"To open our backyard — the solar system — to space exploration will require some combination of private enterprise and national motivation."

When I see people making strongly held decisions, I just say, 'Why?'

It's not a book of opinions. It's a book of observations of your opinions that you might be holding strongly and maybe you didn't really think it through as deeply as you could have or should have. That's what the book is, and every one of those topics lends itself to that kind of analysis. It's an offering to whoever wants to see the world a little differently. — MONICA CULL

This interview has been edited for length and clarity.



HOW THE SUNK COST FALLACY IMPACTS YOUR RELATIONSHIPS

WHETHER YOU'VE INVESTED MONEY, TIME, OR EFFORT, LEARN HOW TO RECOGNIZE AND OVERCOME THIS INSIDIOUS PSYCHOLOGICAL PHENOMENON.

IN ECONOMICS, the sunk cost fallacy — also called the sunk cost effect — is notorious. It occurs whenever we double down on poor financial decisions based on past investments that can't be recouped.

Christopher Olivola, an associate professor of marketing at the Tepper School of Business at Carnegie Mellon University, points to a few ways that

the sunk cost fallacy is tied to your wallet. You might sit through the entirety of a movie that you hated from the beginning, for instance, if only to justify the cost of the ticket. Similarly, you might continue hitting the gym, even after sustaining a painful injury, if your expensive membership is nonrefundable.

“But what’s happening in all these situations is you’re not really getting

that money, or that time, or that effort, or whatever it is you invested, back,” says Olivola. “That’s part of why it’s irrational.”

The sunk cost fallacy can play out on a larger scale, too. Olivola points to the phenomenon as a contributing factor in the length of the U.S. involvement in the Vietnam War. As fatalities mounted, he says, so too did the fear of devaluing those lost lives by pulling out of the war without a victory. Other researchers have tied the same faulty reasoning to ongoing investments in fossil fuels, despite bleak climate projections and increasingly available energy alternatives.

And the phenomenon isn’t confined only to the realm of business or world affairs — it often rears its ugly head in our relationships, too.

RESEARCHERS from the University of Minho in Portugal offer a reason why we stay in unhappy relationships, according to a study published in *Current Psychology* in 2018. Spoiler alert: The sunk cost effect may be to blame.

In one experiment, the research team presented more than 900 participants with a far-from-perfect relationship scenario. When the participants were given a chance to leave this hypothetical relationship, their responses suggested that we’re more likely to stay in such situations when we’ve previously invested significant money and effort.

A follow-up experiment, in which a smaller number of participants were asked to choose how much time they would be prepared to invest in an unhappy marriage, revealed that we’re also willing to put more time in once time has already been invested. Participants were willing to stick with an unfulfilling relationship for nearly 600 days, in fact, so long as that relationship had already lasted for a decade or longer.

Research has shown that the sunk cost fallacy also sinks its claws into our non-romantic relationships — in the workplace, for example. Even if you no longer feel your job is serving you, you



might be more likely to stick around when you think about how long your boss spent training you, or when you consider any generous raises your employer handed out.

THE PSYCHOLOGY of the sunk cost fallacy is a robust phenomenon that's been studied time and time again. But researchers still haven't quite pinned down the reason humans keep falling for it. "There's a lot of different mechanisms that could be explaining it," says Olivola. "And maybe it has multiple mechanisms."

Based on his own research, Olivola tends to blame our desire to minimize waste. "We don't like to see ourselves as wasteful and we don't like to see other people as wasteful," he says.

Another possible reason? We tend to open up a mental "bank account" whenever we invest money, time, or effort into something, he says. Subsequently,

In certain circumstances, the sunk cost fallacy could help you achieve goals like becoming more fit or finishing a degree.

the only way we can then "close" this account is by getting our figurative money's worth.

In certain circumstances, the sunk cost fallacy could actually help you achieve major goals like becoming more fit or finishing a degree. But if you find yourself fixating on past decisions you can't change, the sunk cost fallacy is no longer beneficial.

How, then, do we overcome this bias? When it comes to honoring the effort, time, or money others have invested in us, Olivola says it's important to remember that our friends and family members don't actually *want* us to suffer at their expense. "I don't think you can argue that it's any more rational to honor another person's sunk costs," he says. "If you're suffering, then that's bad for two people: you and the people who care about you, right?"

Of course, don't feel too bad if you still find yourself struggling. Even for Olivola, who has spent more than two decades studying these sorts of things, the sunk cost phenomenon can still be irresistible. "Sometimes I realize I'm doing it, I realize that it's irrational, that it's a bad idea — and I still do it," he adds. "So, you know, if you can overcome it, you're better than me."
—MARISA SLOAN



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DEHORNING RHINOS may have impacts on the animals' behavior, according to a new study.



CAN CONSERVATIONISTS SAVE RHINOS BY DEHORNING THEM?

REMOVING THE VALUABLE HORNS OF RHINOS IN THE WILD CAN DISINCENTIVIZE POACHERS FROM KILLING THEM. BUT IT MAY CARRY AN ADDED RISK FOR THE ENDANGERED AFRICAN ANIMALS.



IF YOU ASK a kindergarten class to draw a rhinoceros, you'll get an amusing variety of artistic renditions. One feature, however, will likely remain constant: a majestic horn adorning its head, defining the rhino's distinct silhouette. Yet, in the wild, this iconic horn is disappearing — faster than the rhinos themselves, in some cases.

In the ongoing battle to protect endangered rhino populations from poaching, conservationists employ a controversial practice known as “dehorning.” This process removes the rhino's valuable horn, and with it much of poachers' incentive to hunt them.

Meticulous planning and careful execution go into dehorning to ensure a swift and safe procedure. Like a well-oiled machine, field rangers, veterinarians, researchers, helicopter pilots, and other experts coordinate to find and tranquilize the target animals. Once the rhino is asleep, the team covers its eyes and ears and cuts the horn with a chainsaw a few inches from the base.

“We get a lot of criticism for cutting with a chainsaw,” says Vanessa Duthé, a South African Ph.D. candidate at the University of Neuchâtel in Switzerland who specializes in black rhino conservation. “But it's the best way, the fastest way [to dehorn].”

Anecdotally, such dehorning has reduced the number of rhino killings in certain reserves, according to Duthé. But controversy still surrounds the practice and the potential consequences.

BLACK RHINOS, one of two African rhino species living today, are listed as critically endangered by the International Union for the Conservation of Nature (IUCN). These giants of the savanna have been decimated, poached for their horns since the 1800s. In the latter half of the 20th century, black rhino populations decreased by 96 percent. By 1993, only about 2,300 remained in the wild.

Today, rhino horns remain a sign of wealth and status in some parts of the world. They are also a highly controversial component in traditional Chinese medicine, despite a lack of evidence for any real medicinal properties. These activities have pushed demand for rhino horn to unsustainable levels and fostered a profitable black-market trade, with prices soaring up to \$65,000 per kilogram (about 2.2 pounds).

While black rhino numbers are trending upward and poaching has been declining, it remains the deadliest threat to black rhinos today, according to the World Wildlife Fund. The impact of this poaching also extends far beyond the loss of individual animals by leaving an ecological role unfilled.

For example, black rhinos use their hooked lips to munch on trees and shrubs, and their behemoth bodies, which can weigh in at nearly 3,000 pounds, trample soil and plants.

This behavior helps maintain open landscapes and transport seeds and nutrients, and greatly impacts the makeup of species in their ecosystems. Rhinos also draw tourists, making them a valuable revenue stream for local economies.

DESPITE ITS relative success in reducing poaching rates, dehorning is not without its drawbacks. For starters, dehorning does not automatically prevent rhino killings. Because not all of the horn is removed, there is still value for poachers to exploit. There have also been cases of poachers killing dehorned rhinos without taking anything of value, potentially to avoid accidentally tracking a hornless rhino.

Dehorning has also been linked to changes in rhino behavior, according to a 2023 study led by Duthé and published in *Proceedings of the National Academy of Science*.

In comparing the area used by rhinos going about their daily activities, also known as a “home range,” Duthé and colleagues found that the home ranges of dehorned rhinos shrunk to almost half of their original size. While the full implications of this reduction in space use are murky, the researchers nonetheless uncovered a clear impact of dehorning.

This finding, however, does not change how Duthé sees the process. “It’s such a dire situation right now,” Duthé says. “It’s urgent. I don’t think we should stop dehorning the [populations] that truly need it.” Continued monitoring will help scientists know if there are other serious long-term consequences of dehorning.

For now, Duthé and colleagues believe the benefits of dehorning outweigh the risks. “At the end of the day,” Duthé adds, “A weird rhino is better than a dead rhino.” —ANNA NORDSETH

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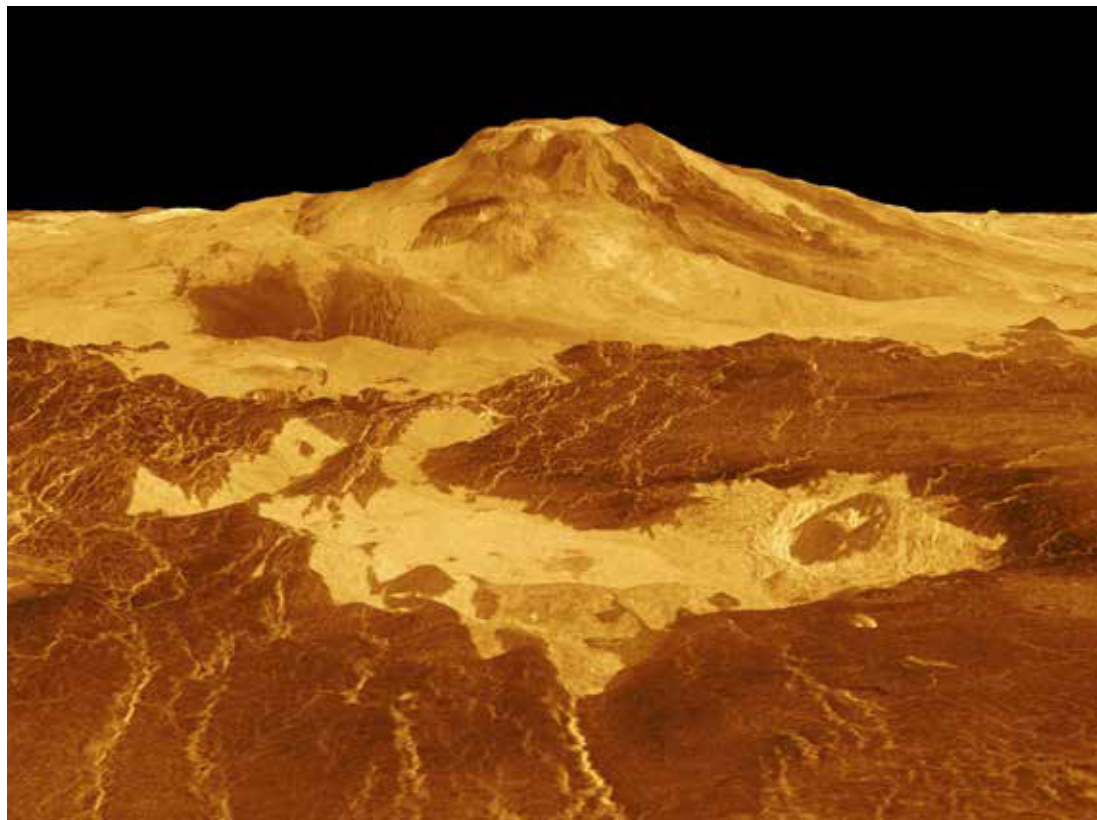
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Venus Is Volcanically Active

A STRIKING NEW STUDY REVEALS THAT OUR NEIGHBORING PLANET MAY HARBOR ACTIVE VOLCANOES — AND COULD HELP FUTURE SCIENTISTS UNDERSTAND WHAT TRANSFORMED IT INTO A FIERY INFERNO.



THIS COMPUTER-GENERATED model of the surface of Venus shows the summit of Maat Mons, the volcano that is displaying signs of activity.



SOMETIMES CALLED

“Earth’s twin,” Venus is similar to our world in size and density. The two rocky planets are also roughly the same distance from the sun, and both have an atmosphere. While Venus’s bleak and inhospitable landscape does make it seem far less like Earth, scientists recently pinpointed another striking similarity between the two — the presence of active volcanoes.

When NASA’s Magellan mission mapped much of the planet with radar in the 1990s, it revealed an unexpectedly youthful surface — there were surprisingly few craters — that hinted at active geologic processes. Although few missions have visited Venus since then, researchers have continued to mine the trove of data from Magellan.

Using this decades-old data, planetary scientist Robert Herrick and radar

expert Scott Hensley discovered that a volcano called Maat Mons is burbling with volcanic activity: In this case, lava flows that moved for eight months during an imaging cycle from 1990 to 1992, according to a study published in *Science* in 2023. The findings are the first real evidence that volcanoes have erupted on Venus during modern times.

What’s more, volcanic activity on Venus could be even more prevalent and dramatic than on Earth. A study

The findings are the first real evidence that volcanoes have erupted on Venus during modern times.

published in *JGR Planets* in 2023 mapped out a whopping 85,000 potential volcanic features on Venus’ surface, and there’s a decent chance that some of them could be active today.

On top of that, another 2023 study, also in *JGR Planets*, found that the very high surface temperature on Venus — over 900 degrees Fahrenheit — allows lava flows to ooze 75 percent further than on Earth.

A slate of new missions are headed to Venus over the next decade, including NASA’s Veritas mission, which aims to map the planet’s surface to better understand its geologic history. These ventures should settle the question of how the paths of Venus and Earth diverged so sharply, with one becoming a hostile inferno and the other able to harbor life — and confirm whether volcanoes are still erupting on the planet today. — ERIK KLEMETTI

WILL TIME EVER END?

TIME IS A FUNDAMENTAL CONCEPT IN OUR LIVES, BUT THE QUESTION OF WHETHER IT WILL EVENTUALLY GRIND TO A HALT MAY BE A MATTER OF PERSPECTIVE.

IF YOU'VE ever watched an ice cube melt or stirred creamer into a pool of black coffee, you've witnessed a fundamental truth about the universe: The "arrow of time" always marches forward. Time flows from past to future. What we call the present is a never-ending series of inflection points, where

the collection of events that have already happened (the past) meets the collection of events that have yet to happen (the future). And while time doesn't ever stop, it can slow down.

EINSTEIN'S THEORY

of special relativity gave us a completely new way to view the cosmos. Prior to Einstein, we had movement through space, and we had passage through time. Special relativity unites those theories into a single, unified framework called spacetime. In this new framework, it's impossible to move through space or time separately; instead, every object in the universe is constantly moving through both simultaneously.

This means that it's (theoretically) possible to slow down your progression into the future. The faster you move in space, the slower you move in time. If you jump on a rocket ship and accelerate yourself to 99 percent of the speed of light, you'll travel through time about seven times slower than stationary observers. (Actually reaching that

velocity, however, is another matter entirely.)

There's a caveat here, though: You will never experience this time dilation yourself — your heart will beat at the same rate, your hairs will gray after the same amount of time and your wristwatch will tick at the same speed. But outside observers looking in will see you move and live in slow motion, seven times slower than they are.

It sounds like a contradiction, but this is what puts the relative in the special theory of relativity: Our perceptions of distance and time depend on our perspective, and no two observers are ever guaranteed to agree.

RELATIVITY ALLOWS

you to (again, theoretically) skip forward into the future, as well. If you travel fast enough, what may only be a handful of years to you can translate to hundreds, thousands, or even millions of years for everybody else. By the time you came back to Earth, it, or the people inhabiting it, could be completely unrecognizable — a major conceit in (spoiler



alert) sci-fi films like *Planet of the Apes* and *Interstellar*.

No matter what, though, you can't stop time, because it's not possible to travel at 100 percent the speed of light. You'll always move

a tiny fraction below that ultimate speed limit, and so you'll always experience at least some progression of time.

As far as we can tell, time will have no end in the future. Our universe is expanding every day, and it appears that it will continue to do so for eternity. The future is wide open, and there will always be another tomorrow. Sure, in the far, far future, all the stuff in our universe will be spread out to incomprehensibly thin dust, but time itself still won't ever come to an end.

—PAUL M. SUTTER

Our perceptions of distance and time depend on our perspective, and no two observers are ever guaranteed to agree.

The History of Swear Words: Where the &%@! Do They Come From?

FROM ANCIENT ROME TO THE RENAISSANCE, DIVE INTO THE SURPRISING ORIGINS AND HISTORY OF SWEAR WORDS.

DON'T DENY it: Sometimes, swearing just feels good.

And it's becoming clear that dropping the occasional profanity bomb is actually good for us, too — at least, according to science.

Research has shown that swearing can boost pain tolerance, increase the persuasiveness of an argument, and signal positive traits like verbal fluency and honesty. What's more, spewing obscenities has the potential to impact our bodies, as well, providing stress relief and even a slight boost in physical performance.

Given their ubiquity in society, it might seem like swear words simply sprouted into existence. But where does profane language really come from? From ancient Rome to the Renaissance to today, there's lots that the history of swearing can teach us about how taboos, language, and culture evolve.

SIMPLY PUT, swearing is taboo language: particular words that certain people deem unacceptable in specific settings within a given culture. "The words that come to fill that role come from certain places in the human experience," says Benjamin Bergen, a linguist

and cognitive scientist at the University of California, San Diego, and author of *What the F: What Swearing Reveals About Our Language, Our Brains, and Ourselves* (Basic Books, 2016). "They tend to describe things that are themselves taboo."

Historically, Bergen continues, taboo language has tended to revolve around religion; in Judeo-Christian and Muslim traditions, profanity emerges when words selected for specific functions are stripped of their intent and used outside of religious contexts. (In Latin, the word *profanus* translates to "outside the temple," signifying words that desecrate sacred precepts.) As such, words in English like *holy*, *hell*, and *goddamn* — or even names of religious figures like Jesus Christ — become swears when they're used accordingly, even if they're pretty

"It's the same general phenomenon [in all cases]. A taboo about the world becomes a taboo about the word."



tame by today's standards.

Beyond religion, profanity can also come from language involving sex and sexual acts, as well as bodily functions — in the latter category, you can find words describing vomit, urine, and, of course, feces. In certain cultures, death and disease can even become fodder for profane language. In Dutch, for example, a long list of expletives are derived from the names of diseases, like the extremely offensive *Kankerlijer*, which literally translates to "cancer-sufferer."

"It's the same general phenomenon [in all cases]," says Bergen. "A taboo about

the world becomes a taboo about the word."

OBSCENITY IN Latin shares a few striking similarities with swearing today, with both drawing from taboos about sex and excrement. The sexual and cultural norms of ancient Rome, however, were markedly different from ours, giving rise to some unique profanity.

"You get swear words from the cultural preoccupations of the time," says Melissa Mohr, author of *Holy Sh*t: A Brief History of Swearing* (Oxford, 2016). "One of the key Roman preoccupations was, 'What does it mean to



be a man? They had all of these different words for man, and the best kind of man you could be was a *vir*, and that's where we get the word *virtuous*."

In ancient Rome, Mohr

continues, it was socially acceptable for a virtuous Roman man to have sex with people of any gender, for example, so long as he was the "active" participant. As such, one of the surest ways to sling mud at a Roman man was to use language putting him in a passive sexual position. Meanwhile, if a woman was active during sex, that was deemed taboo by society.

"When you transgress the rules, that's where you get the swear words," adds Mohr.

BY THE Middle Ages, cultural norms were quite different from those in antiquity, and religion was an even more dominant force in society. As a result, religious oaths — promises before God that your words are true and you'll do what you say — that were made falsely became the predominant form of profanity.

"The cultural preoccupation [in the Middle Ages] is how and when you use God's name," says Mohr. "So when you get 'vain' swearing, which is what they're worried about, that's when you swear and you're lying or you're not sincere."

If you were, say, gambling

in the Middle Ages and lost, you might cry out, "By God's bones!" In particular, oaths on God's body parts — other examples include "by God's wounds" or "by the blood of Christ" — were the most obscene phrases you could say. These swears were deemed so shocking because people thought that saying them was akin to ripping apart the body of Christ in heaven, in a perversion of the Eucharist here on Earth.

Over the centuries, however, the perverse power of religious oaths began to fade. Mohr says that the decline started during the Protestant Reformation of the 1500s, with traditional religion playing a less central role in people's lives.

DURING THE Renaissance, swearing started to resemble modern profanity more closely. Terms that had been direct or descriptive during the Middle Ages — like the C-word, which could once be found in medical treatises describing anatomy — began to take over as the new swear words. "Most of the bad words were around in the Middle Ages, they just weren't swear words," says Mohr.

These swears, often sexual or scatological in nature, reached their peak offensiveness during the Victorian era. This is when profanities largely vanished from print and speech, and polite euphemisms took their place. The societal urge to avoid anything uncouth or explicit was so strong that even now-banal words like *chicken breast* and *trouser* were seen as taboo.



THE POWER of profanity reached its peak during the Victorian era, when words like *trouser* became taboo.

"But in private, there were all of these hints that by around 1860, people were swearing basically the same way that they are now," says Mohr. "It just rarely made it into the record. But it's in court cases and pornography."

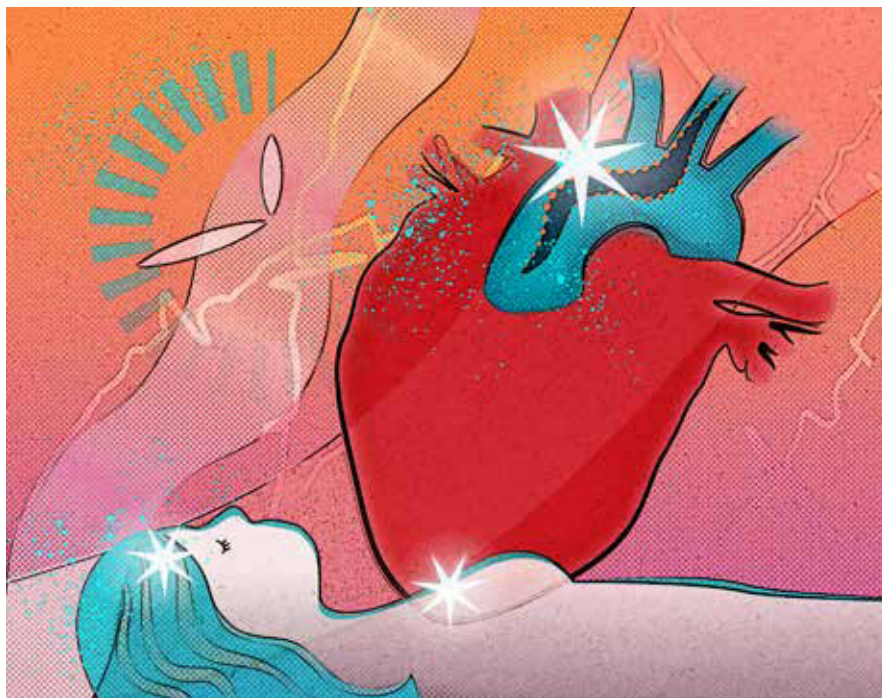
Around the dawn of the 20th century, profanity became much more public. During World War I and World War II, says Mohr, wartime correspondents tried to faithfully report on what soldiers were doing and saying, from trenches to submarines — including all of the colorful language they used.

As a result, that language started to bleed into newspapers and books, setting the stage for swearing as we know it today. "At that point, they're saying *f---* every other word," adds Mohr. "There's a quote [from the era] where someone said, 'We knew it was serious if the sergeant didn't say, 'Get your *f---ing* rifle.'"

—ALEX ORLANDO



FROM TOP: DONNA BEELER/SHUTTERSTOCK; YULIA SEROVA/SHUTTERSTOCK



On a Tear

WHEN A 65-YEAR-OLD WOMAN IS RUSHED TO THE EMERGENCY ROOM WITH A CATASTROPHIC BLOOD VESSEL TEAR, EACH PASSING MINUTE COULD MEAN THE DIFFERENCE BETWEEN LIFE OR DEATH.

“Aortic dissection! Coming back!” Amanda, the triage nurse, cried as she slalomed a gurney down the corridor.

“Sixty-five-year-old, history of hypertension,” she panted. “Sudden chest and back, 10-over-10 pain. Started an hour and a half ago. Headache, too.”

Eight pairs of hands eased a grimacing woman off the stretcher onto our resuscitation bed. Clenching her eyes shut, the woman moaned. “Head hurts, head hurts.”

“Which side?” I asked.

She raised a hand to her left ear. “Here,” she mumbled. “Hurts.”

“Chest pain, back pain?” I added.

“Hurts. Please. Head,” was all she managed.

The team speed-started IVs, applied EKG leads to the patient’s chest and hooked up monitors.

“She sounds confused,” Emily, a physician’s assistant, said softly. “Stroke?”

“Is she already dissecting up her neck into the carotids?” I wondered out loud. “She’s hurting in too many places. This is a bad one.”

Starting as a tear in the innermost layer of the aorta, the big vessel that transports oxygen-rich blood away from the heart,

aortic dissections can be insidious and catastrophic. The defect in the lining allows high-velocity ventricular blood to surge through the tear, splitting the inner layer away from the outer ones.

As long as the bulging inner layer doesn’t occlude arteries like the carotids in the neck or the spinal artery — which can cause a stroke or even sudden lower-body paralysis — you can walk around with a double-barreled aorta for hours, or even days. But death comes eventually, sometimes in a split second if blood blows back into the pericardial sac (the tough double-lining of the heart) and chokes off its ability to contract.

Time to death is impossible to predict. On average, every passing hour bumps mortality by 1 to 2 percent, which means there is no safe interval. Speed saves: Once the diagnosis is made, the next stop is the operating room, pronto. One tragic example was the actor John Ritter, age 54, who spent over four hours in the ER with an aortic dissection before getting to the operating room, where he died.

“Call CAT scan!” I barked. “Tell them we’re coming.”

BY INJECTING intravenous contrast dye into the patient’s bloodstream, a CAT scan allows physicians to highlight a dissection’s flapping inner layer as a black line against radiologically white blood. It takes about 40 minutes, all in all, to go from ordering the CAT scan to the radiologist’s interpretation.

Emily finished taping down the IV she had just placed and looked up. “Hey, why don’t we ultrasound her? Dr. Wynn is here. She teaches it.”

“Great idea,” I replied. An ultrasound can visualize the heart and aorta. It can’t penetrate the whole chest, so you still need a CAT scan even if you don’t see a dissection. But if you do see one, start sprinting.

Wynn and I wheeled the portable ultrasound machine over. She placed the probe at the edge of our patient’s sternum. Black and white pixels coalesced.

Just above the heart, the aorta’s inner layer billowed away from the outer like

Starting as a tear in the innermost layer of the aorta, aortic dissections can be insidious and catastrophic.



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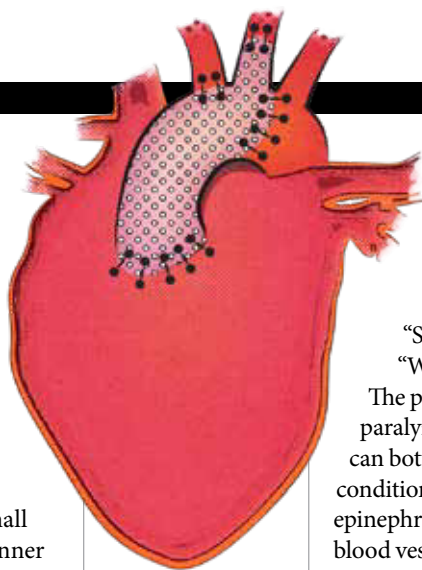
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a sheet flapping on a clothesline. There was our dissection, clear as day.

“Emily,” I shouted, “call transfer center, activate rescue ambulance and tell vascular surgery she needs to go now. We’ll get her to CT to confirm.”

Our patient would need cardiopulmonary bypass, meaning a machine would temporarily take over the function of her heart and lungs while a full vascular surgery team fixed her aorta — resources not available at small community hospitals like ours. On the CT scanner screen, the dark line of the inner flap started at the root of the aorta, wound around its arch, then up the left carotid artery. Emily was right: The patient had suffered a stroke. The dissection flap was now bulging into the carotid, depriving the left side of her brain (and its speech area) of blood flow. Rushing back to the resuscitation bay, we mobilized for transfer. And then we lost her.

“I can’t get a blood pressure,” Amanda cried out. Not trusting the neck, I felt the femoral artery at the thigh. No pulse. A bolt of fear shot through me. This is it, I thought.

Blood pressure usually skyrockets during dissections as the vascular system reacts to disruption. That can worsen the blood surge into the dissection tear, and requires aggressive blood pressure lowering with intravenous medications. The flipside of a dissection’s pressure spike is that a drop in blood pressure can signal catastrophe: either blood in the pericardial sac, which can choke off the heart’s contractions, or a full-blown rupture.

“Start CPR,” I ordered. A nurse locked two hands over the woman’s sternum and started compressions. Emily scrambled to set up a breathing tube.

Wynn and I looked again.

The ultrasound showed no blood around the heart. And a full-thickness tear would be fatal no matter what we did. Still, a vague thought started to gel: What if the patient’s ballooning aorta had gotten too floppy to hold a blood pressure? The EKG monitor was still showing electrical heartbeats.

“Epi,” I ordered. Epinephrine, the big-gun resuscitation drug, could reverse the floppy aorta — but it could also kick the heart into a lethal arrhythmia.

The full 10 milliliters of epinephrine solution went in. The woman’s heart rate sped up, then collapsed into the sawtooth pattern of ventricular fibrillation, electrical chaos that indicates an irregular, life-threatening heart rhythm. My own heart started pounding.

Amanda grabbed defibrillation paddles,

pressed them on the chest and fired. The patient’s torso arced upward, then fell back.

“I have a pulse,” someone else cried.

“Should I intubate?” Emily asked.

“We need a better blood pressure,” I replied.

The potent medications we give to sedate and paralyze patients before inserting a breathing tube can bottom out blood pressure for those in critical condition. With Neo-Syneprine, a gentler cousin to epinephrine that spares the heart and only tightens blood vessels, the pressure rose enough. I told Emily to go ahead with the breathing tube.

“OK, let’s start a Levophed drip and try to keep her systolic around a hundred,” I announced, squelching my misgivings about starting yet another potent artery-constricting drug that could send her blood pressure through the roof.

The nurses started the intravenous drip. Just then, the transfer ambulance team rolled in. Wasting no movements, they double-checked the IV drips, logged vital signs, hoisted her onto their gurney, and sped off.

EMILY AND AMANDA stepped in close as the medics hustled down the hallway, IV bags, wires, and monitors compactly framing their still-breathing charge.

“I can’t believe she made it out,” Emily whispered.

“I don’t think she’ll make it,” I answered somberly. “I’ve never seen a dissection drop their blood pressure and survive.”

Next morning, word came down that the patient was still alive. The ambulance had flown uptown and delivered her directly to the operating room. The surgical team swiftly connected her to the cardiopulmonary bypass machine, then sutured in a synthetic graft to replace her torn aorta.

Every day that passed felt like a victory. On day three, they removed the breathing tube. By day five she was feeding herself. Five days later came the stunning news: Walking and talking with minimal assistance, she had graduated to a rehab facility to regain her strength.

I saw Emily soon after. “Guess what?” I asked.

“What?” she replied, wary.

“Your 40 minutes saved her. Dissections die because of delay.” I watched her eyes widen with relief and astonishment. “Thanks to you, that didn’t happen this time.” ▣

Rushing back to the resuscitation bay, we mobilized for transfer. And then we lost her.

Tony Dajer is an emergency medicine physician in New York City. The cases described in Vital Signs are real, but names and certain details have been changed.

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SPECIAL SECTION

THE STATE OF SCIENCE



HUMANKIND TAKES big steps back to the Moon for the first time in 50 years. AI makes a giant leap forward as the rise of ChatGPT and other models amuse, astound, and unsettle us. Growing climate concerns give rise to the idea of “global weirding.” A doomed queen’s lost letters are deciphered by an unlikely team of amateur codebreakers. New light is shed on the ancient secrets to making a perfect mummy. All of these and dozens of other breakthroughs and discoveries made 2023 a banner year for science. Find out which moments stood out as *Discover’s* top choices for the greatest and most intriguing science stories of the year!

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ALL THE LONELY PEOPLE

Unmasking the hidden epidemic of isolation in the U.S.

▶▶▶ **THE STANDARD** public health threats are all-too familiar: Smoking. High blood pressure. Cancer. More recently, COVID-19. But a new government advisory made headlines in 2023 by adding an unexpected major player to that list. Loneliness, stated the report from Surgeon General Vivek Murthy, is a widely underrecognized U.S. health crisis. In recent years, about 50 percent of Americans have experienced loneliness, which comes with a hefty dose of adverse effects. Lonely people, as Murthy's report warns, run the same mortality risk as people who smoke 15 cigarettes a day.

"Millions of people in America are struggling in the shadows, and that's not right," Murthy told the Associated Press in May. "I issued this advisory to pull back the curtain on a struggle that too many people are experiencing."

Institutions that once fostered social connection, such as churches and community-based organizations like Rotary Clubs, are

shrinking or disappearing. That civic disintegration, along with a COVID-driven remote work boom, is nudging more people into the lonely category.

Still, on its face, Murthy's warning sounds awfully dire — and somewhat baffling. It's hard to fathom how a lack of companionship could be as threatening as an addiction or global pandemic. But humans are so biologically wired to be social that isolation wreaks surprising havoc on our systems. People who lack social support have a 29 percent higher risk of heart disease, a 32 percent higher risk of stroke, and a 26 to 29 percent higher risk of premature death, according to the report. What's more, such health effects in isolated older adults have led to about \$6.7 billion in excess Medicare spending each year.

SCIENTISTS NOW know that loneliness can cause a broad swath of health problems. That may be because ancestral humans thrived in supportive communities — and anything less can set off a biochemical stress response.



"Our brains function more efficiently when we are with others," says Julianne Holt-Lunstad, a professor of psychology and neuroscience at Brigham Young University and the lead scientist on the surgeon general's advisory.

In multiple studies, the stress of aloneness has been linked to higher levels of inflammation in the body. When this inflammation persists, the resulting cellular damage can lead to chronic illnesses like vascular disease, diabetes, and Alzheimer's. The ill effects of excess alone time show up in more immediate ways, too. When University of Vienna

psychologist Giorgia Silani and her team deprived 30 people of social contact and monitored them for eight hours, their energy levels plummeted as if they'd starved themselves for the whole day. The results were published in *Psychological Science* in May.

"If you don't eat, you feel weaker, you don't have the resources for moving and doing things," Silani says. "We found the same effect [with] social isolation." Since humans rely on personal connections to make life easier, she thinks social deprivation may cause us to overestimate the effort it takes to tackle life alone, making us feel depleted.

SINCE LONELINESS can feel so much like a personal failure, it's easy to assume people should just try to handle it on their own. But in reality, many of the

2023 NEWS BRIEF

NEW PERSPECTIVE ON LONELINESS

In an April study, University of California, Los Angeles, researchers found that lonely people perceive the world differently not only in comparison to their nonlonely counterparts, but also in comparison to one another. Unique neural responses in parts of the brain associated with shared perspectives may contribute to the sense of misunderstanding that often accompanies loneliness, even when surrounded by others, the researchers say.



FDA APPROVES CONTROVERSIAL NEW ALZHEIMER'S DRUG

Lecanemab shows clinical benefits — but do they justify the risks?

»» **FEW AILMENTS** are as fearsome as Alzheimer's disease, the most common form of dementia, which robs patients of their minds and memories before it takes their lives. So, when the U.S. Food and Drug Administration approved a new treatment for Alzheimer's in July, the event made front-page news. But it also generated heated arguments.

Lecanemab, branded as Leqembi by pharma companies Eisai and Biogen, is the first drug targeting the disease's underlying mechanisms to receive full approval from the FDA. The medication — an engineered molecule known as a monoclonal antibody — works by removing the sticky plaques of amyloid beta protein that gum up the brain as Alzheimer's progresses.

In that respect, it resembles an earlier drug: aducanumab (marketed by Biogen as Aduhelm), which in 2021 was granted "accelerated" approval based on biomarkers rather than results. While that drug was effective at busting amyloid, its benefits to patients' cognitive health were never clearly demonstrated, and side effects were substantial. The FDA's decision drew near-universal criticism.

Lecanemab, by contrast, was approved last summer on the basis of a large clinical trial showing that patients with early-stage Alzheimer's who received the medication declined 27 percent more slowly over 18 months than patients receiving a placebo. "This gives people more months of recognizing their spouse, children and grandchildren," Joanne Pike, president and CEO of the Alzheimer's Association, said in a statement.

SO WHY THE controversy? For starters, that reduction in disease progression represents less than half a point on an 18-point scale measuring functions such as memory and problem-solving, a difference that some experts suggest is too small to be clinically meaningful. And the drug's potential side effects raise the question

of whether the rewards justify the risks: Nearly 13 percent of trial patients receiving lecanemab experienced brain swelling and 17 percent had brain bleeds. Although these symptoms were mostly mild or moderate, three of the affected patients died (though not during the randomized course of study).

Then there's the cost: a hefty \$26,500 a year. Patients must also undergo regular brain scans, potentially raising the tab to \$90,000 — and adding to the inconvenience posed by biweekly, hour-long infusions of the medication.



MORE THAN 6 million Americans are living with Alzheimer's disease. By 2050, that figure may surge to nearly 13 million.

Patients and physicians may soon have other options to choose from. Days after lecanemab got the nod, a large study of a similar drug, donanemab, reported marginally better efficacy numbers. Meanwhile, more amyloid antibodies are in development and researchers are investigating an array of alternative approaches, including preventive vaccines and anti-inflammatory medications.

"What we can all agree on," says Lon Schneider, director of the California Alzheimer's Disease Center at the University of Southern California, "is that we need much better treatments."

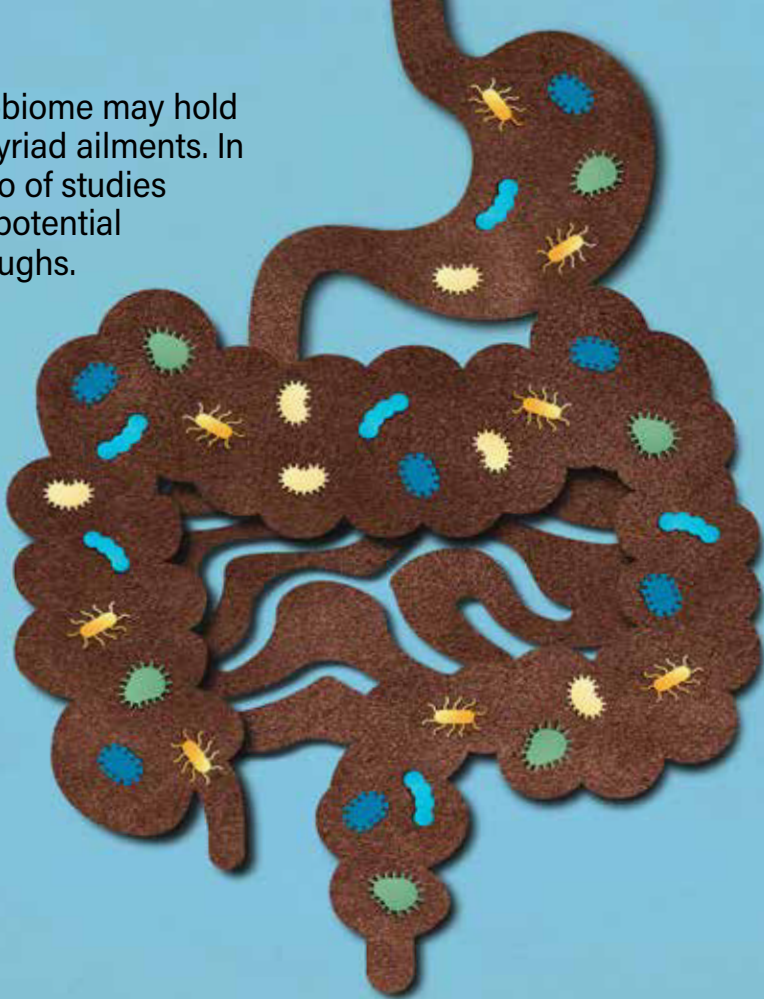
—KENNETH MILLER

factors that promote social isolation are structural ones. "It could be workplace policies that don't allow flexibility to nurture personal relationships," Holt-Lunstad says. "It might be busy or unsafe streets that are barriers to getting to know your neighbors."

As a result, the solutions Murthy and Holt-Lunstad propose aren't all individual lifestyle changes. "We recommend investing in social infrastructure to help build connections in communities," Holt-Lunstad says. That could mean increasing support for civic hubs like volunteer programs, redesigning public spaces to encourage gatherings, or revamping digital spaces in ways that promote bonding.

Some future doctors might prescribe neighborhood mixers or bingo nights to ward off chronic illness. But in an ideal world, social contact would be so effortless that they'd never have to. —ELIZABETH SVOBODA

The microbiome may hold keys to myriad ailments. In 2023, a trio of studies heralded potential breakthroughs.



NEW CLUES TO CHRONIC DISEASES TURN UP IN THE GUT

▶▶▶ **IT'S NO SECRET** that our gut microbiomes — the trillions of bacteria, viruses and fungi that inhabit our gastrointestinal tracts — play a vital role in our lives. In the past decade, researchers have found that these microorganisms help us perform an array of bodily functions and, notably, that they can profoundly affect our mental health.

Still, we're only beginning to learn how those interactions work, and how they might be harnessed to treat or prevent disease. In a study published in February 2023 in *PLOS Biology*, for example, researchers at the University of Virginia found that a protein called aryl hydrocarbon receptor, or AHR, which regulates immune cells' response to chemicals produced by the



gut microbiome, may play an important role in multiple sclerosis (MS). The disease causes the immune system to attack myelin, the insulation around nerve fibers, prompting symptoms that can include muscle weakness, pain, and vision loss.

When the team induced MS in genetically engineered mice whose immune systems lacked AHR, they recovered quickly after only a brief bout

of paralysis. The reason, the team determined, was that their guts contained higher levels of bile acids, which would normally be broken down by gut microbes. The acids, in turn, weakened the animals' T cells — immune-system warriors that go rogue in autoimmune disorders. When gut microbiota from AHR-free mice were transplanted into normal mice with MS, they recovered, too.

These findings could point to improved treatments for the 2.8 million people with MS worldwide, suggests lead author Andrea Merchak. Currently, the only approved drugs are



immunosuppressants, which put patients at risk of infection and troublesome side effects.

Merchak and her team are now testing medications that modify bile acids on mice with MS. Such microbiome-based therapies, she believes, might be able to ward off the disease's ravages without the downsides of immunosuppressants. "If we can slow the progression and prevent lasting damage," she says, "these patients can live longer and fuller lives."

PARKINSON'S DISEASE, a neurodegenerative disorder characterized by tremors, muscle rigidity and dementia, impacts an estimated 8.5 million people globally. It's associated with clumps of misfolded alpha synuclein proteins that accumulate in patients' brains. But these clumps have also been found in patients' intestinal nerves a decade or two before Parkinson's symptoms occur, leading to the theory that resident microbes may cause the aggregation that then travels to the brain.

Researchers at the University of Helsinki in Finland have been investigating the possible role of the bacterial species *Desulfovibrio* (DSV) in Parkinson's. Over the past two years, they've found that DSV is more common in people with the disease, and that the quantity of the bacteria correlates with the severity of symptoms. In a new study, published in May in *Frontiers in Cellular and Infection Microbiology*, the team examined those links in more detail. They recruited 20 participants, half with Parkinson's and half without. Each subject provided fecal samples,

First RSV Vaccines Get FDA Approval

An effort six decades in the making forges new weapons against a potentially deadly respiratory disease.

►►► **FOR A MAJOR** killer of the very young and the very old, respiratory syncytial virus (RSV) gets scant public attention. Although the virus usually causes mild, coldlike symptoms, it can inflame small airways in the lungs of babies and vulnerable adults, triggering severe pneumonia. Globally, RSV is the second leading cause of pediatric deaths after malaria. Among adults, it's responsible for up to 10,000 deaths and 160,000 hospitalizations annually in the U.S., mostly among the elderly or immunocompromised.

RSV made headlines this past May, however, when the FDA approved the first vaccine for the disease. The product, known as Arexvy, was OKed for adults over 60. Its manufacturer, biopharma company GSK, beat several rivals to the finish line — including Pfizer, whose RSV vaccine Abrysvo received approval for the same age group weeks later.

Those twin triumphs took decades to achieve. Until now, the big challenge has

been safety: In the 1960s, babies who received an experimental RSV vaccine in a clinical trial funded by the National Institutes of Health became sicker than those who received a placebo, and two died. What's more, 65 percent of vaccinated babies became infected during the winter RSV season, versus 53 percent in the control group. Researchers from the NIH and elsewhere spent years trying to determine what went wrong and find a fix.

The NIH-funded study that paved the way for the new vaccines involved mapping the crystal structure of a key protein on the virus's surface, and figuring out how to target the form it took before it entered the body's cells — rather than after, as the old vaccine had done. In clinical trials published last year, the GSK and Pfizer vaccines showed overall efficacy rates of 83 percent and 67 percent, respectively, against RSV in people over 60. "It's been a long road to a successful vaccine," says Ann Falsey,



IN THE U.S., RSV is the No. 1 cause of hospitalizations for infants, taking up to hundreds of lives each year.

an infectious diseases expert at the University of Rochester. "We finally have a tool that can prevent a lot of suffering."

The year saw other hopeful news in the fight against RSV. Also in May, an FDA advisory panel recommended approval of Abrysvo for pregnant women, which would shield their babies from infection; the agency greenlit that use of the vaccine in August. And in July, the FDA approved a monoclonal antibody treatment from Sanofi and AstraZeneca, nirsevimab, that provides temporary protection to newborns.

—KENNETH MILLER

which were analyzed for the presence of DSV. Strains of the bacteria found in both groups were fed to tiny *C. elegans* worms, whose heads were then examined under a microscope.

The researchers found that worms fed DSV from Parkinson's patients had more and larger alpha-syn aggregates than worms fed DSV from healthy individuals or a control group that was fed *E. coli*. Worms fed Parkinson's patients' DSV strains also died in greater numbers.

These findings indicate that specific strains of *Desulfovibrio* bacteria are a "likely" cause of Parkinson's, Saris says, though other factors are also involved. "The precautionary principle

suggests that for patients, it would be good to get rid of those strains, or at least reduce them." He and his team are currently investigating methods — including antimicrobial peptides and dietary regimens — that might be able to do just that.

MEANWHILE, also in May, researchers from the Chinese University of Hong Kong reported encouraging news on long COVID: A daily capsule containing live intestinal bacteria was effective in relieving several of the syndrome's key physical and mental symptoms.

The treatment, known as SIM01, comprised three *Bifidobacteria* species along with prebiotic substances to help support their growth.

Earlier studies, led by gastroenterologist Siew Ng, had found a depletion of beneficial gut bacteria in COVID-19 patients — and that SIM01, a cocktail of such microbes, reduced pro-inflammatory cytokines and promoted anti-SARS-CoV-2 antibody development.

For the current study, a team led by Ng's doctoral student Raphaela Iris Lau enrolled 463 patients who had confirmed COVID-19 at least four weeks previously and who had at least one of 14 long COVID symptoms — which can include chronic pain, shortness of breath, loss of taste or smell, and other ills. Half received SIM01, and half received a placebo.

Those in the SIM01 group,

the researchers found, were more likely than controls to see improvements in digestive problems, fatigue, difficulty concentrating, memory impairment and "general unwellness." In the latter category, 77 percent said they felt better after six months with SIM01, compared to 59 percent of those on placebo.

Results were similar for the other four symptom categories, with improvement rates ranging from 42 to 70 percent.

"What we found really fascinating was that probiotic use could treat neuropsychiatric symptoms in many long COVID patients, not just digestive ones," says Lau. "We think that's a breakthrough."

—KENNETH MILLER





NEOANTIGEN VACCINES KEEP CANCER FROM COMING BACK

A new type of jab may radically lower odds of recurrence.

FOR DECADES, cancer vaccines have been touted as a technology with transformative potential — a promise that always seemed to lie beyond some distant horizon. In 2023, however, the results of two clinical trials hinted that the transformation may be near.

The first report came in April, at the annual meeting of the American Association for Cancer Research (ASCO). It concerned melanoma, the deadliest form of skin cancer. In patients whose tumors had been surgically removed, researchers announced, an experimental therapeutic vaccine cut the risk of recurrence by 44 percent compared with the immunotherapy drug pembrolizumab alone — the standard therapy in such cases.

These findings have “absolutely breathed new life into the cancer vaccine field,” declared lead author

MELANOMA AFFLICTS more than 97,000 Americans annually.

Jeffrey Weber, deputy director of NYU Langone’s Laura and Isaac Perlmutter Cancer Center, at the ASCO conference. “I say that as a bona fide skeptic who has put hundreds of patients on prior

trials and seen no benefit until now.”

THE JAB that changed Weber’s mind belongs to a new generation of cancer vaccines. Previous approaches attempted to train the immune system to recognize a protein typically overexpressed by a given type of cancer, though that antigen might also be



present in ordinary cells. The experimental shot, developed by the pharma companies Moderna and Merck, targets neoantigens — proteins expressed by an individual’s unique cancer, but not by normal cells. This personalized inoculation, based on the same mRNA platform as Moderna’s COVID-19 vaccine, can target up to 34 neoantigens at once.

In the phase 2 trial, 107 subjects who’d had surgery to remove melanoma from lymph nodes or other organs received both the vaccine and pembrolizumab, which protects T cells — the immune system’s foot soldiers — from being deactivated by cancer cells. Another 50 received only pembrolizumab. Among the vaccinated group, melanoma returned in just 22 percent of patients within two years, compared to 40 percent in the control group. Most side effects were mild, and immune-related adverse effects (such as endocrine problems) were similar in both groups, suggesting that most came from the drug, not the shot.

More research will be needed to confirm the vaccine’s efficacy, and a larger phase 3 trial is now underway. “I’m getting flooded by patients saying, ‘How can I get this?’” says M.D. Anderson Cancer Center oncologist Rodabe Amaria. “It’s not ready for prime time, but the initial data looks very encouraging.”

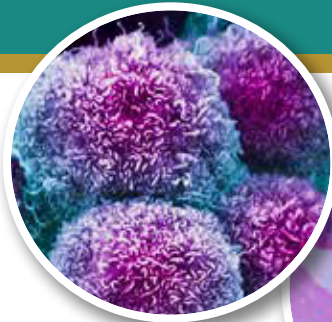
THAT WASN’T the only success story for new cancer vaccines this year. In May, researchers at the Memorial Sloan Kettering Cancer Center in New York reported a similar breakthrough with pancreatic ductal

adenocarcinoma, the most common pancreatic cancer, a disease with a mortality rate of 88 percent. In many ways, this cancer is a harder target than melanoma, often going unnoticed until it has spread widely. Surgery is the main form of treatment, but its recurrence rate is nearly 90 percent within seven to nine months. And chemotherapy and immunotherapy drugs usually do little to improve survival.

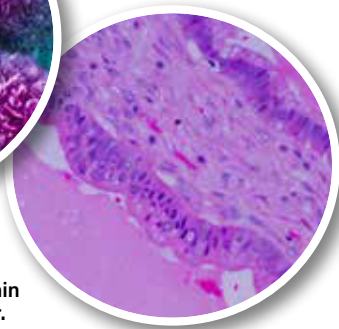
All of this helps explain why a small phase 1 study,

published in the journal *Nature*, made such a big splash. Led by surgeon Vinod Balachandran, the team removed tumors from 16 patients and sent samples to Germany. There, scientists at BioNTech analyzed the neoantigens in each patient's cancer cells and used that data to produce personalized mRNA vaccines tailored to each individual.

Along with those shots, the patients received the immunotherapy drug atezolizumab and an adjuvant — a substance that increases a vaccine's effects. All but one



A CLOSE-UP look at pancreatic cancer cells, which often first spread within the abdomen and to the liver.



patient underwent chemo, as well. The combination provoked an immune response in half the cases, far exceeding the efficacy of any previous treatment for pancreatic cancer. In patients who did not respond, the cancer

returned around 13 months after surgery. But the 8 out of 16 who did respond showed no signs of recurrence during the 18 months of the study.

As with the melanoma vaccine, experts caution that it's too early to declare victory for this new weapon in the war on cancer. Still, says Johns Hopkins oncologist Neeha Zaidi, "These results are very compelling, and they certainly set the stage for larger studies in the future."

—KENNETH MILLER

2023 NEWS BRIEF

FIRST FROZEN ORGANS TRANSPLANTED

University of Minnesota researchers have successfully transplanted cryogenically frozen organs into rats, according to a June study. To avoid damage during thawing, the team added iron oxide nanoparticles to a traditional storage solution; when activated by electromagnetic waves, these heated the kidneys rapidly and uniformly from within. All five rat recipients regained full kidney function within a month, signaling a promising future for long-term organ banking.

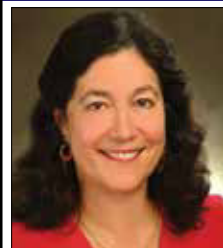
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	2. In-county	-	-
	3. Other classes mailed through the USPS	264	266
	4. Outside the mail	-	-
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i.	Percent paid (15c divided by 15f times 100)	99.87%	99.79%
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FRESHWATER FISH may contain up to 278 times higher levels of “forever chemicals” than farm-raised or marine-caught fish, according to new research.

CLIMATE

THE ESCALATING RISK OF PFAS

New research reveals a troubling abundance of synthetic chemicals in U.S. lakes, streams, and fish, drawing links to elevated risk in humans.

▶▶▶ **FISHING IS** a hallmark of U.S. outdoor culture. Within the country, some 41 million people fished in freshwaters in 2021, including both recreational fishers and those who rely on their catch to supplement their diet. But troubling news broke in spring 2023 when researchers

disclosed the surprising reach of dangerous chemicals in U.S. lakes and streams.

Freshwater fish, it turns out, pack a heavy dose of PFAS (per- and polyfluoroalkyl substances), a body of synthetic chemicals that generally don't break down in nature — or in our bodies. A study published in March

in *Environmental Research* offered a sobering analysis of how the fish we eat in the U.S. affect PFAS levels in the human bloodstream.

The researchers found that freshwater fish contain levels 278 times higher than those that are farm-raised or marine-caught and sold at grocery stores. Eating a single

freshwater fish a year could expose a person to the same PFOS levels (a type of PFAS) as drinking highly polluted water for a month. Currently, no federal regulations or recommendations exist regarding fish consumption and PFAS risk.

“Even a couple meals a year can considerably increase the amount [of PFAS] in your blood,” says study co-author Tasha Stoiber, senior scientist at the research- and advocacy-focused Environmental Working Group. “What we're finding here is that [fish] could be a significant source.”

The chemicals — which create an incredibly strong carbon and fluorine bond — have historically been used in firefighting foams, water-resistant products, and Teflon nonstick pans. Nowadays, PFAS is seemingly everywhere, spanning more than 12,000 types of chemicals, most of which we can't easily detect. It's often present in clothes, food wrapping, dental floss, and tap water across the country.

The chemicals have been associated with health impacts that range from reduced immunity and metabolism to testicular and kidney cancer. Some PFAS chemicals do slowly leave our bodies — through urine, menstrual blood, and breast milk. Yet researchers remain uncertain about the largest common sources of exposure, says Laurel Schaider, a senior scientist at the independent research organization Silent Spring Institute, which focuses on links between everyday chemicals and women's health. “It depends on what you eat and what exact products you have in your home,” she says.

The new freshwater fish research identified an elevated risk for low-income and non-white populations across the U.S. That's because experts know that people of color and those who are older, low-income, Indigenous, or born outside the U.S. are more likely to practice subsistence fishing to feed their households, making them more vulnerable.

THE STUDY found some of the highest levels of PFOS in fish in the Great Lakes, whose commercial fishing industry — valued at over \$19 million in 2015 — provides fish throughout the Upper Midwest and Canada. That means the impact could hit anyone who enjoys a local fish fry, as well as growing refugee populations, such as the Burmese. Many of these relocated families have continued fishing traditions on the Great Lakes — either as a hobby, a job, or as a food source. A 2022 study found that Burmese participants living near Onondaga Lake in New York had elevated blood levels of PFAS compared to the general U.S. population. “People do deserve to know if the food that you’re eating could be a significant source of [PFAS] exposure to your body,” Stoiber says.

After immigrating to the U.S. eight years ago, Mohamed Anwar co-founded the Burmese Rohingya Community of Wisconsin, a grassroots organization that provides education and health programs to resettled Rohingya refugees. He also works as a translator in a hospital, but even he had

never heard of PFAS as of last spring. It's likely many in his community haven't either.

The new paper closes at least one information gap that could help regulators and health officials issue guidance to shield the public from unnecessary PFAS exposure. Diet is likely to be “an important driver of exposure,” Schaidler says, given the ways plants and animals can absorb chemicals from their environments.

But another concerning study surfaced in July from the U.S. Geological Survey. That work estimated that nearly half of all U.S. tap

water is contaminated with one or more PFAS chemicals, elevating the urgency of questions about human exposure. The research emerged just a few months after the Environmental Protection Agency proposed first-of-their-kind regulations on PFAS in drinking water,

which should be finalized by 2024. The effort would establish maximum contaminant levels for multiple PFAS compounds and require monitoring by public water systems. If implemented, the new regulations could prevent thousands of deaths and reduce tens of thousands of PFAS-related illnesses.

—YESSENIA FUNES

BANNING GAS STOVES

New York becomes first state to outlaw gas stoves, targeting emissions and health risks.

»»» In May 2023, the state of New York declared it was going all in on electric. By 2026, many new buildings will have to skip gas stoves (and furnaces or water heaters) to protect household indoor air quality and help the state meet its emissions-reduction targets.

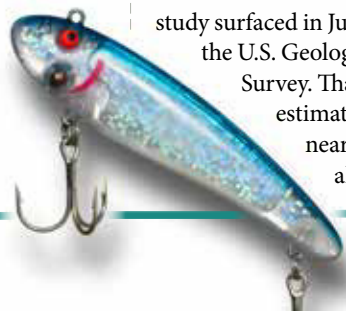
The action came after a study on gas stoves and air pollution ignited a culture war in January. The paper, published in the *International Journal of Environmental Research and Public Health*, indicates that gas stoves are likely behind 1 in 8 cases of asthma among U.S. youth.

“The silver lining is that exposure to gas-stove pollution is entirely preventable,” says study co-author Brady Seals, a manager for the clean energy nonprofit RMI.

President Joe Biden's administration briefly considered banning the sale of gas stoves this past winter. That consideration — and the concern over the appliance's public health risks — was short-lived, as proponents of gas insisted their cooking would suffer. Among the gas-alternative options, electric-powered induction stoves have proven their ability to cook food faster and more evenly than traditional cooktops. Regardless, commercial kitchens and labs are among the facilities exempted in New York — for now.

“New York is investing in our climate and our health by ensuring that modern electric appliances that save energy are the new norm,” Seals says.

The state is following in the footsteps of several California cities with stove bans, including San Francisco (as of March this year) and Berkeley (in 2020). Industry opponents have already overturned at least one local stove ban in court, and the U.S. House passed a bill in June blocking any potential federal bans. —YESSENIA FUNES



2023 NEWS BRIEF

REEF SHARKS IN DECLINE

Overfishing is pushing five common reef shark species toward extinction, reports a June study in *Science*. The global survey of nearly 400 coral reefs revealed population declines of up to 73 percent, disproportionately affecting less-wealthy countries with limited resources for management and enforcement. The loss of these predators further disrupts an ecological balance already threatened by rising ocean temperatures.



CANADIAN WILDFIRES in 2023 were the worst on record, engulfing American cities like New York (below right) in smoke. In the Southwest (below left), high temps turned pavement burning hot.

THE YEAR OF GLOBAL WEIRDING

Weather extremes in 2023 continued a trend of shattering records.

▶▶▶ **WHILE TEMPERATURES** in Phoenix soared above 110 degrees Fahrenheit for a record-shattering 31 straight days in July, people began turning up in emergency rooms with third-degree burns they'd suffered after falling — their skin seared by blistering hot pavement. Although not unprecedented,

burn specialists said the number and severity of injuries were much higher than ever before.

Meanwhile, 30,000 feet up, the jet stream had become deranged. Its wavy, loopy

and swirling pattern helped lock heat domes in place, like the one over south-central Arizona. Meteorologist Jeff Berardelli called the pattern “insane.” University of Pennsylvania climate scientist

Michael Mann likened it to a Vincent Van Gogh painting.

In Canada, by midsummer, wildfire season was already twice as bad as any other on record, thanks to abnormally warm and dry conditions. By early September, 63,700 square miles had burned — about half the size of South Carolina. Far-flung smoke from the blazes choked millions in major cities like

New York and turned skies a sickening shade of orange.

Elsewhere in the world, parts of India saw particularly heavy monsoon deluges that inundated several cities for days. Over the past seven decades, the monsoon has become more erratic, with more extreme rainfall as well as sudden droughts, at least partially tied to warming Indian Ocean waters.





FLORIDA OCEAN temperatures surged past 101 degrees Fahrenheit this past summer, threatening both coral and marine life.

Back in the early 2000s, author and environmentalist L. Hunter Lovins coined the term “global weirding” as an alternative to “global warming.” The idea was to describe where Earth was heading with continued emissions of greenhouse gases. The weather extremes of 2023 suggest she was prescient.

“I do think there’s something to the ‘global weirding’ framing,” says Mann. “We’re experiencing a type of weather behavior we haven’t seen before.” Research by Mann and colleagues has tied certain behaviors — like stalled weather systems floating over a place for weeks on end — to a jet stream flow made wavier than normal by climate change. But that possible connection is still the focus of intense scientific study.

WHILE SOME of the detailed mechanisms are still being worked out, there’s no doubt humans have been tilting the climatic scales toward more intense and frequent extreme weather. In addition to hotter and longer-lasting heat waves, that includes drier droughts (with both hot and dry conditions contributing to wildfire disasters), as well as heavier deluges.

In 2023, our hand seemed to push even more heavily on the scales. On July 6, for example, Earth’s average surface temperature soared to an unofficial record high. It could well have been the warmest

day in 120,000 years. Research has shown that heat waves in Southern Europe, North America, and China were made 1.8 F to 4.5 F hotter by climate change. Moreover, the maximum heat experienced in some of these regions would have been all but impossible without our influence.

With broiling heat still gripping large parts of the planet, scientists knew well before the end of July that the month would be the warmest on record. This prompted U.N. Secretary-General António Guterres to say, “The era of global warming has ended; the era of global boiling has arrived.”

Outside of the polar oceans, April’s average global sea surface temperature had vaulted to a record-high seasonal value, and sea temperatures continued shattering records every day through September. A burgeoning El Niño — characterized by large amounts of oceanic heat surfacing in the equatorial Pacific — contributed to the sweltering surface waters. But that couldn’t explain all of what was happening.

The current El Niño is building on top of long-term, human-caused warming of the oceans. Thanks to both, 2023 is likely to go down in the record books as the warmest year ever observed. And 2024 could be warmer still, with weather becoming even more extreme.

—TOM YULSMAN

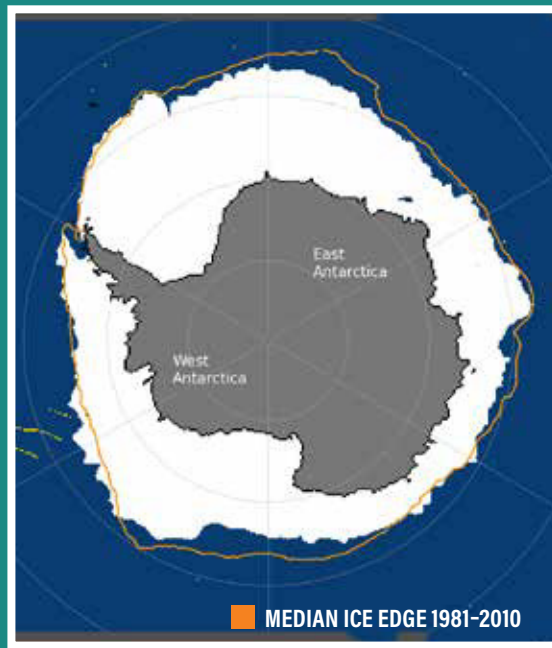
Icy Trouble in Antarctica

AS 2023 dawned, the giant aprons of sea ice that fringe Antarctica had shriveled to a record-low extent. Then, the situation worsened: Despite plunging winter temperatures, the seasonal ice expanded at a record-slow pace. By mid-August, the expanse was lacking an area more than one-quarter the size of the U.S. compared to the long-term average. Experts said they had never seen anything quite like it.

This lack of seasonal ice could have a ripple effect of further loss, as its formation shields long-lasting shelves of Antarctic ice from pounding ocean waves. These floating ice shelves in turn buttress the flow of glaciers draining from the endangered West Antarctic Ice Sheet, or WAIS, on land. When sea ice shrivels, the buttressing can weaken — potentially hastening runaway ice flow from the WAIS into the sea. That could raise sea levels dramatically before this century’s end.

The WAIS has already shed more than 3 trillion tons of ice in 25 years, possibly the start of a catastrophic collapse of the ice sheet. Experts say that reducing greenhouse gas emissions remains the most vital action humans can take to slow down or prevent this outcome. —TOM YULSMAN

SEA ICE EXTENT AS OF SEPTEMBER 2023



AS OF SEPTEMBER 2023, the sea ice surrounding Antarctica was more than 1 million square kilometers (or about 400,000 square miles) below any previous record lows.

THE SLOWING OF DEEP-SEA CURRENTS



AS THE MELTING of Antarctica's ice shelf accelerates, an ominous slowdown in ocean circulation could have devastating climate impacts.

New research flags an alarming shift in the ocean's coldest, deepest water.

DOWN IN THE coldest recesses of the deepest oceans, Earth's circulatory system is pumping the brakes. Left unchecked, it threatens to halt a process that regulates the planet's energy balance and stabilizes our climate.

"Earth's climate is fundamentally controlled by our ocean and by the ocean's overturning circulation," says Matthew England, an oceanographer at Australia's University of New South Wales. In March, he and a team published the most detailed global model of Antarctic water masses and other deep-sea currents to date in the journal *Nature*. They found that, compared to its flow in the 1990s, this vital oceanic conveyor belt could slow by about 40 percent before 2050.

Deep water circulation kicks off at the polar extremes. In the southern Antarctic seas, freezing seawater relinquishes its salt, causing the water around it

to grow heavy. Cold as ice and far saltier than a can of sardines, it plunges to more than 13,000 feet and begins slinking northward into the planet's sunken ocean basins.

As decades pass, this extra-salty Antarctic Bottom Water (AABW) creeps toward the subtropics. There, waves and gyres pull it to the surface, making room up top by pushing warmer water to higher, colder latitudes where it too begins to freeze, descend, and join the loop.

In this way, some of the coldest water on Earth moves heat, carbon, oxygen and other nutrients around the globe. It feeds phytoplankton, fuels ecosystems and wields enormous influence over our climate. But the system

is failing, and England's research proves why — with an answer that shouldn't be a surprise.

Our greenhouse gas emissions have warmed the poles, causing the Antarctic ice shelf to melt and release huge amounts of freshwater into the sea. This influx causes polar water to become less salty, less dense, and thus less apt to sink.

"It's alarming in the sense that the feedback from this collapse of the overturning is more warming, and that means more ice melt," England says. "There's a chance that we've locked in a collapse of this overturning."

SUCH A breakdown hasn't happened for more than 100,000 years, since at least the last interglacial period. And it would be devastating. Changes we already endure — collapsing marine

ecosystems, strengthening cyclones, smothering heat waves, bleaching coral reefs, and calamitous sea level rise — would only intensify. In July, a team from Denmark revealed how similar warming in northern seas is on pace to stall the AABW's Atlantic sister current by midcentury.

To model circulation strength at unthinkable depths, England's team relied on direct observations of temperature, as well as vital measurements taken by the larger oceanographic community. These included oxygen levels recorded across ocean strata, and even measurements taken from transducers strapped to elephant seals — a technique used to get as close to the ice shelf as possible.

"They made a model that created Antarctic Bottom Water in a realistic way, and nobody else had understood that," says Spencer Jones, a physical oceanographer at Texas A&M University who was not involved in the study.

Using data at an incredibly fine scale, the landmark research is consistent with circulation slowdowns projected in recent Intergovernmental Panel on Climate Change reports, and exposed how the melting ice shelf, specifically, is driving this change.

England says getting his team's experiment right also took a bit of luck. Avoiding its predictions, however, will require deliberate action. "We're probably halfway into the slowdown we projected," he says. "It's a tough ship to turn around, but with dramatic emissions reductions, we can save it from a full collapse." — STEPHEN ROBERT MILLER



PSYCH & NEURO

THE NEURODIVERSITY MOVEMENT HAS A MOMENT

Gaining ground in 2023, the movement is making its mark on social media as well as science.

»» **BY THE MIDDLE** of August 2023, one of Joey Lawrence’s videos on TikTok had over 3 million views — and it wasn’t a viral dance or recipe. Lawrence, a psychologist who also happens to be autistic, had posted the video about a month prior to talk about a new autism assessment on monotropism, when a person’s attention is dedicated to a narrow range of interests.

The views on Lawrence’s video aren’t entirely surprising: TikTok has exploded with content on neurodiversity since the app’s surge in popularity during the pandemic. Now there are over 11 billion views on TikTok’s hashtag #neurodivergent, and Google searches for the term have increased steadily over the past year.

Neurodiversity is a term that refers to the natural range of differences in people’s brains. The neurodiversity movement says that the brains that diverge from the average within that

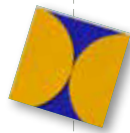
range shouldn’t be dismissed as deficient automatically. Instead, if a neurodivergent person struggles to function in society, it may be because there’s a mismatch between their abilities and their surroundings, not because there’s something inherently wrong with their thinking.

The term dates back to the autism community in the 1990s, though it’s now applied to all sorts of mental differences — from ADHD to synesthesia. And though neurodiversity went mainstream as

a social justice movement, it’s now transforming the way we research the brain, with more and more researchers applying neurodiversity-inspired approaches to cognition.

IN THE PAST, “autism was widely seen as an individual medical tragedy,” writes Robert Chapman, a neurodivergent philosopher with autism, in their 2023 book *Empire of Normality: Neurodiversity and Capitalism*. “The only hope for autistic people and our families, it was thought, was that we would one day be fixed through behavioral conditioning or biomedical intervention.”

Neurodiversity challenges that notion. Rather than assuming, for instance, that an autistic person’s



2023 NEWS BRIEF

CARDIAC CLOCKS

This year, two separate studies revealed that the rates and rhythms of our hearts affect our perceptions of time. The first study, published in March, found that a shorter span between heartbeats causes our senses of time to speed up, while the second, published in April, found that assessing a short, neutral stimulus — whether auditory or visual — at the same time as the heart contracts causes that stimulus to feel faster. Taken together, the studies suggest that the brain isn't the only timekeeper in the body.

struggles to find a job are the result of some internal shortcoming, neurodiversity research considers the existence of external explanations. By doing so, researchers in 2023 added to the growing body of evidence that non-autistic people can react negatively to the style, not content, of autistic communication, suggesting that barriers to autistic employment emerge from the environment, not only the individual.

Added to this are shifting understandings of the theory of mind, or the ability to consider other people's perspectives. "Traditionally, researchers suggested [the] theory of mind was deficient in autism," says Patrick Dwyer, an autistic graduate student studying developmental psychology at the University of California, Davis. "Some even said this was a core, central deficit common to all autistic people."

Studies from 2022 and 2023 have shown, however, that many autistic people are prosocial and skilled at seeing others' perspectives, while neurodiversity advocates stress it takes two to communicate. Though autistic people may struggle to understand a neurotypical perspective, neurotypical people may struggle to understand an autistic perspective, "making it a 'double empathy problem,'" Dwyer says.

This thread of research is already having an impact, helping autism interventions like the "social stories" technique take off. In June 2023, a study in *Frontiers in Psychology* proposed that this intervention, which introduces autistic children to common social situations, works by facilitating communication between neurodivergent and neurotypical individuals, with

a focus on supporting children, rather than "fixing" them.

The technique is compatible with what autistic individuals advocate for themselves. In February 2023, Elizabeth Pellicano, an autism researcher at University College London, published an assessment of the funding of recent autism research. She found the majority was directed toward the biological causes of autism, while the minority was directed toward services, support and education. Consulting members of the autistic community, she asked if the funding reflected their priorities. "They felt that there was such an imbalance in the research profile ... that most of the research was not going to have any effect on everyday lives," she says.

Among the topics that participants felt were ignored were the advantages of mental difference. "Wouldn't it be amazing to see research examples of,

like, autistic people's resilience and ability to thrive?" one participant responded.

BY BREAKING down the negative connotations of cognitive difference, the neurodiversity movement could change how cognitive science is conducted, pushing researchers to embrace and explain a broader assortment of brains, according to a February 2023 *Cognitive Science* paper. "Cognitive science can develop more general theories of cognitive diversity by broadening the range of diversity it considers worthy of attention," write the authors of the paper, including the University of Munich's Justin Sulik, a cognitive scientist with ADHD.

IN RECENT YEARS, more research has shown that the inner workings of our brains are strikingly varied. Some people have aphantasia and lack a mind's

eye, while some lack an internal monologue. Others have synesthesia and see colors or numbers decorating their perception. These differences are all forms of neurodivergence, Sulik says, and aren't always detrimental. A January 2023 study suggests, for instance, that people with aphantasia aren't negatively affected by their inability to create mental images. "There's no one way that the mind is supposed to work," Sulik says.

Crucially, the neurodiversity movement allows neurodivergent people to transform their thinking about themselves. "The dominant medicalized narrative suggested that being autistic made me somehow tragic, broken, and in need of fixing," Chapman writes in their 2023 book. "This was why I found discovering the neurodiversity movement, which offered a different analysis, so liberating."

As for neurodivergent people on TikTok, they're finding communities to celebrate their minds. "One of my favorite things about being neurodivergent is that my thoughts make no sense," one user shared in a video from April 2023. "But other neurodivergent people, they understand." —SHAYLA LOVE





ALEXANDER HUTH and his team trained their AI decoder on brain activity data from fMRI machines. The result is a tool that translates thoughts into written words.

AI MIND-READING

Artificial intelligence tools like ChatGPT and Midjourney have become notorious for creating text and visuals according to our direct commands. Next up: reconstructing our thoughts.

»»» **HERE'S A SHORT** story: "I got up from the air mattress and pressed my face against the glass of the bedroom window expecting to see eyes staring back at me, but instead finding only darkness."

Now here's another: "I just continued to walk up to the window and open the glass I stood on my toes and peered out I didn't see anything and looked up again I saw nothing."

The first is a snippet that a person heard while in a functional magnetic resonance imaging (fMRI) machine, which measures blood flow in the brain. The second is what artificial intelligence (AI) recreated, based on that brain activity.

In a study published in May 2023 in *Nature Neuroscience*, a team of researchers from the

University of Texas at Austin showed that an AI decoder could translate the words people heard while listening to podcasts and the images people saw while watching silent movies. Matching specific patterns of brain activity to specific phrases, the AI was trained on three people as they consumed 16 hours of storytelling. From that learning, the technology could decode the thoughts of someone "imagining a story in their head," says neuroscientist and senior study author Alexander Huth, though its accuracy was greatly reduced for

individuals who were not involved in its training.

According to the team, the AI could one day be used to assist stroke patients and others who have lost the ability to speak, by converting their brain activity into words. And the team's decoder isn't alone in its mind-reading applications. In March, researchers from Osaka University reported that they'd developed a similar model, dubbed Stable Diffusion, that reconstructs images from fMRI scans.

If it feels invasive, researchers stress that it's unlikely AI will be able to read your mind without your consent anytime soon. "The current technology is still very far removed from a general-purpose

mind-reading device," says Iris Groen, a neuroscientist at the Informatics Institute at the University of Amsterdam not involved in the new work.

Both approaches require participants to spend hours in fMRI scanners, and the University of Texas AI can make mistakes, spouting gibberish if a person thinks unrelated thoughts. And researchers are still prioritizing the privacy of our internal imaginings, given the pace of AI's progress.

"The brain contains extremely sensitive personal information," says Yu Takagi, a neuroscientist involved in the Stable Diffusion project. "It should not be subjected to any form of analysis without informed consent."

— SHAYLA LOVE



A COLLECTION of abyssal specimens adorns the lab of Muriel Rabone, a biologist at the Natural History Museum in London, including a sea anemone (far left) and several varieties of sea cucumbers (middle left and far right).

EARTH SCIENCE

BATTLE FOR THE DEEP SEA

The bottom of the Pacific is home to thousands of sea creatures new to science. Will that be enough to save it from the destruction of deep-sea mining?

▶▶▶ **BETWEEN** Mexico and Hawaii, at the bottom of the Pacific Ocean, lies the Clarion-Clipperton Zone. This abyssal plain sprawls over 2.3 million square miles, over half the size of the contiguous U.S., and plunges to depths exceeding 3 miles in some places. The water here is just above freezing,

and no sunlight reaches it. Yet for thousands of species that scientists know almost nothing about, the strange landscape is a happy home — for now.

The creatures in the CCZ are nothing short of bizarre: long-tentacled creatures that resemble shooting stars, bristly worms that look like they're made of ice crystals,

and a sea cucumber nicknamed “the gummy squirrel” because of its translucent, candy-yellow color and tail-like sail. Each represents a tiny fraction of the 5,142 unnamed species announced in May in the journal *Current Biology*.

There are a few key caveats to that number — some of those unidentified creatures

might belong to the same species, for example — but, ultimately, “around 90 percent of the diversity from the area is new to science,” says Muriel Rabone, a biologist at the Natural History Museum in London and lead author of this first-ever checklist of animals in the CCZ.

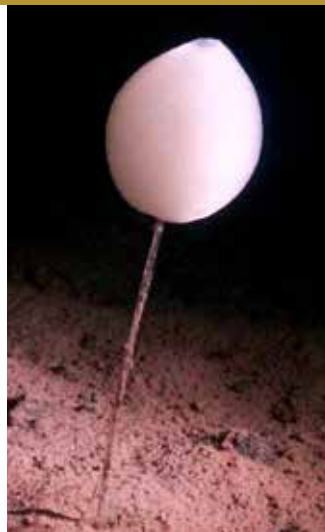
Back on land, however, an ongoing debate about

deep-sea mining threatens to upend this hidden world. The unusually high concentration of bumpy, metal-bearing nodules on the region's seafloor makes it an attractive mining prospect; these nodules have grown over the course of millions of years, as metals like manganese, iron and cobalt dissipated from the seawater and clung to small fragments of shell or bone. "It is one of the slowest known geological processes," says Rabone.

The potato-sized lumps could help fuel the rising demand for rechargeable batteries in electric cars and other electronics — though, perhaps, at a cost. Deep-sea mining has not yet begun anywhere, but budding tools include AI-equipped robots that select and grab nodules or dredge pumps that stir up sediment and suction the nodules back to the surface.

The potential carbon footprint of such activities is unknown, Rabone says, and might even outweigh the proposed benefits of electric vehicles in curbing climate change. "People don't know what the environmental risk will be, and what the associated socioeconomic risk will be," she says.

TO REMEDY this lack of knowledge, scientists like Rabone have worked for the past few decades to survey the life found in the deep sea, with a goal of learning what lives where and how different populations interact. Because the CCZ is too deep for easy human exploration, researchers turn to box corers: These stainless steel contraptions take samples of sediment from the seafloor and return them to scientists waiting on ships above.



"We sift all the mud, we take a look at all the nodules, we look at all the animals on the nodules, take photos, catalog everything," says Rabone. The May study compiled results from similar missions undertaken in recent years.

Stefanie Kaiser, a biologist at the Senckenberg Research Institute and Natural History Museum in Germany, also studies life in the CCZ. Though she was not involved with the recent paper, she thinks the estimate of new species is a conservative one. And the fact that we know next to nothing about these creatures, or what they do for the planet, is why we should protect them, she adds.

As laws currently stand, 54 percent of the deep ocean



THIS MENAGERIE of deep-sea critters includes (clockwise, from top left) a carnivorous sponge, a squat lobster, and two varieties of sea cucumber.

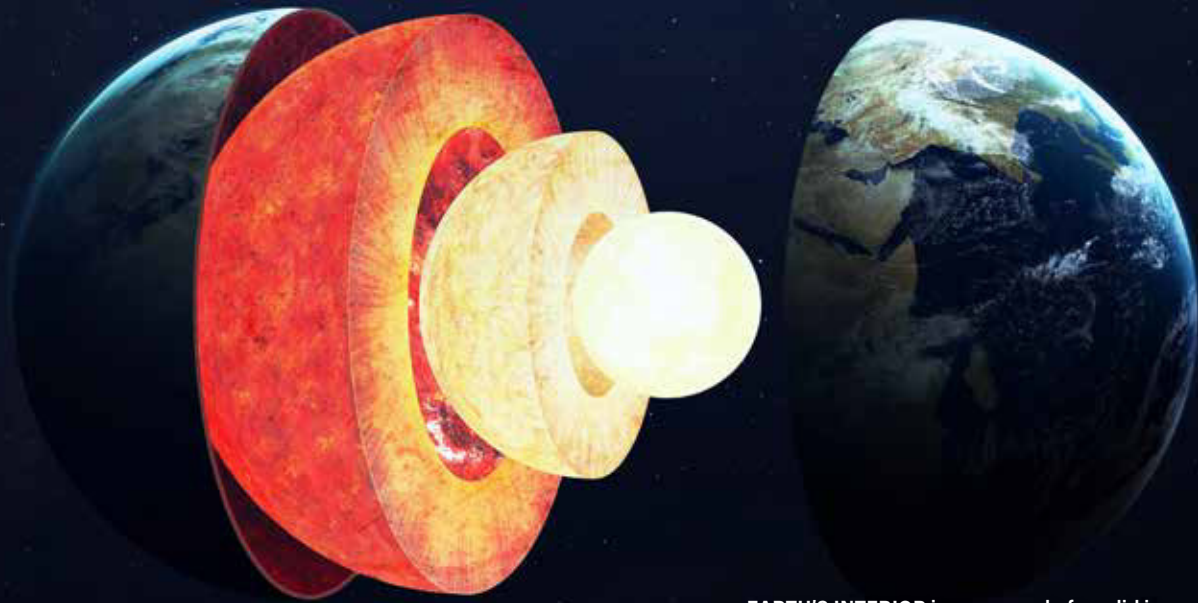
established this rule, further states that if no code is reached within two years of a country putting forth a proposal to mine in this area, mining can begin.

And in the summer of 2021, the Oceanic nation Nauru, along with Canadian mining firm The Metals Company, requested to do just that in the CCZ. As of July 9, 2023, with no code agreed upon and the waiting period expired, the region became, at least theoretically, open for business. Later that month, the International Seabed Authority, a U.N. regulatory body, postponed the possibility of mining until 2024 at the earliest.

Rabone hopes that further studies will inform and even temper these interests. She notes that researchers have isolated anticancer compounds from sponges in the past, and that the CCZ's animals could someday provide similar benefits. "What we potentially lose if we mine," she says, "is an important question for us to ask."

— KATE GOLEMBIEWSKI

— including the CCZ — is considered "the common heritage of mankind," unavailable for mining until a code is established to mitigate ecological damage and ensure global sharing of the wealth generated. The 1982 United Nations Convention on the Law of the Sea, which



EARTH'S INTERIOR is composed of a solid inner core and a liquid outer core, both surrounded by a rocky mantle beneath its outer crust.

EARTH'S CORE IS CHANGING

A rotational slowdown could alter the length of a day or slightly influence the planet's weather patterns.

▶▶▶ **DEEP BENEATH** our feet, under 1,800 miles of rock, the planet's core is undergoing profound change. How quickly it is changing, however, has long remained a mystery.

In a January 2023 study published in *Nature Geoscience*, Yi Yang and Xiaodong Song of Peking University in China used the seismic waves produced by many sets of nearly identical

earthquakes to deduce the motion of Earth's inner core. This dense center appears to have consistently spun faster than the outer layers of the planet from the 1970s to the early 2000s.

Much to the researchers' surprise, however, they also found evidence that core motion may have slowed to match — and then fall behind — the speed of Earth as recently as 2009. The core

is still rotating in the same direction but, from the perspective of someone on the planet's surface, it appears as though the core has reversed its spin.

The outer and inner layers of Earth's core — the former liquid, the latter solid — are made almost entirely of iron and nickel. When our planet and other rocky planets formed, these heavy elements naturally sank to the interior

and concentrated into metallic cores.

Humans have yet to drill even one-hundredth of the distance to where the rocks of Earth's mantle give way to its core. We know, however, that this central structure generates one of the most important requirements for life: a powerful magnetic field. On Earth, the field protects against cosmic rays and their radiation.

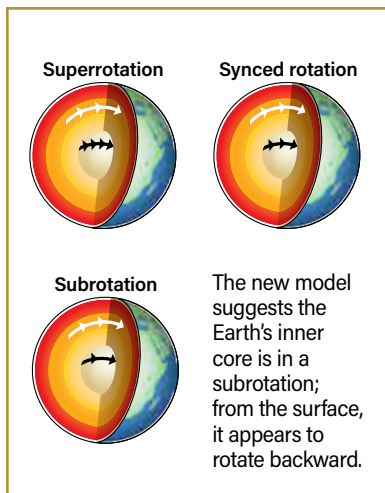
SUNKEN SEAFLOORS

Where does oceanic crust go after it is thrust back into Earth's mantle in places like the Andes or Cascades? Using seismic waves, the same basic technique Yi Yang and Xiaodong Song employed in their investigation of the Earth's core, an April study in *Science Advances* may have found evidence for the fate of these slabs of basalt.

Some areas along the core-mantle boundary are known as ultra-low velocity zones, meaning that seismic waves produced by earthquakes move much more slowly here than in surrounding rock. The authors of the latest study propose that these zones are oceanic crust — denser and colder than the mantle rocks around it — that

has sunk to the core-mantle boundary.

Some of these underground "mountains" reach heights up to five times taller than Mount Everest. They may help explain changes in the heat emanating from the planet's core and the composition of hot mantle plumes that fuel volcanism in places like Hawaii and Iceland. —E.K.



But according to the geologic record, Earth's magnetic field is far from a constant phenomenon. Instead, it goes through periods of reversals where magnetic north becomes magnetic south. Could the change in the inner core's rotation be a harbinger of such a magnetic field reversal coming soon? Probably not.

It might instead be part of a routine 70-year cycle of oscillations, Yang and Song suggest. One effect of the oscillations is very minor variations to the length of a day, around a millisecond at most. The researchers also suggest that the changes in the core's behavior might indirectly influence Earth's climate system through small, cyclic movement of the planet's surface. For most people, these changes fly well under the radar.

Additionally, the proposed 70-year timescale for these oscillations remains controversial. Others have suggested the core alters its rotation on timescales ranging from a few years to a few decades, much shorter than Yang and Song's model suggest. In an interview with *Phys.org*, seismologist Hrvoje Tkalčić attributes the differences to the potentially incomplete data sets from which many models draw.

And with miles of solid rock separating us from the core, it will likely be a long time before we unearth all its secrets.

—ERIK KLEMETTI

WRITTEN IN SAND

Amazon River sediments reveal exactly when (and how quickly) the Andes grew to such great heights.



➤➤➤ **SAND IS EVERYWHERE.** Most people don't take notice of the tiny grains of broken rock or shells within it, and may even curse the way it gets all over the car after a beach trip. But in that sand could lie a geological record of some of the planet's mightiest mountains.

Research published in *Nature Communications* in late 2022 examined the sands washed from the Andes Mountains by the Amazon River. Millions of years' worth of this sand has accumulated in the Atlantic Ocean, thousands of miles away and on the opposite coastline from its source. The researchers, led by Cody Mason from the University of West Georgia, turned to the tiny zircon crystals found within this dusty debris to map out a part of the continent's tectonic history.

Zircon is tough. When exposed to the wind, rain and waves that break down other rocks at the Earth's surface, this ultra-durable mineral survives. It is also a fabulous clock because it's rich in radioactive elements like uranium and thorium. As these slowly transform into lead, through a predictable process called radioactive decay, they release helium atoms along the way. By analyzing the ratio of these elements within the crystals, researchers can pinpoint not only when the zircon first formed, but also when it made its way to the surface as surrounding mountain eroded.

In this way, Mason and his colleagues found a recorded history of Andean mountain growth spanning the past 180 million years within the grains of sand from the Atlantic, with the modern Andes popping up as recently as 12 million years ago — a blink of the geologic eye. In many cases, this sand might be all that is left from mountains long since leveled. "Sedimentary rocks provide important insights into the systems shaping our planet's surface," says geologist Chelsea Mackaman-Lofland of Ohio's Denison University, who was not involved with the study. "But not every Earth event gets preserved in sedimentary rock."

Filling in these gaps using the Amazon sand record and cutting-edge techniques is what she finds so exciting about the new work.

So, to those who love to lounge on the beach, surrounded by seemingly infinite grains of sand: Consider that millions of years ago, you might have needed to climb mountains as tall as the Andes to stand on the same stuff. —ERIK KLEMETTI



THIS SATELLITE image shows just how much sediment the Amazon River dumps into the Atlantic Ocean: a whopping 1.3 million tons per day.



THE SHAPE AND SIZE of its skull and the neuronal scaling rules of its modern relatives informed a new attempt at quantifying the intelligence of *Tyrannosaurus rex*.

PALEONTOLOGY

BEASTS WITH BRAINS

A controversial study suggests that *T. rex* brains brimmed with neurons.

▶▶▶ **PALEONTOLOGISTS KNOW** a lot about *Tyrannosaurus rex* from the abundance of fossilized specimens they've found throughout North America. They know, for instance, that the theropod had sharp, serrated teeth, each the size of a banana, and a bite force over a hundred times that of a human. They also know that the species had a huge head, almost 5 feet from front to back. But, in the absence of brain

tissue, what was inside that massive skull has remained a mystery.

In a study published in the June 2023 issue of the *Journal of Comparative Neurology*, Suzana Herculano-Houzel, a neuroscientist and associate professor of psychology at Vanderbilt University, took a controversial first stab at calculating the neuronal count of several species of dinosaur, including *T. rex*.

Neuronal numbers are difficult to determine without brain tissue, though they aren't impossible to approximate in modern species, since there are scalable relationships between an animal's brain mass and number of neurons that differ depending on the animal. The scalable relationships for birds can estimate the

neuron count of a sparrow, for instance, while the scalable relationships for reptiles can estimate the neuron count of a snake. Armed with that wisdom, Herculano-Houzel set out to estimate the neuronal numbers of *Tyrannosaurus*, based off the neuronal scaling rules of the theropod's distant, modern-day relatives.

Comparing the brain mass of *T. rex* (extrapolated using the shape and size of its brain cavity) with the brain masses of birds and reptiles, she found that *T. rex* and ostrich brains were similarly sized in comparison to their bodies. From this, she surmised that the theropod followed a similar set of scaling rules as ostriches and ostrich-related birds. Using those birds as a guide, she then developed a set of scaling equations, which would supposedly estimate the dinosaur's neuronal composition.

Herculano-Houzel's calculations suggested that the theropod carried over 3 billion neurons in its cerebrum — a

2023 NEWS BRIEF

DINO EGG DISCOVERY

Surprise! Experts announced in March that an agate specimen from central India — added to the Natural History Museum's collections in London in 1883 — is also a 67-million-year-old dinosaur egg. Its size, shape and shell are consistent with those laid by titanosaurs, the most common dinosaur in India at the time, and could offer insights into the reproductive strategies of these prehistoric giants.

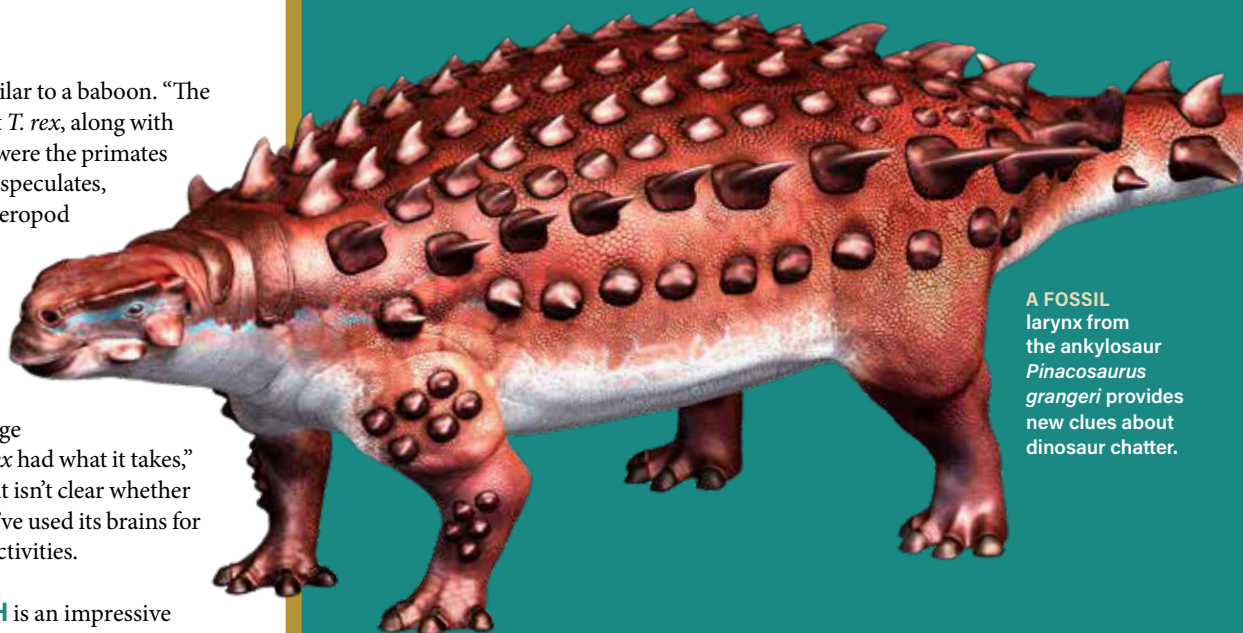
neuron count similar to a baboon. “The study showed that *T. rex*, along with other theropods, were the primates of their time,” she speculates, adding that the theropod may have been capable of the same complex cognition that allows primates to produce tools and pass knowledge to offspring. “*T. rex* had what it takes,” she adds, though it isn’t clear whether the species would’ve used its brains for those particular activities.

THE RESEARCH is an impressive attempt to quantify the intelligence of a species from 66 million years ago, says Amy Balanoff, a paleontologist at Johns Hopkins University not involved in the study, “but the author uses too broad of a brushstroke when trying to estimate the [theropod’s] brain mass.” Failing to account for a sinus that did not contain brain tissue inside the *Tyrannosaurus* skull, Herculano-Houzel’s equations may have assumed a greater similarity between *T. rex* and ostrich brains than truly exists, potentially throwing off the neuron estimates.

Ashley Morhardt, a paleoneurologist at Washington University School of Medicine in St. Louis, has her own concerns about the approach. Not only is it possible that the equations over- or underestimated the number of neurons in the *T. rex* brain, but there’s also no way to verify the truth of their estimations. “It’s never been done before,” she says, and “because of the fact that ... soft tissues at the neuronal level don’t fossilize, there’s no way for us to ground truth it.”

Both Balanoff and Morhardt argue that the baboon comparison is a stretch, but Balanoff believes the research is promising for future studies of *T. rex* smarts. “It’s given us the idea that maybe this is possible,” Balanoff says. “We might, at some point, get to an estimation of neurons.” Until then, all that’s safe to say is that *Tyrannosaurus* was as smart as it needed to be, whether the theropod was on par with modern primates or not.

—SARA NOVAK



A FOSSIL larynx from the ankylosaur *Pinacosaurus grangeri* provides new clues about dinosaur chatter.

DINOSAUR FOSSILS FIND THEIR VOICE

A first-of-its-kind analysis indicates that the ankylosaurs sang a surprisingly sophisticated — and birdlike — tune.

➤ **ON THE** topic of dinosaur sounds, there’s a whole lot of silence. And it’s no wonder, since most of their sound-producing structures were made of fragile tissues that usually failed to fossilize. But in February 2023, an analysis of the first dinosaur larynx fossil ever discovered provided new insights into their vocalization. Taken from an ankylosaur that lived in Mongolia between 84 million and 72 million years ago, the voice box suggests that the dinosaur may have tweeted, twittered, and cooed rather than roared.

Comparing the fossil to the sound-producing anatomy of birds and reptiles, researchers found that the ankylosaur’s larynx was much more avian than reptilian. Though the ankylosaur — a member of the species *Pinacosaurus grangeri* — possessed some of the same

laryngeal structures as both birds and reptiles, only in ankylosaurs and birds were those structures ossified, enlarged, and linked together by firm, highly kinetic joints. According to the analysis, which was published in *Communications Biology*, this likely means that the dinosaur produced a slew of loud, birdlike sounds.

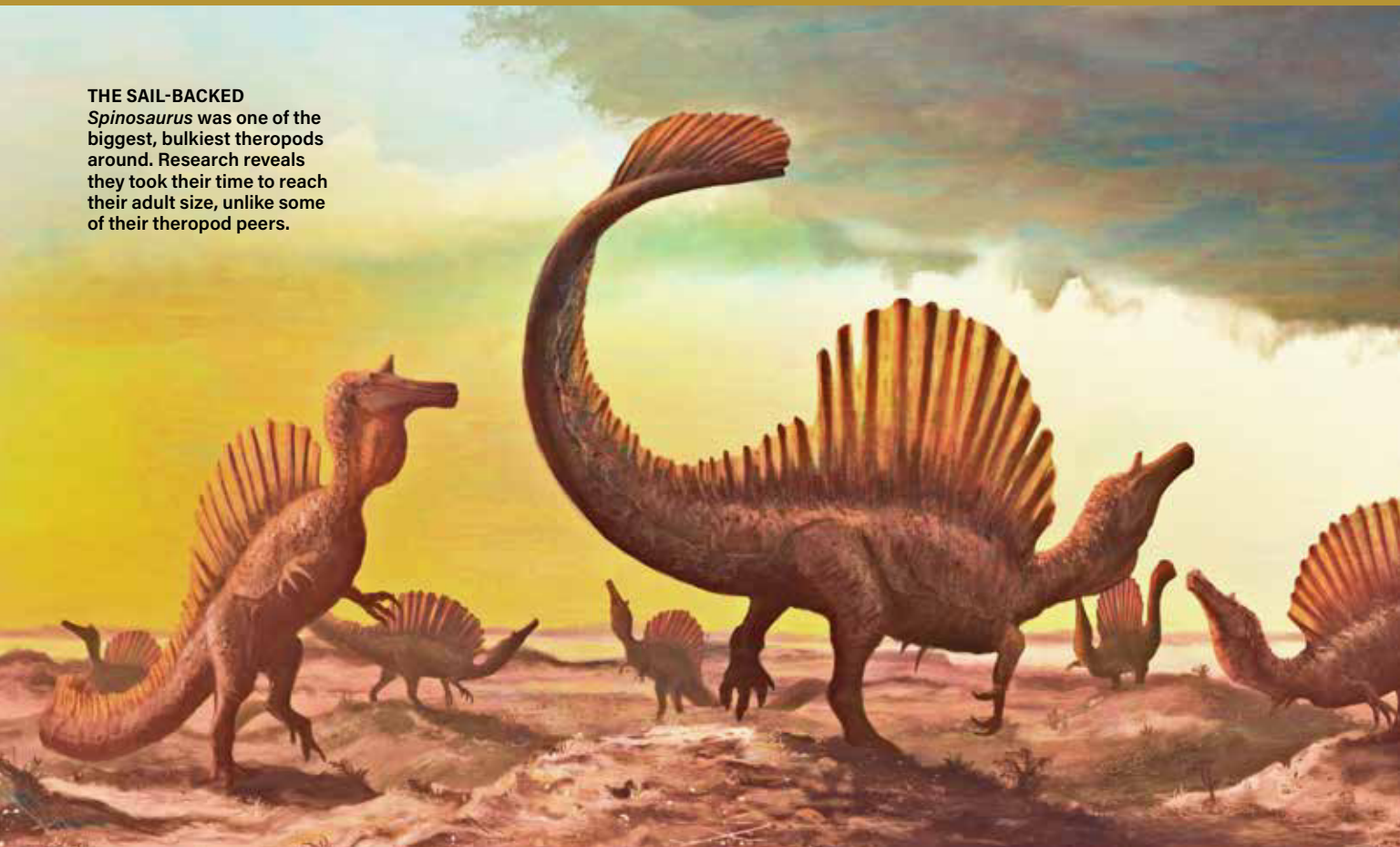
“This is the first discovery that a non-avian dinosaur larynx can fossilize and that it is similar to that of birds,” says study author Junki Yoshida, a paleontologist at the Fukushima Museum in

Japan. But while the study did discern a level of complexity in ankylosaur vocalization, it didn’t define what that vocalization specifically sounded like. “We still don’t know because we only found part of the vocal organ,” Yoshida says, though reconstructing those sounds no longer seems so out of reach. —SARA NOVAK



THE SAIL-BACKED

Spinosaurus was one of the biggest, bulkiest theropods around. Research reveals they took their time to reach their adult size, unlike some of their theropod peers.



Dinosaur Dimensions Weren't One-Size-Fits-All

An analysis of theropod bones tests the traditional theories of dinosaur development.

▶▶▶ **FIRST SCAMPERING** onto the scene around 230 million years ago, theropod dinosaurs were some of the biggest predators on the block — and also some of the smallest. From the ferocious 14,500-pound *Tyrannosaurus* to the feathery 2-pound *Microraptor*, these prehistoric beasts pushed size to the extremes.

For decades, paleontologists thought the theropods evolved into giants and pipsqueaks by adjusting the pace of their growth: Only by growing more quickly than their ancestors did they bulk up, and only by growing more slowly did they trim down. But in 2023, an analysis of bones from 42 separate species of theropod put that theory to the test. Published in *Science* in February, the results revealed that the theropods

used an assortment of developmental mechanisms to size up and size down.

To understand the diverse statures of these predators, the researchers took a microscopic approach. Michael D'Emic, paleontologist at Adelphi University in New York, and colleagues examined sliced, paper-thin sections of more than 80 fossilized bones belonging

to species that ranged from the pigeon-sized *Mei* to the yacht-sized *Spinosaurus*. They then stuck these cross sections under a powerful microscope to analyze their features.

Like tree trunks, the cross sections contained annual growth rings, which were deposited as the dinosaurs developed. These minuscule rings allowed the researchers to determine the age and rate of growth of the different theropods, with wide rings indicating an accelerated growth rate and narrow rings indicating a decelerated growth rate.

OVER THE COURSE of a decade, the researchers



SLIVERED SECTIONS of fossilized bones revealed the theropods' ages at death, as well as the rates and the durations of their growth.

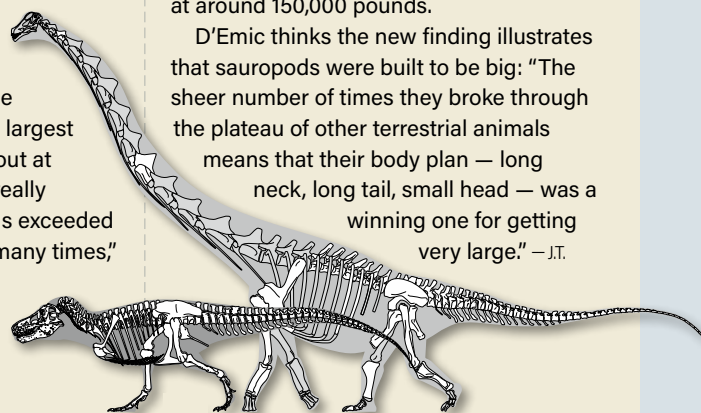


SAUROPODS SIZE UP

Paleontologist Michael D’Emic also analyzed how sauropods, the long-necked herbivores, evolved to such staggering sizes. In a paper published in *Current Biology* in 2023, D’Emic estimated the mass of nearly 200 species of sauropod and plotted the estimates onto an evolutionary tree, visualizing their transformations over time.

He found that sauropods maxed out dozens of times. Over the course of 100 million years, at least 36 different lineages surpassed the maximum size achieved by the largest land mammals, which topped out at almost 53,000 pounds. “I was really surprised to find that sauropods exceeded terrestrial mammalian size so many times,”

ONE OF THE largest sauropods to ever exist, *Dreadnoughtus* would’ve loomed over large theropods like *Tyrannosaurus* if they lived side by side.



D’Emic says. “I thought I’d find five or six examples, not 36.”

Members of these supersized lineages included Jurassic icons, like *Diplodocus* and *Brachiosaurus*, which lived when a splintering supercontinent offered plenty of space and food for plodding sauropods. And several Cretaceous lineages outdid those from the Jurassic, with *Argentinosaurus* tipping the scales at around 150,000 pounds.

D’Emic thinks the new finding illustrates that sauropods were built to be big: “The sheer number of times they broke through the plateau of other terrestrial animals means that their body plan — long neck, long tail, small head — was a winning one for getting very large.” —J.T.

measured around 500 of these rings, revealing a series of approaches for adding and dropping bulk. Mapping these approaches out on an evolutionary tree, they then gauged the theropods’ growth across the entire fossil family. “Pound for pound their growth rates were all over the place,” D’Emic says. “We have to basically look at each species or lineage on a case-by-case basis to figure out how they grew.”

Roughly 60 percent of theropod lineages, including tyrannosaurs and allosaurs, became bigger over evolutionary time. But their transformations into apex predators did not occur in only one way. Instead, these bulky beasts were split between increasing the rate and increasing the duration of their growth. While the 2,500-pound *Ceratosaurus*

picked up the pace of its development, for example, reaching full size after several years, its close relative *Majungasaurus* prolonged the period, reaching a similar size after two to three decades.

THE RESEARCHERS also found a similar split among the 40 percent of theropods that became smaller over evolutionary time, including the sickle-clawed raptors. Like their larger relatives, these downsizing dinosaurs displayed multiple growth patterns, including decreased growth rates and decreased growth durations. But whatever their method, shrinking down was an essential step, as some of these lineages eventually evolved into birds, which needed lightweight bodies to take flight.

According to Thomas Cullen, a paleontologist at Auburn University who was not involved in the study, the analysis suggests that the theropods developed different growth mechanisms depending on their surroundings. “Rather than there being a single pathway of growth,” Cullen says, “it’s likely that a range of different ecological factors drove changes in body sizes.”

Though *Ceratosaurus* and *Majungasaurus* both became giants, for instance, differences in their environments encouraged their different styles of development. While competition with allosaurs and other fearsome foes drove the accelerated growth spurts of *Ceratosaurus* in the Jurassic, an absence of competition enabled the more leisurely and energy-efficient growth of *Majungasaurus*,

which was unrivaled in its home turf of Cretaceous Madagascar.

According to D’Emic, the study sheds light on much more than the lives of the theropods, with the results hinting at the diverse developmental strategies that have been available to animals throughout history. “We can’t just study the evolution of growth by looking at groups of animals alive today,” D’Emic says, stressing that human hunting and climate change have obscured the full gamut of growth possibilities. Instead, a comprehensive understanding of development must consider creatures from the past as well as the present, with the theropods and their bones revealing only one small piece of the puzzle of animal size.

— JACK TAMISIEA



THE ARTEMIS CREW MODULE will head to the moon atop the Space Launch System, NASA's most powerful rocket yet.

OUT THERE

ARTEMIS PREPARES TO TAKE PEOPLE TO THE MOON AND BEYOND

After 50+ years, NASA names a new crew of astronauts for a lunar mission.

▶▶▶ **AFTER DECADES** of stumbling, humankind has taken a big step forward in the ongoing quest to return to the moon — and to travel beyond. The journey has been a long time in the making: Our last visit was more than 50 years ago,

during the Apollo 17 mission in 1972. In April 2023, NASA named the four astronauts in the crew for Artemis II, the upcoming mission that could launch as early as November 2024. During the 10-day journey, the spacecraft will circle the moon, traveling deeper into space than any

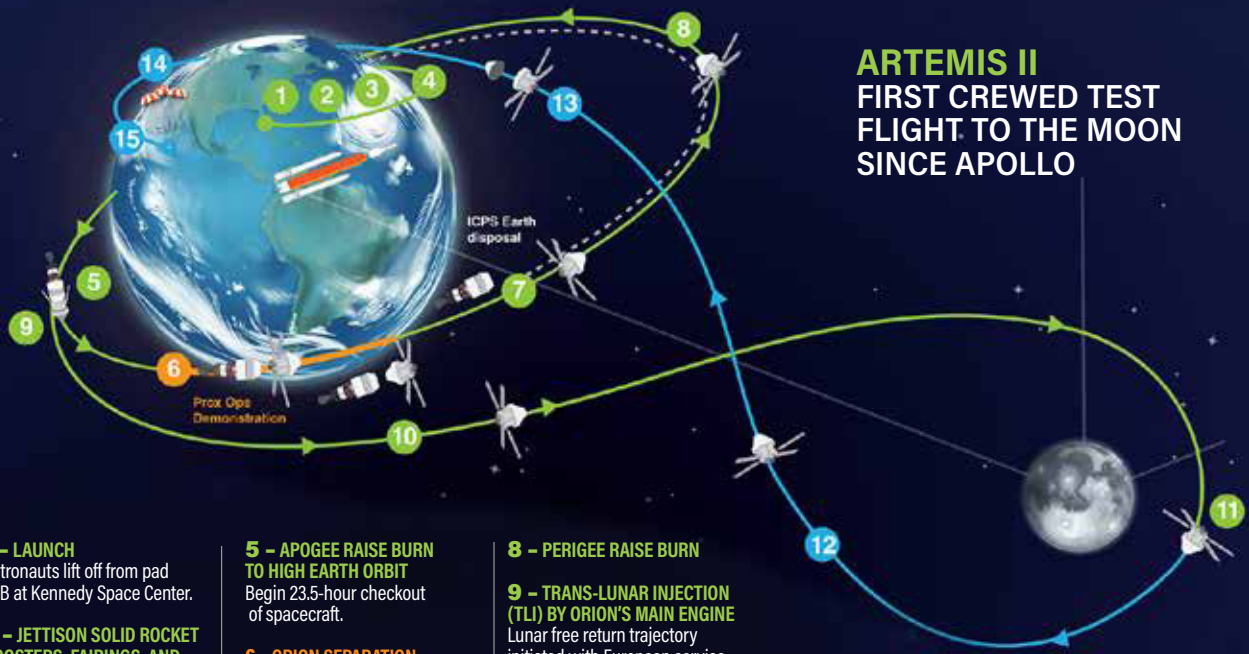
crewed spacecraft has ever gone before.

It will help pave the way for Artemis III, which is planned to touch down on the lunar surface in 2025, and Artemis IV, a future mission to both land on the moon and visit the yet-to-be-built Lunar Gateway space station. The outpost will be positioned beyond the moon and serve a number of purposes — not

least of which as a stopover for missions to Mars.

“We’ve only scratched the surface of what the moon has to tell us,” says Andrew Chaikin, a space historian whose books include *A Man on the Moon*, a recounting of the Apollo program. He points out that moon rocks, pristinely preserved on the lunar surface, can help scientists piece together the evolution of our cosmic neighborhood. “They truly are Rosetta stones for decoding the earliest chapters of solar system history. Going to

ARTEMIS II FIRST CREWED TEST FLIGHT TO THE MOON SINCE APOLLO



1 – LAUNCH
Astronauts lift off from pad 39B at Kennedy Space Center.

2 – JETTISON SOLID ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM

3 – CORE STAGE MAIN ENGINE CUT OFF
With separation.

4 – PERIGEE RAISE MANEUVER

5 – APOGEE RAISE BURN TO HIGH EARTH ORBIT
Begin 23.5-hour checkout of spacecraft.

6 – ORION SEPARATION FROM INTERIM CRYOGENIC PROPULSION STAGE (ICPS) FOLLOWED BY PROX OPS DEMO
Plus manual handling qualities assessment for up to two hours.

7 – ORION UPPER STAGE SEPARATION (USS) BURN
Begin high Earth orbit checkout. Life support, exercise, and habitation equipment evaluations.

8 – PERIGEE RAISE BURN

9 – TRANS-LUNAR INJECTION (TLI) BY ORION'S MAIN ENGINE
Lunar free return trajectory initiated with European service module.

10 – OUTBOUND TRANSIT TO MOON
Outbound Trajectory Correction (OTC) burns as necessary for Lunar free return trajectory; travel time approximately four days.

11 – LUNAR FLYBY
6,479 miles (mean) lunar farside altitude.

12 – TRANS-EARTH RETURN
Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere; travel time approximately four days.

13 – CREW MODULE SEPARATION FROM SERVICE MODULE

14 – ENTRY INTERFACE (EI)
Enter Earth's atmosphere.

15 – SPLASHDOWN
Ship recovers astronauts and capsule.

the moon is like being let in to the rare book room of the cosmic library.”

The named Artemis II crew members include Americans Victor Glover, Reid Wiseman, and Christina Koch, and Canadian astronaut Jeremy Hansen. The astronauts will be carried around the moon inside Orion, a solar-powered,

reusable spacecraft roughly 16 feet in diameter at its widest — about the length of a large sedan — that was designed to ferry humans into deep space. Orion will sit atop the Space Launch System (SLS), NASA's most powerful rocket to date.

Getting the program off the ground has been a bumpy, and often delayed,

journey. Although the Artemis program officially started in 2019, the design of Orion began in 2006 as part of NASA's Constellation, a crewed spacecraft program that was canceled in 2010. It was a collaboration between NASA and the European Space Agency, which built the service module.

ORION'S FIRST flight test came in 2014, when it launched to space on top of a Delta IV Heavy rocket and splashed down in the Pacific Ocean 4.5 hours later. Planning for the SLS launch rocket, which incorporates

THE ARTEMIS II crew checks out the Orion module. From left: NASA astronauts Victor Glover, Reid Wiseman, and Christina Koch, and Canadian astronaut Jeremy Hansen.



parts left from NASA's canceled Space Shuttle program, began in 2011. By the time Artemis II is done, NASA will have spent more than \$90 billion on Artemis, according to a November 2021 report from the space agency. NASA



FROM TOP: NASA; NASA/KEEGAN BARBER; NASA/KIM SHIFLETT



ORION, SEEN HERE in a concept illustration, is the reusable, solar-powered spacecraft that will ferry the crew into space and make humanity's return to the moon possible.

has already spent \$11.8 billion on development of the SLS alone, and admits that, at current costs levels, the SLS could be unaffordable.

ARTEMIS I, an uncrewed mission, was planned for Aug. 29, 2022, from the Kennedy Space Center in Florida, but shortly before liftoff the launch was scrubbed due to a problem with one of the SLS's four engines. Bad luck struck again on Sept. 3, 2022, when the agency canceled a second attempt due to a liquid hydrogen fuel leak. A third launch attempt, planned for Sept. 27, 2022, was canceled due to concerns about a growing hurricane. Finally, on Nov. 16, 2022, the rocket lifted off, and 25 days later, after a journey of more than a million miles, the Orion capsule returned to Earth. Its only occupant was a mannequin, wearing a spacesuit and equipped with a barrage of sensors, named Moonikin Campos. —STEPHEN ORNES



A MANNEQUIN NAMED MOONIKIN helps NASA determine what the experience of flying in Orion will be like for the actual crew.

TUNING IN TO THE "GREAT HUM"

▶▶▶ **THE UNIVERSE** is constantly churning from the movement of its most massive objects, a 15-year survey has reported. Using pulsars as distant beacons and radio telescopes to plumb the galaxy, a collaboration of astronomers and physicists has found strong evidence of low-frequency gravitational waves undulating through the cosmos.

The detection of these ripples is a long-awaited result, anticipated since the detection of high-frequency gravitational waves almost a decade ago. The ability to measure these waves directly is a major breakthrough that will inform scientists about the origin and history of the universe.

The results were published in June 2023 in a series of papers in *The Astrophysical Journal Letters* and were based on collaborative efforts between the North American Nanohertz Observatory for Gravitational Waves (NANOGrav), the Physics Frontiers Center (PFC), researchers with the International Pulsar Timing Array, and international collaborators in India, Australia, Europe, and China.

"This is key evidence for gravitational waves at very low frequencies," said Stephen Taylor, a gravitational-wave astrophysicist at Vanderbilt University who co-led the research, in a statement. "After years of work, NANOGrav is opening an entirely new window on the gravitational-wave universe."

Scientists think these low-frequency ripples result from supermassive black holes at the centers of merging galaxies, with some contribution possibly from the Big Bang itself. As black holes spiral toward each other and their

USING THE MILKY WAY GALAXY AS A GIANT RADIO TELESCOPE, SCIENTISTS FINALLY DETECT CONTINUOUS GRAVITATIONAL WAVES RIPPLING ACROSS SPACE-TIME.

accelerations increase, they send off energy as gravitational waves, which can take between years and decades to crest and fall. When these waves are created, they cause space-time, or the fabric of the universe, to writhe like a wiggling waterbed.

THE FIRST-EVER detection of gravitational waves was reported in 2015 by researchers at the Laser Interferometer Gravitational-wave Observatory (LIGO), a set of miles-long observatories in Washington and Louisiana. The signals observed by LIGO and subsequent similar facilities can only detect higher-frequency waves produced by relatively small objects, like merging neutron stars or black holes born from single supernova explosions.

But scientists have long predicted another form of gravitational waves: a continuous hum produced by binary systems of supermassive black holes, each with the mass of millions to billions of suns. As these binaries form, they emit lower-frequency gravitational waves than observatories like LIGO can detect. Rumbling across the



AS THOUGH CAUGHT IN AN ocean swell, the stars in our galaxy move in concert with waves of space-time that can take decades to crest and fall.

Xavier Siemens, co-director of the NANOGrav PFC and physicist at Oregon State University, in a statement.

The NANOGrav result shows that pulsar timing arrays can open a new window to the universe, allowing astronomers to “hear” even more of the gravitational-wave spectrum than before. Now, scientists are eager to learn more about what causes these signals, which will help explore the events that have shaped the universe.

While supermassive black hole binaries are the likely generator of swells on the cosmic sea, they have not been directly observed. The hum does indicate, however, that supermassive black holes in binary systems do close in on each other over time, a process astronomers weren’t sure could happen.

“This finding gives us more confidence that our understanding of galaxy growth and black hole evolution are on the right track,” says Holley-Bockelmann. “However, this discovery may also be consistent with more exotic sources, like cosmic strings,” which are theoretical strands of matter that could have formed as defects in the early universe. “We’ll need to keep observing to reveal the true nature of these gravitational waves.” —ELIZABETH GAMILLO

universe at the speed of light, these stochastic, or background, waves buffet Earth from all directions.

“Like a huge ocean swell, the stars in our galaxy are all moving in concert to waves in space-time that take more than a decade just to complete one cycle of the wave,” says Kelly Holley-Bockelmann, a Vanderbilt astrophysicist who was not involved with the studies.

“What NANOGrav was looking for was the signature of the coalescence of those supermassive black holes at the center of massive galaxies,” says Gabriela González, an astrophysicist at Louisiana State University and member of the LIGO Scientific Collaboration, also not involved with the studies. Those signals come from different points in the universe and create a constant hum, like noise in a crowded room.

The long timescales of low-frequency gravitational waves make them tough to detect. NANOGrav’s strategy is to



turn the pulsars — the rapidly rotating neutron stars — in a vast swath of the Milky Way into a giant, gravitational-wave antenna. Each of these pulsars sends flashes of radiation toward Earth at such regular intervals that they can be timed like the hands of a ticking clock.

But gravitational waves can alter their timing, causing signals to arrive behind or ahead of schedule. The

changes are subtle, since the ripples released by merging supermassive holes contract and stretch space-time by only 1 part in 1 quadrillion, but they’re still detectable, allowing researchers to pinpoint patterns associated with the waves.

TO CREATE NANOGrav’s pulsar timing array, researchers from all over the globe compiled radio-telescope data from 68 pulsars. The more pulsars they included in this array, the more sensitive it was to gravitational waves. “The large number of pulsars used in the NANOGrav analysis has enabled us to see what we think are the first signs of the correlation pattern predicted by general relativity,” said

2023 NEWS BRIEF

PHOSPHORUS ON SATURN’S MOON

Using data from NASA’s retired Cassini mission, researchers announced in June that Enceladus, one of Saturn’s moons, possesses a key ingredient for life as we know it: phosphorus. The element was identified in icy particles ejected from the moon’s ice-covered ocean. It is the last of six critical building blocks for life to be identified (with varying degrees of certainty) on Enceladus, making the moon one of the most promising places to search for life in the solar system.

TOP: AURORE SIMONNET FOR THE NANOGrav COLLABORATION. INSET: NASA/CXC/UNIV OF TORONTO/M. DURANT ET AL.



ENABLING SCIENTISTS to compare DNA in unprecedented ways, new genomics databases may reveal the roots of human diseases.

GENETICS

NEW GENOMICS DATABASES COULD DRIVE MAJOR BREAKTHROUGHS

The projects are poised to offer unprecedented insights into human genetic diversity and improve treatment of disease.

▶▶▶ **THE YEAR** 2023 brought a flurry of pivotal advancements to the field of genomics. Three large databases — one of humans, one more broadly of mammals, and one of primates (see sidebar on page 54) — are promising brand new revelations about the source code of life, especially as it pertains

to our own species. A notable milestone for a one-of-a-kind repository of ancient DNA could hold similar insights from our ancestors, as well.

These massive genomic repositories will grant scientists novel tools for comparing DNA between humans, between humans and animals, and between us and our ancestral relatives. While genome sequencing has been a reality for decades, much of

the value of genomics lies in comparing different genomes to one another to understand how they differ, and why those differences matter.

Past work in comparative genomics has revealed the underlying genetics behind conditions like autism, and has even uncovered entirely new lineages of humans. Those kinds of discoveries could be just the beginning.

By putting dozens of

genomes in one place, the new databases are opening the door to key questions not possible to ask before — from “What does human genetic diversity truly look like?” to “How different are humans and Siberian huskies?”

Taken together, the projects show that even though it’s been around for decades, the field of genomics is still young indeed. “There is a rainforest of hidden stuff out there that we haven’t looked at yet,” says Benedict Paten, a geneticist and associate director of the genomics institute at the University of California, Santa Cruz.

THE FIRST OF these projects, published in the journal *Nature* in May, presented the human pangenome. It’s made of dozens of highly accurately sequenced human genomes — compiled in a single database — that will inform all human genomics work moving forward. Notably, it updates the current reference genome scientists still use as a guideline, which is based on the first fully-sequenced human genome in 2003.

That prior reference genome had one big flaw: It came largely from one individual, meaning it couldn’t capture the full spectrum

of human genetic diversity. “The variations are the things that uniquely define us genetically,” says Paten, a member of the Human Pangenome Reference Consortium (HPRC) that assembled the new database.

While millions of people have had their genomes read, few have been sequenced in sufficient detail to serve as a comprehensive scientific reference. Researchers with the HPRC changed that by taking fully sequenced genomes from 47 people from five continents, and then lining them up side-by-side to review and compare each section. The final result, Paten says, is like a map — adding coordinates to key variations that long went unseen.

Paten says the new pangenome will allow researchers to find and study genetic variations in humans everywhere, potentially shedding light on the roots of diseases like Type 1 diabetes and multiple sclerosis. And that’s just the starting point: The HPRC aims to eventually sequence and add hundreds, and perhaps thousands, of



BALTO THE sled dog, seen here with musher Gunnar Kaasen in 1925, was among the 240 mammalian species whose DNA was sequenced and compared as part of the Zoonomia Project.

human genomes to expand the range of genetic variation included. That work could also help answer many basic questions about our genes that still stump researchers.

“We’ve gotten really good at sequencing DNA and we’re still not very good at actually telling you which changes are actually important ... and which ones are just random noise,” says Elinor Karlsson, a geneticist at the University of Massachusetts Chan Medical School and the Broad Institute at MIT and Harvard University.

TO FIGURE that out, scientists need more genomes

— and not just from humans, either. That’s where the Zoonomia Project, which Karlsson helped lead, comes in. Scientists with the project compared DNA sequences from 240 species of mammals that exist today, including horses, humans, ground squirrels, and even Balto the sled dog, the famed husky who helped deliver lifesaving medications in Alaska in 1925. Then, using the alignment method Paten and his team helped pioneer, they compared certain regions to each other.

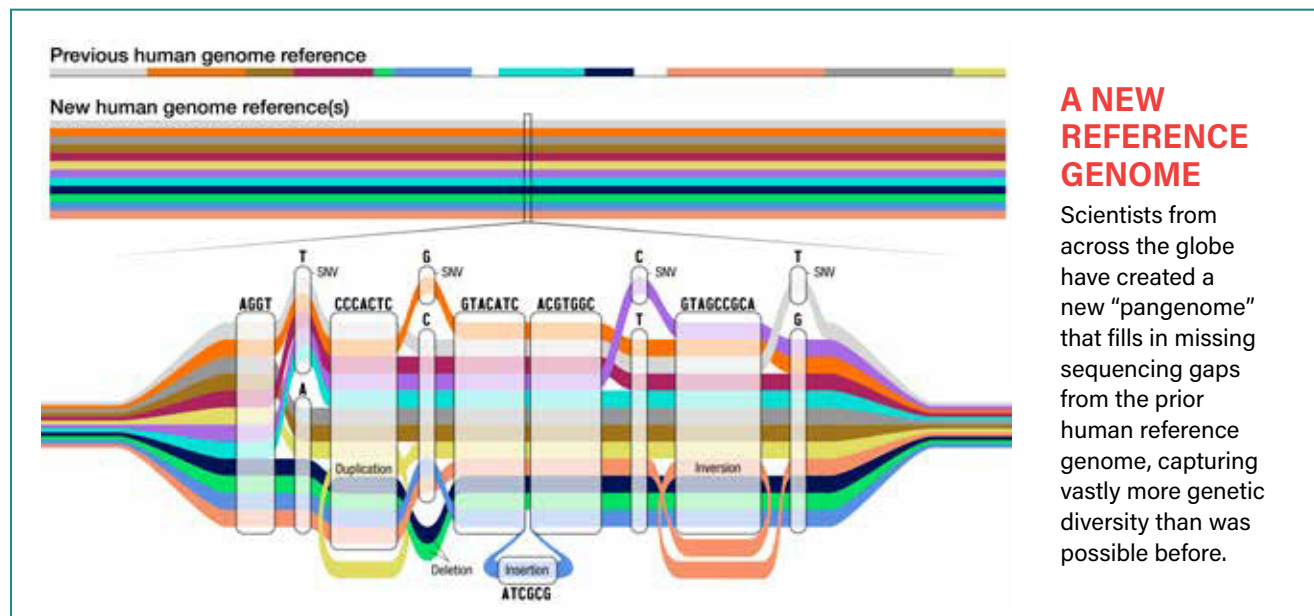
Much as with the human pangenome, seeing all those genomes side-by-side can be

enlightening. Karlsson says one priority is ascertaining which regions of the genome are open to evolutionary changes and which aren’t, as well as which regions of the genome are so critical for survival that evolutionary changes rarely occur.

To that end, with the Zoonomia Project, which published its most comprehensive batch of research papers in *Science* in April, researchers are now targeting genomic regions that look the same in many or all mammals. That’s a strong sign that those areas of the genome code for traits that can’t be changed without causing dire side effects.

Those evolutionarily-conserved regions could help direct scientists studying genetic diseases to crucial mutations. That’s because pinpointing an alteration in a region of the genome that typically never changes is a strong sign it may be tied to disease.

Scientists involved with the project are also exploring other fundamental questions concerning



A NEW REFERENCE GENOME

Scientists from across the globe have created a new “pangenome” that fills in missing sequencing gaps from the prior human reference genome, capturing vastly more genetic diversity than was possible before.

the differences between species. For instance, the project highlights where the human genome contains unique variations of genes that control how DNA gets folded in cells, which affects gene expression. Those changes could reveal why human brains are so much bigger than those of our close chimpanzee relatives, Karlsson says.

OUR ANCESTRAL relatives aren't excluded from the 2023 genomics boom, either. This year, the tally of genomes in

the world's largest database of curated ancient human DNA, the Allen Ancient DNA Resource (AADR), crossed the 10,000 mark. The database includes genomes from not only modern humans, but our evolutionary cousins like the Neanderthals and Denisovans, as well.

The AADR is the brainchild of David Reich, who researches ancient DNA at Harvard, and his lab, and includes genomes ranging from just a few hundred years old to over a hundred thousand years

old. As the resource crosses the five-figure mark, he says it's opening up new possibilities for archaeology and anthropology.

With thousands of ancient genomes, scientists can move beyond asking questions about just one or several individuals to studying entire cemeteries — and even whole populations — to understand how those early humans differed from each other. For example, recent work in ancient genomics has revealed sweeping population changes across Europe and

Asia thousands of years ago as new groups of ancient humans moved in, painting a far more complex portrait of our evolutionary history than scientists previously imagined.

Reich estimates there are tens of thousands of ancient genomes still waiting to be formally published, meaning the AADR will only continue to grow in coming years, just like the human pangenome and the Zoonomia Project. Large-scale genomics is just getting started.

—NATHANIEL SCHARPING

PRIMATE GENOME DATABASE COULD UNLOCK NEW INSIGHTS FOR HUMANS

Variety abounds across primates. Monkeys tumble on snowy Japanese mountains, orangutans munch fruit on Sumatra, lemurs pogo between trees in Madagascar, and the naked apes — humans — strut on two legs worldwide. Scientists can now interrogate the DNA differences underlying that diversity, thanks to a databank of genomes from 233 species.

To understand the good and bad of human evolution — both our extraordinary adaptations and disease-causing mutations — scientists must compare the genomes of *Homo sapiens* to our closest evolutionary relatives, the primates. But researchers investigating diverse topics, from contemporary genetic diseases to human origins, have long faced a roadblock when pursuing this approach: While genomic data exists from millions of people, most of the 500-plus primate species never had their genomes read. So, in 2019, Tomàs Marquès-Bonet at the Institute of Evolutionary Biology, in Barcelona, Spain, and other



THE GOLDEN snub-nosed monkey (*Rhinopithecus roxellana*) is just one of the 233 species scientists sequenced for the project; taken together, the database represents almost half of all known primates.

biologists teamed up with disease researchers at the company Illumina, determined to obtain as many primate genomes as possible.

Navigating wilderness and local permitting laws, the international researchers obtained hundreds of blood samples from anesthetized wild and captive animals in South America, Africa, and Asia. Sequencing DNA from these samples and adding data from previous studies, the team built a bank of 809 genomes from individual baboons, gorillas, gibbons, and more, representing nearly half the known primate species.

The data revealed insights about human origins and health, as well as primate conservation, published by more than 100 scientists across 10 papers in *Science* and *Science Advances* in June 2023. One study trained artificial intelligence to search human genomes for DNA differences likely to cause disease, based on whether nonhuman primates can live with those variants. According to Marquès-Bonet, “We now have a really good catalog of the foundations of our species” and a “good idea of the kind of mutations that are tolerated in any primate” — including humans. —BRIDGET ALEX



MALE YELLOW crazy ants are real-life chimeras, meaning they possess separate populations of cells from two distinct genetic lineages.

These Ants Are All Chimeras

Scientists find a species of ant who have turned a biological mistake into business as usual.

»» **YELLOW CRAZY** ants, or *Anoplolepis gracilipes*, are among the most pernicious invasive insect species in the world. Still, these organisms — named for the erratic way they move when disturbed — are not what they seem.

Though the long-legged insects look much like ordinary ants, males of the species are actually composed of distinct populations of cells from two separate genomes, researchers revealed in a study published in April in *Science*. That makes them a biological oddity known as a chimera, a name shared with a mythological creature that's part fire-breathing lion, part goat, and part serpent.

In most animals, humans included, all of our cells contain the same set of DNA. But male yellow crazy ants have two types of cells, each

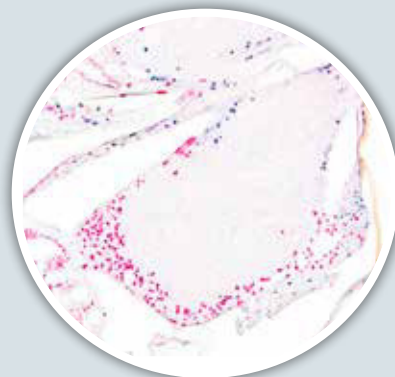
with a different genome, all living side by side to make up a single organism.

Chimeras are usually a developmental accident in nature, happening when two fertilized eggs fuse. But for the yellow crazy ant, it's become a way of life. "There was no example so far of something that's systematic," says Hugo Darras, an evolutionary biologist at the Johannes Gutenberg University Mainz

in Germany and study co-author.

The ants' chimerism stems from a mode of reproduction not previously known to scientists. While most creatures develop when genetic material from both parents fuses together, male yellow crazy ants sprout from fertilized eggs in which maternal and paternal nuclei divide separately.

The unique adaptation is unprecedented, but that's



A LONGITUDINAL section of the brain of a chimeric male yellow crazy ant, with cell clusters from both maternal (pink) and paternal (blue) genomes.

not entirely surprising when studying ants, which have proven to be a treasure chest of biological weirdness. For example, *Adetomyrma venatrix*, also known as the Dracula ant, drinks the blood of its own young.

"In about 10 percent of the cases [when studying ants], we find something extraordinary," says Darras. "[And] once you find something in one species, you often find it in other species as well."

—NATHANIEL SCHARPING

2023 NEWS BRIEF

AIRBORNE DNA

According to a June study in *Current Biology*, routine air quality monitoring stations have been passively picking up environmental DNA — bits of genetic information shed by organisms during their daily activities — for decades. Using filters from two air quality monitoring stations in the U.K., researchers identified eDNA from more than 180 different species. With minor modifications, they suggest, this existing infrastructure could keep tabs on biodiversity across continents.



MUMMY-MAKING, UNWRAPPED

An analysis of ancient pots has revealed the complex chemistry and rare ingredients involved in Egyptian mummification.

▶▶▶ **AROUND 2,600** years ago, a small ceramic bowl sat in a subterranean workshop. Carrying hints of cedar and honey, the bowl was used by Egyptian embalmers to blend essential oils and beeswax for the multimonth process that transformed corpses into mummies. Reciting incantations,

removing organs, and applying substances that made bodies dry, fragrant, and microbe-free, the embalmers employed a multifaceted set of skills. “They knew the ritual practices, but also [a] kind of chemistry,” says Maxime Rageot, a biomolecular archaeologist at the University of Tübingen in Germany.

Over the past four years, Rageot and colleagues have gained unprecedented insights into the substances and steps involved in ancient Egyptian mummy-making. Their analysis of molecules

A FEW STRIDES SOUTH of the pyramid of Unas, the mummification workshop was used to treat dead bodies between 664 and 525 B.C.E.

trapped in pottery, as published in a *Nature* paper from February 2023, revealed that embalmers sourced ingredients from surprisingly far-flung lands for their specific biomolecular properties.

The Egyptians perfected

the practice of mummification over the course of several thousand years, transforming the natural desiccation of bodies into a sophisticated ritual and chemical process between the fifth and first millenniums B.C.E. During the time of the pharaohs, professionals spent up to 70 days transforming a tender corpse into a linen-wrapped, afterlife-ready mummy — treating it with spells and

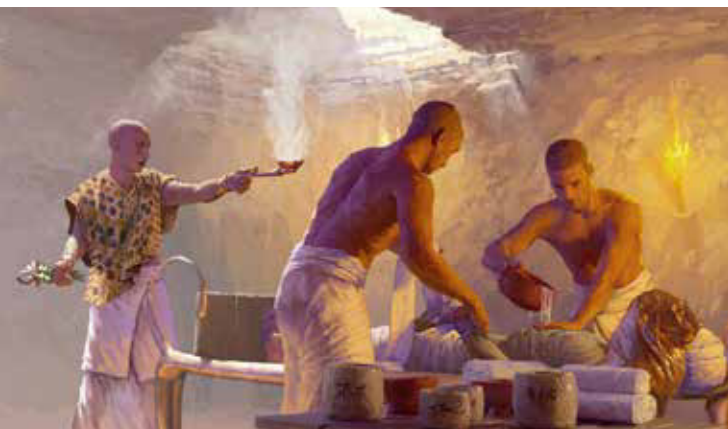


POTS FROM A subterranean workshop in the ancient city of Saqqara contained clues to the identity of rare mummy-making ingredients.

prayers, as well as substances that mitigated moisture, bacteria, fungi, and stink.

But scholars have long debated how to translate the ingredients named in ancient inscriptions and papyri, meaning that much of the mummy recipe has remained a mystery. And while some ingredients have been identified from the molecular analyses of mummies from museums around the world, these methods cannot reveal how specific substances figured into the mummification process — whether they were applied to the bandages or the head, for instance, for the purpose of preserving tissues or fending off bacteria.

The possibility of linking substances and steps arrived in 2018, when the late archaeologist Ramadan Hussein invited Rageot to join his excavations at Saqqara, an ancient city about 12 miles south of Cairo. There, Hussein’s team had uncovered an ancient facility for treating and storing corpses, dated to around 664 to 525 B.C.E. Featuring a



workshop more than 40 feet underground, the facility held over 100 pottery vessels bearing instructions like “to make the odor pleasant,” “for making beautiful the skin,” and “head, boil.”

SELECTING 31 of these pots for closer analysis, Rageot set out to identify their long-lost contents. But because Egypt lacked a specialized laboratory for this kind of work, he and his team brought the pots to a local food chemistry lab, which they converted into one of the country’s only facilities for analyzing ancient biomolecules. Drilling pinches of clay powder from the pots’ interiors and analyzing the powder in the lab’s mass spectrometer, they determined which ancient molecules had seeped into the pottery’s pores.

The successful analyses of the pots revealed embalmers used diverse and exotic materials that could curb moisture, smells, and mummy-munching organisms: Bitumen tar probably from the Dead Sea; pistachio, juniper, and olive oils from the Mediterranean; and tree resins from the tropical forests of Asia and possibly sub-Saharan Africa. To source these items, the embalmers relied on trade that spanned much of their known world. “The diversity of bioproducts which were used,” Rageot says, “was really impressive.”

Now that the Egyptian lab exists, the researchers plan to analyze mummy-making ingredients from more sites. Their hope is to trace how mummification transformed across time and space, applying modern chemical methods to unravel their ancient counterparts. —BRIDGET ALEX

2023 NEWS BRIEF

AVIAN AEROPHONES

In a June study, researchers announced the discovery of several aerophones more than 12,000 years old in northern Israel. Fashioned from perforated bird bones, these woodwind instruments imitated raptor calls and may have been used to hunt the birds of prey or make music. As the first prehistoric instruments unearthed in the Near East, they shed light on a hunter-gatherer culture on the cusp of agriculture.



THE STUMPF LOCK, believed to be the hair of Ludwig van Beethoven, was affixed to a page with a poem: “The head, these hair’s have grac’d lies low. But what it wrought — will ever grow.”

LOCKS OF LUDWIG

Strands of hair have uncovered a tangle of truths about Beethoven’s health and history.

IN 1827, a harpist tacked strands of hair to a page with a poem. He then folded the paper and penned “Beethovens hair” on the outside. Nearly two centuries later, researchers have used these locks to reconstruct the genome of Ludwig van Beethoven, lifting the curtain on the composer’s life and pushing the frontiers of paleogenetics.

Beethoven died in Vienna at age 56, after reportedly suffering from hearing loss, jaundice, debilitating stomach pains, and suicidal ideations. Scholars seeking the causes of these maladies have previously analyzed historical documents and bits of Beethoven himself, including tufts of hair snipped as mementos for fans, to no avail.

In 2014, William Meredith, the director of the Ira F. Brilliant Center for Beethoven Studies at San José State University, set out to salvage DNA from these strands, 15 years after a first, unsuccessful attempt. Accessing and analyzing eight locks over eight years, the historian and his colleagues found that five of the tresses came from a single male (or set of identical male twins) with Central European ancestry from the 1800s. “I’m extremely confident that this is the Beethoven DNA,” Meredith says.

The analysis discovered Beethoven had a genetic predisposition to liver disease, an infection of hepatitis B, and a twist in his family tree: someone sired by a father outside the Beethoven paternal line. Opening a window into the composer’s history, the research — reported in *Current Biology* in April 2023 — marks a milestone for the analysis of ancient DNA. —BRIDGET ALEX



A History of Horseback

BRONZE AGE BONES SUGGEST THAT HUMANS HOPPED ON HORSES A THOUSAND YEARS EARLIER THAN PREVIOUSLY BELIEVED.

ROUGHLY 4,000 years ago, where the Romanian Plains border the Carpathian Mountains, mourners tucked a 30-something man into a tomb. Adorned with red pigment and faced toward the west, his body was buried in the typical fashion of the Yamnaya: within a sprawling mound of dirt.

Less typical was the wear and tear on the man's skeleton, which bore signs of repeated horseback riding. While a healed sacral fracture hinted that the man had suffered a traumatic fall, mounting horses had left him with an arthritic spine, a roughened pelvis, and a pair of accentuated thighbones.

Now in scientists' hands, this skeleton from the Strejnicu archaeological site, and other skeletons like it, have rewritten

first Indo-European tongues. Spoken by around 3 billion people today, the 400-plus languages within this family may trace their popularity to the Yamnaya.

Scholars have wondered whether horses aided the Yamnaya's spread, some 1,000 years before the earliest convincing evidence of equestrianism, both written and illustrated. Animal bones from Yamnaya sites confirm they kept horses, and proteins trapped in tooth tartar show

As part of that project, biological anthropologist Martin Trautmann examined Yamnaya-era skeletons, stored in museums and other collections, to document their injuries and other traits. Early on, the Strejnicu skeleton stood out, displaying the distinctive wear-and-tear of regular horse riding. Suspecting others might too, Trautmann decided to search all the skeletons for signs of riding, including thickened and roughened hips, femurs, and spines, as well as broken bones from falls and other accidents. Between 2019 and 2022, he evaluated 217 sets of remains from across Romania, Bulgaria, Hungary, and Czechia.



BURIAL MOUNDS, also known as kurgans, are some of the only structures that survive from the Yamnaya people. This mound, excavated in 2021 in Malomirovo, Bulgaria, contained the remains of a 65- to 75-year-old man who probably rode horses regularly.

the history of horse riding. Pushing the origins of the practice back by over 1,000 years, the remains also explain the swiftness of ancient migrations that shaped the genetic and cultural fabric of Eurasia.

At the beginning of the Bronze Age, between about 3200 and 2500 B.C.E., the Yamnaya people set off from their native territory, probably north of the Black and Caspian seas. Within a couple of centuries, it seems the nomadic herders had overrun lands spanning at least 3,000 miles from what is now Hungary to Mongolia. As they moved, they had offspring with locals and likely spread their language, potentially one of the

they drank horse milk. But having and riding horses aren't one and the same.

ATOP HORSES or not, the Yamnaya migrations were "one of the key moments that changed [the] culture and people of Eurasia," says Volker Heyd, an archaeologist at the University of Helsinki. But because the Yamnaya rarely built permanent settlements, evidence for their expansion mostly comes from their burial mounds. "They are [some of the] only leftovers that we still see of this civilization," says Heyd, who leads a European Research Council project investigating the Yamnaya's influence.

Publishing the results in *Science Advances* in March 2023, Trautmann, Heyd, and colleagues reported about two dozen probable or possible riders, including five from Yamnaya sites and one from a pre-Yamnaya site, active before the Yamnaya's arrival in Romania. The results suggest that some cultures had mastered horseback riding — "one of the big innovations of humankind" according to Heyd — by the third millennium B.C.E. Accelerating the exchange of people and ideas, the results help elucidate how the Yamnaya spread so far so quickly, altering Eurasian genes and cultures in their wake. —BRIDGET ALEX





THE ILL-FATED *TITAN* submersible used a carbon fiber hull known to be unsuited for deep-sea exploration.

POLICY & CULTURE

AFTER OCEANGATE

A widely publicized deep-sea excursion leaves five dead, raising big questions for ocean exploration.

»»» **FOR SEVERAL** days in June, millions around the globe were gripped by news of five people missing 12,500 feet under the ocean, lost while attempting to catch a glimpse of the wreckage of the RMS *Titanic*. By the time evidence confirmed that their poorly designed submersible, the *Titan*, had imploded under the immense pressure of the deep, their fate was hardly a surprise.

Following the disaster, information came to light that the *Titan* did not meet industry safety standards: The carbon fiber cylinder making up the *Titan*'s hull was known to be inappropriate for deep sea craft, and OceanGate, the company that developed and operated the submersible, had a history of safety-related allegations. Interview footage resurfaced of OceanGate CEO Stockton Rush, who was aboard at the time and died in the disaster, boasting of breaking rules in the name of innovation. In addition, a group of professionals in the field had drafted a letter warning of safety concerns in 2018.

Because of the rogue nature of the expedition, deep-sea experts don't expect to see regulatory changes in the

industry. Nor do researchers expect new hurdles with funding, as properly certified research vessels remain safe. Since 1968, the American Bureau of Shipping (ABS) has maintained a set of guidelines today known as the "Rules for Building and Classing Underwater Vehicles,

Systems and Hyperbaric Facilities," or the "Underwater Rules" for short, which outline standards for design and construction of manned submersibles. Additional agencies offer standards and certifications in other parts of the world as well.

"The rules have been working quite well for 50 years," says Tony Lawson, engineering director at DOER Marine, which makes submersibles. "Many of the areas OceanGate was supposedly 'pushing' tech are actually all areas that were investigated in the '70s and '80s. Those findings seemed to have been ignored." Lawson sits on the ABS underwater vehicle systems subcommittee,

A FUTILE SEARCH

After four days of frantic searching, debris from the imploded submersible was positively identified some 1,600 feet from the final resting place of the *Titanic*, about 350 miles off the coast of Newfoundland.



which will likely meet next in spring 2024.

SUCH SAFETY measures helped Dawn Wright, chief scientist for the Environmental Systems Research Institute (ESRI), reach the deepest point on Earth, Challenger Deep in the Mariana Trench, in July 2022. The oceanographer's voyage was in the submersible *Limiting Factor*, whose hull is a titanium sphere. "I had absolutely no fear, no qualms, no worries at all, because of what the crew had done to ensure that the craft was safe," Wright says.

Despite the impressive safety record of deep-sea exploration — prior to June, only a handful of deaths have occurred over seven decades and countless dives — the catastrophe has certainly marred public perceptions of the field.

"One of the collateral tragedies of this terrible event is that people may be afraid to go too deep in the ocean," said Sylvia Earle, oceanographer and deep-sea explorer, in an online discussion on June 26. "We need to know: What's down there? Who's down there? And how does it all connect with life on the surface?"

Wright is hopeful OceanGate won't set back deep-sea exploration, including one of her current projects: Seabed 2030. ESRI is working with dozens of partners on the U.N.-endorsed program to map the entire ocean seafloor in the next six years. It's a lofty goal, given that modern maps are only 25 percent filled in, but an important step toward understanding our oceans. Wright hopes to see more data contributions, not just from typical research submersibles, but from dropships and any craft travelling the ocean that's equipped to map the seafloor. "We need all the data we can get," she says. —ANNA FUNK

MONOTILE MANIA

An unexpectedly simple "einstein tile" settles a decades-old math conundrum.

▶▶▶ **IN MARCH 2023**, researchers introduced the world's first aperiodic monotile — a 13-sided polygon that vaguely resembles a hat, or a T-shirt, depending on whom you ask. The shape answers a question that has haunted mathematicians for nearly 60 years: Can an infinite number of copies of a single shape fit together to cover a plane without gaps, and without repeating the same pattern?

This tile can. So can a related polygon — shaped more like a turtle — introduced in the same paper. And so can a ghost-shaped tile that debuted in May. The "Spectre," as one of its discoverers named it, goes even further: Unlike the other two, it doesn't require mirror images of itself to cover the plane.

Before the hat-shaped tile, it wasn't clear whether an aperiodic monotile could exist. In 1966, mathematician Robert Berger described a set of 20,426 tiles that could aperiodically cover a plane. In the 1970s, Sir Roger Penrose brought that number down to a few pairs, most notably in shapes called a kite and dart, but whether one tile would suffice remained a mathematical mystery.

"Undecidable questions are everywhere in mathematics," says mathematician Chaim Goodman-Strauss of the National Museum of Mathematics in New York City.

If such a tile existed, mathematicians didn't know what it might look like, but some expected it to be impossibly complicated. "I thought it would be some fractally mess," says computer scientist and mathematical artist Craig Kaplan of the University of Waterloo in Ontario. "But it turns out to be this comically boring shape."

The hat was the brainchild of David Smith, a retired print technician in England with a deep interest in shapes that could cover a two-dimensional surface. He had been experimenting with polykites — shapes built from multiple kites — and stumbled across a configuration that resisted forming periodic patterns, no

matter how he arranged them. He reached out to Kaplan, whom he'd met in online discussions about tiling the plane.

KAPLAN PLUGGED the new shape into a computer program that suggested tiling was possible. But it was not mathematically rigorous. "My software doesn't provide any kind of proof," he says. "It provides evidence."

The duo brought in Goodman-Strauss and Joseph Myers, a mathematician and software engineer, to hammer out proofs for both the hat and the turtle,

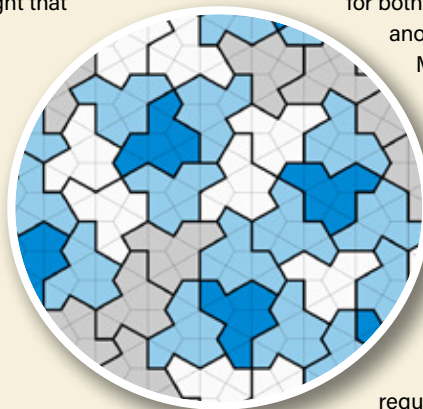
another of Smith's creations.

Myers found connections between them that led to the discovery of a continuum of *einsteins* — German for "one stone," a clever name for the monotiles. Smith hadn't found one; he'd found infinitely many.

The hat and turtle required mirror reflections to tile the plane, which could arguably be treated as two independent tiles. Then, in May, the collaborators unveiled the Spectre

(named by Smith), sometimes called a vampire, which worked alone and, like the bloodthirsty creature, has no reflections.

The researchers plan to continue computational explorations of these forms, both to find new ones and to explore the phenomenon of aperiodicity. "If there's an underlying phenomenon that links these things, we know nothing," Kaplan says. "Maybe there's a way to look at it that we don't yet understand." —STEPHEN ORNES



MATHEMATICIANS call the monotile an *einstein*, no relation to Albert. In German, the term means "one stone."



A CACHE OF LETTERS written in cipher in the 1500s were decrypted by three amateur codebreakers, and turned out to have a royal pedigree.

a homophonic cipher, which means common characters may be represented by multiple symbols. Lasry began by working solo, using a “hill climber” algorithm — incrementally testing random keys — to tackle the codes. “I got stuck, and I decided to contact the two best,” he says, explaining how Tomokiyo and Biermann joined him.

AS NEW clues emerged, Tomokiyo also unearthed an additional 28 previously unknown letters. The mysterious author used the feminine forms of words to refer to herself, and she mentioned “freedom” and “my son.” The smoking gun, Lasry says, came when they identified the name Walsingham; Sir Francis Walsingham was spymaster and secretary to Queen Elizabeth I. “When we saw that, we were more or less convinced,” Lasry says.

The team consulted with historians and found that seven of the 57 letters also existed in plain-text versions and were known to historians, but the rest were new. Since the publication, Lasry says the group has cracked a few other historical ciphers, but “none of them are as sensational as Mary Queen of Scots.” —STEPHEN ORNES

Lost Letters of Mary Queen of Scots Found and Deciphered

How a computer scientist, a patent expert, and a musician cracked the historic code.

▶▶▶ **ALMOST** three years ago, an amateur codebreaker named Satoshi Tomokiyo discovered a cache of dozens of encrypted letters in the digital collection of the National Library of France, all dating to the 16th century. He posted them to his cryptology website, *Cryptiana*, under the heading “unsolved historical ciphers.”

In February of 2023, Tomokiyo and codebreaker George Lasry, together with German musician Norbert Biermann, announced that they had deciphered the documents and unmasked the author as Mary Queen of Scots. The former monarch wrote the letters over a six-year period of her life while imprisoned by her distant cousin, Queen Elizabeth I.

The letters reveal insights about Mary’s life in captivity. “We see her very active,

well-connected and astute,” says Lasry. Historians quickly hailed the discovery — which totaled 50,000 words — as a significant new find in the life of the deposed queen, who was beheaded, at the behest of her cousin, in 1587.

The three researchers came from different backgrounds. Lasry is a computer scientist who applies his programming skills to cracking codes and works with DECRYPT, a multi-institutional

decryption effort. Tomokiyo, a patent expert who also studied astrophysics, focuses on historical documents in his cryptography work. And Biermann is a musician and opera arranger in Berlin with a penchant for solving hard-to-break codes in his spare time.

The letters were written in

2023 NEWS BRIEF

OVER-THE-COUNTER BIRTH CONTROL

In July, the U.S. Food and Drug Administration approved norgestrel, commonly called Opill, as the first daily oral contraceptive that can be obtained without a prescription. Health advocates hail the move as a step toward reducing the nearly 3 million unintended pregnancies estimated to occur in the U.S. each year, as it eliminates the need to visit a health care provider before obtaining the progestin-only pill.



WITH AN ASSIST from AI, a new interface converted signals from Gert-Jan Oskam's brain to impulses that activated his leg muscles.

TECHNOLOGY

“DIGITAL BRIDGE” RECONNECTS BRAIN AND LEGS AFTER SPINAL CORD INJURY

Breakthrough interface allows paralyzed man to stand, walk, and more.

▶▶▶ **IN MAY 2023**, a team in Switzerland announced that they had created a brain-spine interface that enabled a man who'd been paralyzed in a bicycle accident to walk naturally again. This “digital bridge” connects the brain and the spinal cord, bypassing the injured area in his neck. Electrodes implanted in the patient's brain record activity in the part of the cortex that controls the legs.

The activity patterns are then transmitted wirelessly to electrodes connected to the region of the spinal cord that governs leg movement. Machine learning, a form of artificial intelligence, is used to convert the brain signals into sequences of electrical stimulation in the spinal cord, which in turn activate leg muscles.

The patient, then-38-year-old Gert-Jan Oskam, was able to control his movements naturally, standing, walking, climbing stairs, even walking up and down ramps and over irregular terrain using only a walker. After the interface was switched off, Oskam could still walk using crutches, suggesting

the approach has spurred the development of new neural pathways.

“For the first time, after ten years, [I was able] to stand up and have a beer with my friends,” Oskam said in a statement announcing the

breakthrough. The researchers hope the technique could also one day be used with patients who are paralyzed due to neurological disease or stroke.

While being able to walk, stand at a bar, and have a beer is wonderful, there are more profound possibilities. Breanne Christie, a researcher at the Johns Hopkins University Applied Physics Laboratory, is part of a multidisciplinary, multicenter team using similar

techniques to not only help paralyzed patients stand and walk again, but to restore autonomic, or involuntary, functions. “A stable blood pressure and the ability to control one's bladder and bowel movements and even sexual function are all really high priorities for patients with spinal cord injuries, and contribute to quality of life and independence,” says Christie. Controlling autonomic functions is less well understood than controlling muscles; however, the team is working with clinical partners at the University of Louisville's Kentucky Spinal Cord Injury Research Center to advance these technologies to the point where patients can use them at home.

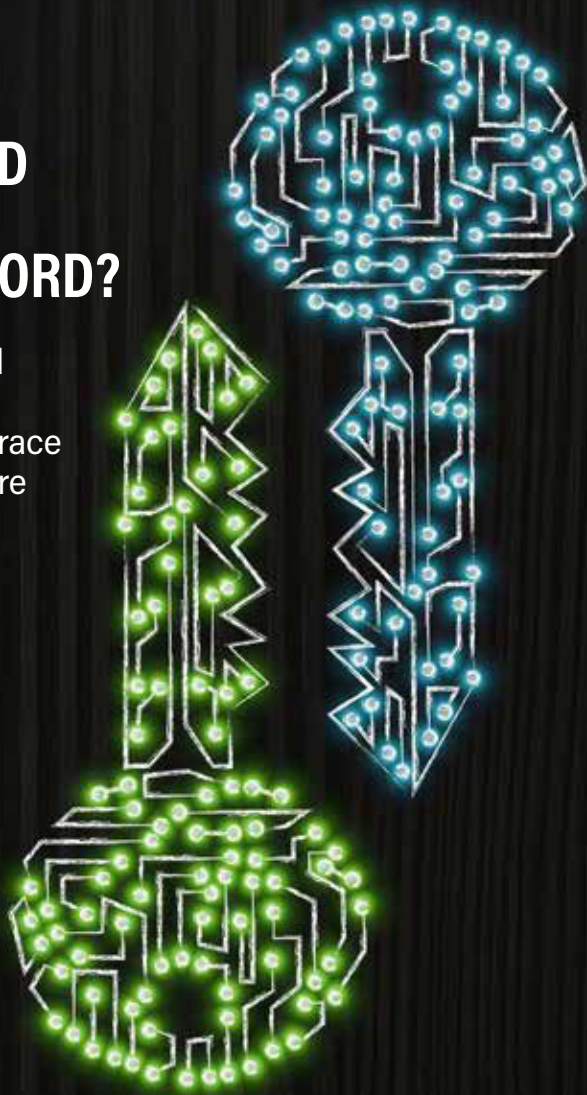
Meanwhile, the European Innovation Council (EIC) is funding development of a version of the digital bridge that would be available worldwide. — AVERY HURT



OSKAM STANDS with the neuroscientists who made his interface possible, at a press conference explaining the device in 2023.

THE END OF THE PASSWORD?

Google and other tech giants embrace super-secure passkeys.



AS MAJOR TECH companies like Google, Apple, and Microsoft begin giving users the option of adopting more-secure passkeys, will consumers want to give up their old passwords?

▶▶▶ **COME UP WITH** something at least 10 characters long. Include numbers, at least one symbol, and — just to be safe — maybe some hieroglyphics. Oh, and make it something you'll remember, of course. Yes, passwords are maddening, but their days are numbered: Passkeys are here to make passwords obsolete.

An even better reason to kick passwords to the curb is that they're a security nightmare. Data breaches, hacking tools, and phishing scams to trick users into revealing sensitive information are all becoming more frequent and more sophisticated. Better security was the impetus behind the Fast Identity Online (FIDO) Alliance,

a nonprofit association of over 300 companies that has been working for over a decade to develop authentication standards to reduce reliance on passwords. Their solution? Passkeys.

With passkeys you don't have to remember — or make up — anything. When you register to use a site or app, your device generates two cryptographically linked keys: a public key and a private key. The public key stays on the servers of the app or website you're signing in to. The private key, a long string of characters, is stored only on your device. When you sign in, the server, like the guard at the gate demanding "friend or foe," presents a challenge to your device. Your device

responds by using the private key as your personal signature or authorization. You then use your PIN, fingerprint, facial recognition, or similar means use to unlock your device to approve the signature, and the server verifies your signature by matching it with your corresponding public key. Your private passkey is safe because there's no way to derive a private key from a public key.

Because passkeys are generated for a specific site or app, they won't work on fake sites (those that look just like your bank's website, for example, and steal your password when you try to sign in). Passkeys are also immune to social engineering attacks like phishing, because you don't know the passkey; only your device does.

Andrew Shikiar, executive director of FIDO, says the new process is now a reality because the major tech players — who are often, as he puts it, "fierce competitors" — worked in close collaboration to make passkeys possible. In 2023, Google joined Apple, Microsoft, and many other tech companies in giving users the option of using passkeys across all their sites, greatly increasing passkey availability.

While acknowledging that nothing is completely bulletproof, Jonathan S. Weissman, a cybersecurity expert on the Rochester Institute of Technology faculty, says passkeys are "as foolproof a solution as has ever existed." But for passkeys to work, we have to use them. As long as companies offer an option to use a password, many people will stick with what they're comfortable with, Weissman says.

Shikiar agrees that people resist change, but believes that consumers eventually adapt to new technologies. People were slow to adopt touch ID, he says. But then they realized it's not only safer, but faster and more convenient than a PIN. It's now widely used. "I think the same thing will happen with passkeys," Shikiar says. He predicts that the vast majority of consumer services will offer a passkey option within three years, and people will use them exclusively a couple of years after that. "We'll come to a point where we look back on passwords like we do the rotary phone," he says. —AVERY HURT

THE YEAR OF THE AI CONVERSATION

Generative AI tools have unleashed a new world of promise and pitfalls.



▶▶▶ **BY EARLY 2023**, large language models (LLMs) were taking the world by storm. Arguably, ChatGPT led the revolution. The interactive chatbot allows users to make comments, ask questions, make requests, or enter into dialogue with the computer program. It is a kind of generative AI, which means that after training on enormous stores of data, it can

produce something new and reads fairly convincingly — and eerily — as though it were created by a human.

Despite its ability to mimic human verbiage, ChatGPT was trained to do a straightforward job: use probability and training data to predict the next text that follows a sequence of words. That ability could make it useful for people who work with text, says computer scientist Mark Finlayson of Florida International University. “It’s very good at generating generic, middle school-level English, and that’s a good starting point for 80 percent of what people write in their day-to-day lives,” he says.

By the end of January, barely two months after its online debut, ChatGPT had racked up 100 million users, according to analysts at the financial firm UBS. That caught everyone — including OpenAI, the company behind the technology — by surprise.

“We really underestimated the impact it would have,” says Andrew Mayne, who helped test Chat-GPT and develop applications at OpenAI. For comparison, that user milestone was crossed by the social media platform TikTok after nine months, and Twitter (now X)

required more than five years. (ChatGPT broke the record, but it was broken in turn by Threads, a social media program to rival Twitter, which in July gained 100 million users in only five days.)

What were those users doing with this new AI tool? Anything they could think of. Unethical college students wrote papers, while aspiring creators solicited the program to generate song lyrics, poems, recipes, short stories, and fanfiction.

ChatGPT also demonstrated unexpected talents, such as solving math problems (though not always correctly), writing computer code, and other abilities

that seemed to have little to do with its training data. “We started to see it doing things that we did not

explicitly train it to do,” says Mayne.

ChatGPT produces text, but other generative AI tools produce music, images, videos, or other media — the source of much misinformation, mischief, and trouble. AI is not always trustworthy; these programs can produce nonsensical or factually inaccurate statements (or images) that are nonetheless packaged in a convincing way. They can also amplify inequalities and societal or racial biases from the training data, or generate art or music that imitates a human creator (and may be shared, wittingly or unwittingly, by tens of millions of people online).

LAST FEBRUARY, Google unveiled its own chatbot, called Bard, but in its first public demonstration it made an embarrassing factual mistake. (It reported that the

97%
THE NUMBER OF OWNERS THAT BELIEVE AI WILL HELP THEIR BUSINESS*



at the RAND Corporation, the research organization and think tank based in Santa Monica, California. “That’s radical.”

The quest to build an AI system dates back at least to the 1960s and a system called ELIZA, designed by Joseph Weizenbaum, a computer science pioneer at MIT. It was a kind of mechanical therapist that used keywords from a user’s input to generate responses, but it gave the appearance of carrying on an informal conversation.

It was the type of program — maybe the first of its kind — that could even attempt the Turing Test. Named for Alan Turing, the computer science pioneer, the test is a way to gauge the capabilities of an AI system. If the person conversing with the system can’t tell if it’s human or machine, then the system passes. ELIZA didn’t. Experts disagree on whether more recent AI tools like ChatGPT pass the test, or whether the Turing Test even remains a useful metric.

“LLMs have the ability to do something that looks like reasoning,” Marcellino says. But that’s not the same as human thinking. “I don’t want to make claims about actual intelligence.”

Importantly, ELIZA was rule-based, which means it

responded mechanically to the user’s input. The newer LLMs don’t follow a set of rules, but instead analyze prior patterns to offer probabilities for how to predict new text (or images, or music).

Generative AI programs are typically based on artificial neural networks, which analyze data and find connections among inputs (which words often appear together, for example). They took a major leap forward in 2017, when Google unveiled the transformer, a kind of neural network approach that can quickly identify patterns and connections between individual inputs. For example, it looks for ways that every word in a text connects to every other word within a certain input length.

The transformer revolutionized language models. It enabled them to quickly find connections between words in enormous datasets. ChatGPT was originally powered by GPT-3.5, a LLM that trained on a dataset that included text from books, articles, and the internet, totaling an estimated 300 billion words. GPT-4, which was released in March, performed even better. (One metric: When ChatGPT took the Uniform Bar Exam, the knowledge test of those seeking a license to practice

law, the model scored in the lowest 10 percent of scores. When GPT-4 took the test, it reached the top 10 percent.)

THE FIELD is continuing to evolve, says Marcellino.

Researchers are looking for ways to build smaller, more nimble models that harness the potential of ChatGPT, applying the tool to medicine, the military, and more. He and his team, for example, have built a chatbot for use with the lingo of the U.S. Army.

The potential good that could come from generative AI programs is matched — and often overshadowed — by the increased risks, to everything from cybersecurity to copyright infringement, from identify theft to national security. Those threats already exist; the question is whether LLMs could increase their reach. More regulation could help: Health care researchers have called for increased government oversight, for example, to ensure that the use of LLMs does not cause harm and that it protects the privacy of patient data.

Finlayson predicts that these new tools will boost efficiency among workers, but doesn’t think they’ll obviate the need for humans — at least in most fields.

“ChatGPT has no sense of what’s right or wrong, what’s correct or factual. It’s not anchored to the real world,” he says. “It’s moving very quickly, and human ingenuity continues to be needed in very serious ways, to address these problems that have developed. I think we will rise to that challenge.”

—STEPHEN ORNES

180.5 MILLION
THE NUMBER OF
CHATGPT USERS*
(AS OF 8/23)

77%
OF WORKERS
BELIEVE AI WILL
CAUSE JOB LOSS
IN THE NEXT
YEAR*

James Webb Space Telescope had captured the first image of an exoplanet, but that feat was achieved in 2004 by the Very Large Telescope.) In April, an earworm called “Heart on My Sleeve” began to circulate online, reported to be a collaboration between the musicians Drake and The Weeknd. Except that it wasn’t: “Heart on My Sleeve” was a musical deepfake. An anonymous creator trained a generative AI program to convincingly mimic the singers.

With so many applications — and opportunities for error — the rise of these tools has ignited interest, debate, anxiety and excitement.

“For the first time you can really talk to a computer,” says Bill Marcellino, a sociolinguist and behavioral scientist

2023 NEWS BRIEF

3D-PRINTED “SUPERALLOY”

A team from NASA and Ohio State announced in April the development of a heat-tolerant, 3D-printed alloy that could revolutionize the construction of aerospace parts. Tiny, oxygen-containing particles spread throughout the so-called superalloy — dubbed GRX-810 — make it twice as strong, twice as resistant to oxidation, and over 1,000 times more durable than current 3D-printed superalloys.



THIS HISTORIC BANYAN TREE towered high over downtown Lahaina prior to the deadly wildfire that destroyed much of the city (upper right inset). Experts are optimistic that, with care, the scorched tree will recover.

BELOVED BANYAN

Humans have long nurtured the 150-year-old banyan tree at the heart of downtown Lahaina in Hawaii. In its earliest days, residents hung jars from its aerial roots to encourage the growth of additional trunks. Now, following the deadly wildfire that tore through Lahaina and thousands of acres across Maui late last summer, the largest banyan tree in the U.S. needs a different kind of care.

Many arborists feared that the scorched tree, in a near comatose state, would not survive. But volunteers immediately set to work, punching air into the soil around the tree's massive root network as trucks doused the area in hundreds of gallons of water daily. Also on the menu: a concoction of microbes and nutrients called "compost tea," plus layers of solid compost and chopped-up alfalfa for extra nourishment.

Experts are optimistic the efforts will not be in vain. About a month after the devastating fire, according to Hawaii's Department of Land and Natural Resources, new leaves began sprouting from the tree — a welcome flash of green among so much char, and a symbol of Lahaina's recovery. **▣**



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