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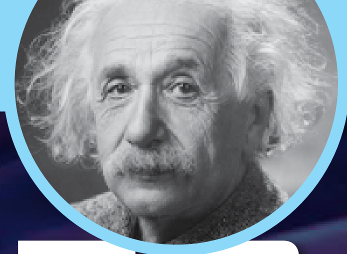

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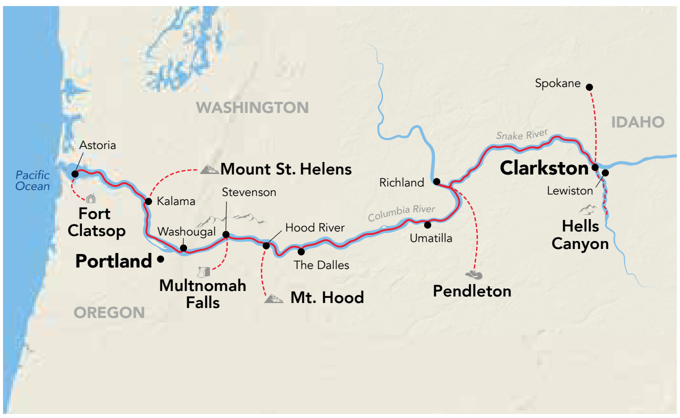

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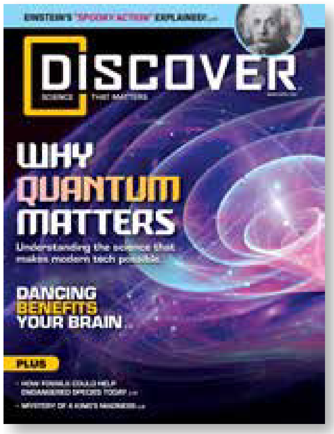
FROM LEFT CLOCKWISE: MOLA VIA GETTY IMAGES; KURIT AFSHEN/SHUTTERSTOCK; NASA/JOHNS HOPKINS APL/STEVE GRIBBEN

EDITOR'S NOTE

BY STEPHEN C. GEORGE

A Very Quantum Year

EDITORS OF science magazines aren't supposed to admit this, but when it comes to the topics we cover, we don't know everything. How could we? Before I came to *Discover*, my main focus was in covering medicine and health. As for other areas of scientific endeavor? I knew a little about a lot of things, but there were some fields of which I was radiantly ignorant.



This is not a shamefaced admission. In fact, there are times in this job when I positively revel in my ignorance; it reminds me that I have something new to learn. (And when you work at *Discover*, you really do live the cliché of learning something new every day.)

Take quantum mechanics. Ever since I first encountered it in high school, I found it hard to grasp, sometimes downright impenetrable. I still struggle with many aspects of it, but I want to know more; maybe you do, too. And this just might be the year when we can all make a, well, quantum leap in our knowledge and understanding. That's because the United Nations has declared 2025, the 100th anniversary of the development of quantum mechanics, as the International Year of Quantum Science and Technology (IYQ).

What area of science do you wish you knew more about? Email me at editorial@discovermagazine.com and let me know!

As IYQ noted in their initial announcement: "Looking forward, quantum science and technology will be a key cross-cutting scientific field of the 21st century, having a tremendous impact on critical societal challenges … including climate, energy, food safety and security, and clean water." During the year, IYQ will support efforts and events to increase awareness of quantum science and technology and its importance to all of us. You can find out more at quantum2025.org.

And you can start increasing your own awareness right here, starting on page 44.

Stephen C. George, Editorial Director

Feel free to send comments and questions to **editorial@discovermagazine.com**

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THE LATEST NEWS AND NOTES

A STELLAR START

Two objects float freely in this image of NGC 1333, a nebula almost 1,000 light-years away in the Perseus constellation. Spotted in a James Webb Space Telescope spectroscopic survey, the objects (circled above) are among six plausible free-floating planetary-mass objects (FFPMOs) newly identified in the nebula, all five to 15 times the size of Jupiter and free from the orbits of the stars. At least one of the objects, introduced in *The Astronomical Journal* in September 2024, originated in isolation. While some FFPMOs arise alongside stars through the process of planet formation (only to split from their star systems at a later time), others arise alone, a lot like stars themselves. Evidence indicates that the least massive plausible FFPMO is likely one of the smallest examples of the latter in existence, testing the lower limits of size for the process of star formation. — SAM WALTERS; IMAGE BY ESA/WEBB, NASA & CSA, A. SCHOLZ, K. MUZIC, A. LANGEVELD, R. JAYAWARDHANA

The Psychological Toll of Method Acting

WHETHER IT'S ON STAGE OR SCREEN, ACTING DEMANDS A LOT FROM PERFORMERS. NEUROSCIENCE AND PSYCHOLOGY REVEAL WHAT HAPPENS IN THE BRAIN WHEN AN ACTOR FULLY IMMERSES THEMSELVES IN A ROLE.

THE ART OF theater is probably one of the oldest forms of entertainment out there. Even now, audiences still gather in open-air amphitheaters, black box theaters, and multiplex cinemas to sit and watch all kinds of stories unfold before their eyes.

And those experiences would not be possible without the performers who take on various roles to tell the tales.

Acting is far more than just pretending to be someone else, and with certain techniques, like method acting, it's a complex process that requires an individual to fully embody another person. This includes their personality, emotions, motivations, and mannerisms.

Given acting's demands, let's take a look at the neural mechanisms of getting into character.

THE INTRICATE cognitive pathways and emotional processes involved in acting are little understood by science: Only a few studies have looked into the neuroscience of taking on a role.

But some recent research is starting to change that. In 2019, a study published in the journal *Royal Society Open Science* examined the brain regions that are activated when method actors adopt a fictional first-person perspective during dramatic role-playing.

The authors asked the participants, who were in an MRI scanner, to respond to a series of hypothetical questions as both themselves and their assigned characters.

They found that the actors' brain activity in the areas involved in self-processing — the dorsomedial and ventromedial prefrontal cortices — was reduced when responding in character, rather than responding as themselves. The authors interpret these brain changes as a suppression of self.

This suggests that acting, to an extent, is a suppression of self-processing. "Theatrical art forms are unique in that performers have to portray themselves on stage as people who they themselves are not," says Steven Brown, a cognitive scientist at McMaster University in Canada who was involved in the 2019 study. "Children across cultures engage in pretend play, and so play-acting seems to be an important developmental step in socialization."

A more recent study also found that theater actors might be suppressing their sense of self, to a degree, when acting. The authors of a small 2022 study in the *Journal of Cognitive Neuroscience* used wearable brain-imaging technologies to record actors' brain activity when performing a role. The prefrontal cortex usually gets activated when an individual's name is called out, but when the actors heard their own names

ZEPHYR_P/SHUTTERSTOCK

during a performance, they didn't respond as strongly as they normally would.

EMBODYING a character and evoking realistic emotions to tell their story, whether it's on a theater stage or a film set, can blur the lines sometimes. Characters can "take over" the actor's self and have them doing or saying things they normally wouldn't. (For instance, somebody performing as an angry person may find themselves being short-tempered around everyone.) Meanwhile, a 2019 literature review found that blurring the boundaries with the character may result in a change of personality or even dissociation.

"It has been reported in [the] media that acting techniques such as method acting can have severe effects on an actor's mental health," says Dwaynica Greaves, a cognitive neuroscientist at University College London who was involved in the 2022 study.

When an actor goes too deep into a role, especially for a long period, they might find it challenging to drop the character. After shooting *Black Panther*, Michael B. Jordan reportedly had a difficult time getting out of the mindset of his film's villain, Erik Killmonger. Lady Gaga also experienced some "psychological difficulty" towards the end of filming *House of Gucci* when she was too absorbed by her character, Patrizia Reggiani. And, famously, Austin Butler confessed to losing touch with his own personality after playing the titular King of Rock and Roll in Baz Luhrmann's *Elvis*.

AT PRESENT, a large gap in research remains when it comes to the psychological impacts of acting. Extensive studies on the neuroscience of acting are also needed to further explore the subject, and what happens when actors slip in and out of roles.

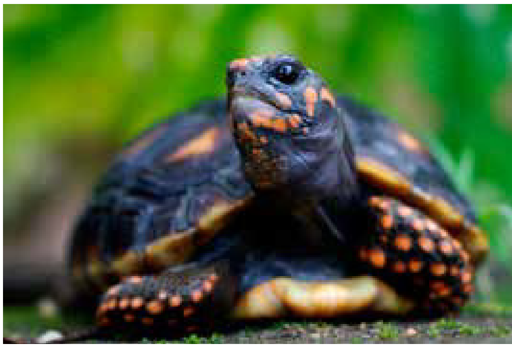
There may be degrees to how much being in character can affect oneself, something Greaves is continuing to investigate. "I would hypothesize that an actor's training technique will influence the distance actors create between themselves and their character," she adds. "This distance will then determine whether there are long- or short-term effects on the sense of self."

— CARLA DELGADO

REPTILES HAVE A REPUTATION AS PRIMITIVE, EMOTIONLESS CREATURES. EXPERTS SAY COUNTERING THIS MYTH COULD HELP PROTECT THEM FROM HABITAT LOSS.

NOT-SO COLD BLOODED

THE WORD *reptilian* doesn't describe just lizards and snakes. When applied to humans, it denotes an unfriendly, unfeeling type of person. That's because for decades, reptiles have been characterized as cold, emotionless, and even primitive creatures.



But scientists agree that reptiles aren't emotionless — they're misunderstood. Extensive research has shown that reptiles experience a wide range of emotions, and that they're highly socially complex animals.

Despite this wealth of evidence demonstrating reptiles' emotional capacity, however, they've retained a reputation for being as cold-blooded emotionally as they are physically. These misconceptions can lead to a lack of awareness for reptiles' needs in captivity and in the wild, advocates say.

"They don't follow the same sort of rules that birds or mammals follow, and so we understand them a lot less," says conservationist JJ Apodaca, executive director of the Amphibian and Reptile Conservancy. "That just leads to us often leaving them out of important policy or conservation efforts."

As more and more reptilian species are threatened by habitat loss, scientists and conservationists say that recognizing reptiles' capacity for emotion can help pet owners and policymakers alike take better care of them.

ANXIETY, STRESS, excitement, fear, frustration, pain, and suffering — all of these are emotions that humans might feel on a daily basis, and scientists have repeatedly found that reptiles experience those things, too, per a 2019 literature review published in the journal *Animals*.

That growing body of work pushes back on the widely accepted notion that reptiles only have the capacity for survival instincts, and not for emotional intelligence. Yet the myth of the emotionless "lizard brain" persists. Popularized in the 1970s by astronomer and science communicator Carl Sagan, the term refers to the parts of the human brain that we use for survival instincts.

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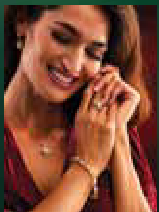

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According to this misconception, the human brain evolved over time by adding progressively more sophisticated structures to this rudimentary lizard brain, including the limbic system, which is the source of our emotions. Because reptiles are our evolutionary predecessors, some researchers long believed that this instinctual part of the brain was the only part that originated with our scaly ancestors — and that without humanlike brain structures, reptiles didn't have the capacity for emotions at all.

Scientists have consistently disproven this theory throughout the 20th and 21st centuries. The 2019 review, which analyzed a cross-section of scientific literature on reptile sentience conducted between 1999 and 2018, found 37 studies that showed evidence of reptiles' capacity for emotion. One of these studies, for instance, found that handling lizards caused an increase in their heart rate, indicating an emotional response. Another found that red-footed tortoises exhibited anxiety-like behavior when placed in a new environment.

While they may not be outwardly expressive in the same way that humans or other mammals are, reptiles are indeed highly social animals, and have developed complex rituals for parental care, courtship, and nesting. Yet even as research on reptile socialization continues to build, the stereotypes around reptilian emotions have persisted.

Scientists say part of this is simply because reptiles show their emotions differently than humans. In a 2021 study published in the journal *Integrative and Comparative Biology*, researchers found that lizards emit chemicals to communicate with each other, meaning they're much harder to read than their mammalian counterparts.

PSYCHOLOGICAL studies show that lack of awareness about animal emotions, in general, also plays a major role in our misconceptions. The 2019 literature review found that humans are more likely to empathize with animals that share physical and emotional characteristics with us, which is why many people might have a deeper understanding of dogs and cats than of turtles, for instance.

What's more, in a study published in *Applied Animal Behaviour Science* in 2023, researchers found that reptile owners were more likely to highly rate reptiles' cognitive abilities than non-owners were. Nonetheless, both groups still said that reptiles had limited emotional capacity.

Today, 21 percent of reptile species are considered endangered, according to the International Union for Conservation of Nature. And recently, scientists found that desert-dwelling reptiles are particularly vulnerable in the face of extreme heat, per a study published in 2024 in the *Journal of Arid Environments*.

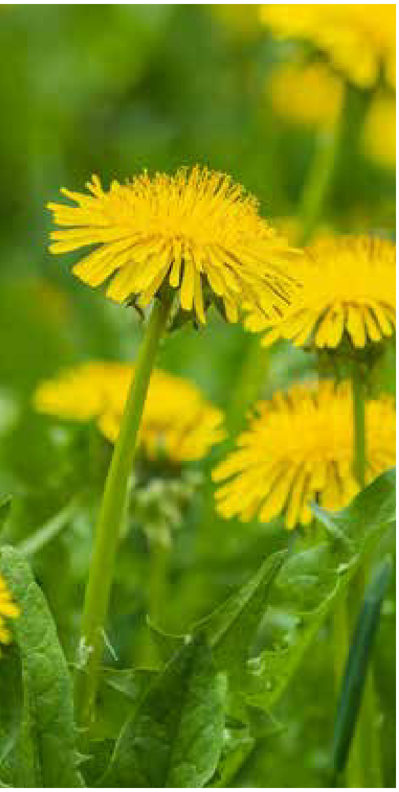
Psychological studies show that lack of awareness about animal emotions, in general, also plays a major role in our misconceptions.

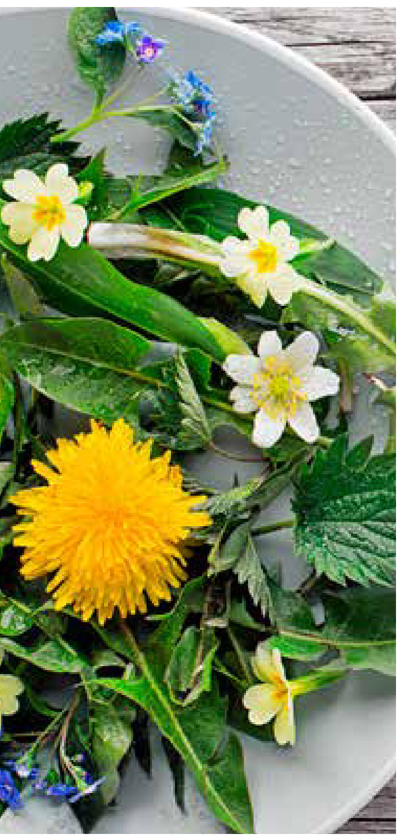
But our tendency to dismiss reptiles isn't just psychological — for decades, it's impacted the level of habitat protections they're afforded in the U.S. "Amphibians and reptiles are two of the most endangered groups in the world, but their listing [in the U.S. Endangered Species Act] lags way behind that of mammals and birds," Apodaca says. "Some of that's because of advocacy, but also because of the data that's available."

Apodaca says he's noticed gaps in species recovery funding for reptiles versus mammals, birds, and fish. However, he's also noticed a huge increase in awareness of reptiles' conservation needs — a development which could prove crucial to combatting habitat loss in the coming years.

"We're learning more and more about the behavior of reptiles," Apodaca says. "They're more complex, and they feel more, and they're smarter than we ever thought." — LILY CAREY

KURIT AFSHEN/SHUTTERSTOCK (2)





DANDELION MAY HAVE DISTINCT HEALTH BENEFITS

THE COMMON YELLOW WEED HAS LEAVES RICH IN VITAMINS AND MAY BOOST HEALTH IN OTHER WAYS, BUT IT'S UNDERSTUDIED IN COMPARISON TO OTHER NUTRACEUTICALS.

A HOMEOWNERS association might look at a house with a lawn carpeted in dandelions and see violations worthy of hefty fines. Yet researchers who study nutraceuticals, or plant or animal products with known health benefits beyond nutrition, increasingly see the yellow weed as a natural remedy with chemical compounds that can help with various ailments.

The first known recorded use of dandelion benefits occurred in China around 657 C.E. during the Tang Dynasty, when it was noted as an effective treatment for breast swelling and pain. In the coming centuries, it was used to detoxify sores.

Historically, the leaves, which have anti-inflammatory, choleretic, and diuretic properties, were used as a remedy for a wide variety of ailments, including gastric, hepatic, and renal disorders, while dandelion root was used to help with digestion and provide relief for rheumatism.

THERE ARE more than 2,500 species of dandelion, and *taraxacum officinale* is the most studied. A 2021 literature review in the *Bulletin of the National Research Centre* examined 54 studies that tested the benefits of dandelion and found that it has many protective properties, including as a diuretic, immune booster, anti-inflammatory treatment, and even potential diabetic aid.

In addition to those qualities, the literature review also found studies with evidence that dandelion could help treat cancer. It can also have antibacterial, antifungal, and antiviral properties.

Notably, most studies with dandelion have been conducted in test tubes or with mice. Without more rigorous studies, medical practitioners will likely hesitate to incorporate it into their work.

"What health care providers want to see is clinical evidence, at least double-blind, randomized control studies. Ideally, they'd like to see a meta-analysis or two," says Jean Bokelmann, a medical doctor and the author of *Medicinal Herbs in Primary Care: An Evidence-Guided Reference for Healthcare Providers*.

In her book, Bokelmann examined 55 herbs. Of those, dandelion had been the least studied, which she says makes it difficult for clinicians to want to include it in their treatment plans.

Without more rigorous studies, medical practitioners will likely hesitate to incorporate it into their work.

Dandelion or supplements derived from it can be used at home, although consumers should be aware that all supplements are loosely regulated by the FDA. Bokelmann recommends discussing dandelion usage with a medical care provider — just as a patient would do with any other nutraceutical — to see if it is right for them. Dandelion, for example, stimulates the secretion of bile from the liver, so she says it might not be right for people with liver conditions.

For people who want to try incorporating fresh dandelion into their diet, young plants from the yard will suffice. Bokelmann grabs a few early in the season and adds them to salads because they are high in potassium and vitamins C and K. When grabbing dandelion from the ground, she recommends digging up the roots.

Bokelmann doesn't think attitudes toward dandelion will change in the near future. Private industry is often responsible for leading the charge for new remedies. "What private industry will want to study dandelions when everyone has them in their yards?" she asks.

— EMILIE LE BEAU LUCCHESI

FROM TOP: DARK_SIDE/SHUTTERSTOCK; DUSAN ZIDAR/SHUTTERSTOCK

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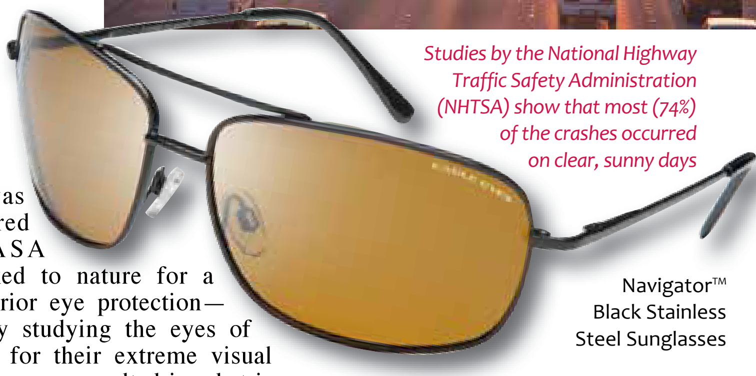

Studies by the National Highway Traffic Safety Administration (NHTSA) show that most (74%) of the crashes occurred on clear, sunny days

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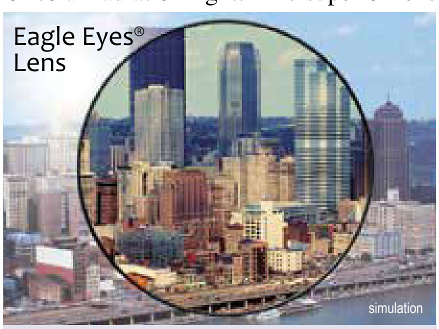

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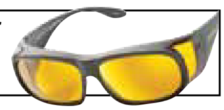

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THE CANCEROUS lesions and clean cuts on Skull 236 are a sign of an ancient surgical operation, over 4,000 years ago.

Ancient Egyptians Dabbled in Brain Surgery

INCISIONS DEMONSTRATE ANCIENT EGYPTIANS WERE PERFORMING SURGERY MORE THAN 4,000 YEARS AGO, POSSIBLY AS A MEANS TO TREAT BRAIN CANCER.

IT'S OFTEN appropriate to say that a particular practice "isn't brain surgery" — except when it is. That may be the case in incisions to an ancient Egyptian skull that shows signs of an operation, according to a study published in *Frontiers in Medicine* in May 2024.

The researchers in the study examined two skulls from the University of Cambridge's Duckworth Collection, curious about cancer in ancient Egypt.

In Skull 236 (dating from between 2687 and 2345 B.C.E., from a male), microscopic observation revealed a large wound consistent with excessive tissue destruction caused by a tumor, as well as 30 or so smaller lesions that resemble marks made by metastasis. But what took the scientists aback was the trace of incisions around some wounds.

"It was surprising to see the cut marks at the microscope, because we immediately realized the significance and implications of the discovery: Ancient Egyptians, more than 4,000 years ago, were already performing a surgical intervention in relation to tumors," says lead author Edgard Camarós, a paleopathologist at the University of Santiago de Compostela.

HOWEVER, the researchers have no conclusive way to determine whether the surgery was performed before or after the subject died. "There is a narrow window of time when the surgical cut marks could have been performed," adds Camarós.

Someone could have cut into the skull either as an attempt to treat the cancer, or as an exploratory medical autopsy to determine the patient's cause of death. Either option makes the find no less remarkable.

"Both possibilities reveal an oncological surgical intervention intimately related with the tumors, which is itself an exciting discovery," says Camarós.

Another specimen, Skull E270 (dating from between 664 and 343 B.C.E., from a female) doesn't show signs of surgery. But it does show lesions, one consistent with a tumor and two consistent with traumatic injuries. That the latter lesions eventually healed could mean that the injuries were successfully treated.

What's more, E270 belonged to a female, and the conventional wisdom is that Egyptian women didn't participate in warfare. Signs that she was wounded, then treated and healed, could rewrite the role of Egyptian women in battle. The alternatives to combat wounds are that the injuries — one likely caused by a sharp blade — were either the result of punishment or a domestic dispute.

Many ancient Egyptian writings discussed medicine. Other archaeological discoveries have shown evidence of dental fillings and prosthetic limbs. But this finding represents a new landmark. "This is the first surgical intervention in relation to tumors," says Camarós.

— PAUL SMAGLIK

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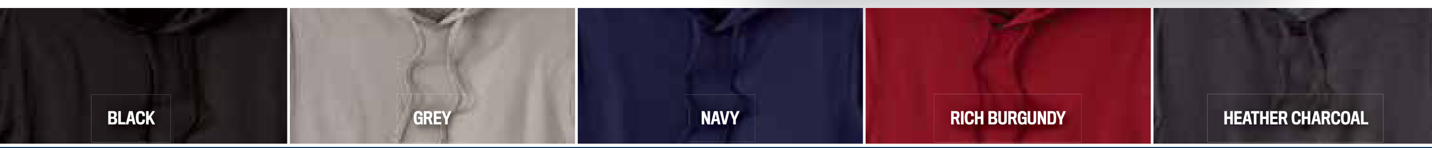

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HOW TO STOP RELIVING YOUR MOST EMBARRASSING MOMENTS

REVISITING MORTIFYING MEMORIES MAY BE AN EVOLUTIONARY TRAIT. LEARN WHY EMBARRASSING EXPERIENCES LINGER AND HOW TO HELP THEM FADE OVER TIME.

THERE ARE some moments in life that jolt you into awareness when you think of them: You're minding your own business, and all of a sudden, you're reminded of how mortified you felt at a specific moment, weeks, months, or even years ago.

Embarrassing memories can still carry the same emotional weight in the present as they did in the moment they were happening. It's the brain's way of telling us not to make the same mistake twice. The good news is that you don't have to suffer at the hands of past cringeworthy moments — and over time, their power over your psychological state will start to diminish.

THE BRAIN is programmed to respond to negative threats, so we're more likely to relive negative memories out of nowhere compared to positive ones, all in an effort to avoid making the same mistakes again, says David Hallford, a clinical psychologist at Deakin University in Victoria, Australia.

Embarrassing memories tend to emerge more readily when we're going to sleep or when we're waking up — the times when we're at rest and not focused on the things we have to do in our day. That's when the default mode network, a part of the brain related to thoughts about the self and general self-reflection, is more active.

Plus, the purpose of the brain is to keep us alive and keep us procreating, says Halford, and our social skills are important for our place at the top of the food chain. As such, we often relive memories of when we said and did the wrong thing socially, in order to help us fix our social missteps.

"Being able to affiliate with people and be liked and valued is really important for us. Social relatedness is one of our core needs," Hallford says. "In those times when we embarrass ourselves, that's a threat to our social relatedness."

Compounding the problem, some people have a negativity bias, which means they're more likely to be "scanning for threats." These

ALPHAVECTOR/SHUTTERSTOCK (2)

are often people who have PTSD, depression, anxiety, or personality disorders, says Hallford. For those individuals, it's not unusual to jump to negative, disappointing, or sad memories.

People with mental health issues also tend to think of embarrassing or generally negative memories as self-defining, thinking things like, "I always do this" or "This shows who I am."

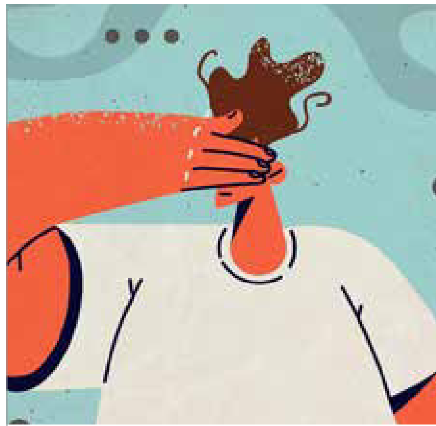
HOWEVER, for the majority of people, negative or embarrassing memories fade. A phenomenon known as the fading affect bias says that the negative impact of an embarrassing personal event tends to become more

> If you label a memory as something that you can't handle, it gives that memory more power.

positive over time. What's more, it's possible to actively adapt our memories as we're reexperiencing them: In a 2021 study in *Nature Communications*, researchers found that participants who practiced recalling the positive aspects of a negative experience were able to shift the focus of those memories to be more uplifting.

And for those painful memories that still linger, it can be helpful to learn to sit with any feelings that make you feel uncomfortable in order to process them. For example, if you're meditating and a memory emerges with a negative emotion attached, you can label what the emotion is, locate where you feel it in the body, and identify how it makes you feel. You can then notice the impermanence of that feeling — even if the emotion itself is terrible, it will pass like a cloud in the sky.

If you label a memory as something that you can't handle because it's



so negative, it gives that memory more power. But once you sit with the emotions behind it, no matter how mortifying they once were, the memory loses its strength and fades away as time passes. — SARA NOVAK

SOME SPECIALISTS have suggested that the anatomical traits of the Neanderthals, including their wide noses and large nasal cavities, would have produced high-pitched voices.

Pitch Perfect

RESEARCHERS DEBATE A CONTROVERSIAL THEORY THAT SUGGESTS NEANDERTHALS MAY HAVE HAD HIGH-PITCHED VOICES.

NEANDERTHALS stopped roaming Earth around 40,000 years ago. As time marches on, however, new technologies are helping scientists learn more about *Homo neanderthalensis*, how they might have lived, and what similarities they may have shared with *Homo sapiens*.

For instance: Scientists have long debated what Neanderthals sounded like, or whether they even possessed the anatomical ability to vocalize. In the 1980s, scientists discovered the skeleton of a Neanderthal male in Kebara Cave, Israel. Known as Kebara 2, the skeleton was well intact and allowed scientists to examine its neck bones. In particular, the researchers found that the specimen's hyoid bone, a U-shaped bone in the neck that supports the tongue, was similar to the same structure in humans, suggesting that Neanderthals were indeed capable of speech.

But the question of what Neanderthals actually sounded like is still open to interpretation.

ONE THEORY POSITS that Neanderthals may have had high-pitched voices. The theory was introduced in a 2005 BBC documentary, *Neanderthal: The Rebirth*, in which producers worked with famed vocal coach Patsy Rodenburg. Producers gave Rodenburg a model of a Neanderthal vocal tract and provided details on the Neanderthals' anatomy.

Rodenburg was told that Neanderthals had wide noses with large nasal cavities, broad rib cages, and short voice boxes. Rodenburg then coached an actor, Elliot, into changing his voice to accommodate these traits. Elliot pitched his voice higher on command, and then gave it a more nasal quality to reflect the Neanderthal nasal cavity.

Rodenburg suggested that the Neanderthals' heavy skulls would have pulled down on their throats while their large rib cages would have allowed for chest resonance. As such, she provided a grip for Elliot to push down and out while he repeated the exercise.

The result? A high-pitched voice that one might not associate with a heavy-browed, barrel-chested Neanderthal.

THE HIGH-PITCHED voice theory is controversial, and some scientists argue the Neanderthals likely sounded more like modern humans.

> The question of what Neanderthals actually sounded like is still open to interpretation.

"The vocal tract reconstructions have been highly criticized as not necessarily accurate. I really don't buy the high-pitch voice theory," says Rolf M. Quam, a paleoanthropologist, professor, and anthropology department chair at Binghamton University in New York.

Quam says the high-pitched voice theory is too focused on bones, discounting how soft tissues would have shaped the sounds Neanderthals made. Without these tissues to determine the length and structure of the vocal tract, he says, scientists can't be sure what Neanderthals sounded like.

Still, Quam says there is increasing evidence that Neanderthals were capable of hearing and producing language. Although scientists don't know the extent of the sophistication of their language, he thinks they could produce a range of sounds. "It wouldn't be grunting and shrieking like chimpanzees," he adds.

In a 2021 study in *Nature Ecology & Evolution*, Quam was part of a team that used computerized tomography to examine sound transmission in Neanderthals' outer and middle ears.

The study found "that the auditory capacities in Neanderthals do not differ from those in modern humans." Most notably, it found that Neanderthals would have been capable of hearing and understanding consonant sounds, which means they could have been capable of more sophisticated vocal communication.

— EMILIE LE BEAU LUCCHESI

ESIN DENIZ/SHUTTERSTOCK

A SWIRLING STORM once large enough to engulf three Earths, Jupiter's Great Red Spot is getting smaller and smaller.

NASA, ESA, A. SIMON (GODDARD SPACE FLIGHT CENTER) AND M.H. WONG (UNIVERSITY OF CALIFORNIA, BERKELEY)

JUPITER'S GREAT RED SPOT KEEPS SHRINKING

THE LARGEST STORM IN OUR SOLAR SYSTEM, AN 8,700-MILE-WIDE ANTICYCLONE LONG BELOVED BY ASTRONOMERS, MAY BE SLOWLY FIZZLING OUT.

EARTH'S ATMOSPHERE is in such constant flux that we have a tired old saying about it: "If you don't like the weather, wait five minutes." If we lived on Jupiter — where a single storm has been raging uninterrupted for almost two centuries, and possibly much longer — we'd have to muster more patience.

But perhaps we wouldn't have to wait forever. The Great Red Spot, an enormous high-pressure system which astronomers have tracked regularly since the late 19th century, is steadily dwindling. In its heyday at about 25,500 miles across at its long axis, it was large enough to engulf our planet three times over; now it hardly spans a single Earth.

On Jan. 6, 2024, the spot measured just 8,700 miles at its long axis and 6,100 miles at its short axis. That's in line with a consistent, decades-old trend. And while it's unclear whether our solar system's most famous planetary feature will ever vanish entirely, there's no reason to think its decline will stop or reverse anytime soon.

"It is still shrinking," says Amy Simon, a senior scientist at the NASA Goddard Space Flight Center. As in previous years, "it's the smallest size we've ever measured it at. That's definitely not changing." ›

ROBERT HOOKE and Giovanni Cassini, two of the leading astronomers of the 1600s, both noted spots on Jupiter's surface that resemble the modern storm. But there's a gap of many decades before the next recorded sighting, and no one has been able to prove whether those early scientists were looking at the same thing we see today.

That means the first reliable observation comes from 1831, and consistent observation only began in 1878. At that time, the spot was much bigger, and much more oblong. "At this very large size," Simon says, "it's not really stable."

In fact, that initial structure may be partly responsible for its shrinking. A storm's internal winds tend to make it rounder, as seen in satellite images of hurricanes on Earth. In a similar way, the winds that rip around the spot — in excess of 400 mph — may be whittling that unsustainable oval into a more durable shape. Indeed, its waist is the dimension that's narrowing fastest.

THAT SAID, no one is sure why the Great Red Spot has shrunk so drastically — or, for that matter, what lies ahead. Its fate depends on an interplay of complex meteorological mechanisms.

On Earth, storms can dissipate as they make landfall, or fall apart as they drift to different latitudes. But on a gas giant like Jupiter, there is no land, and Simon says the spot is locked in its current latitude by powerful east-west jet streams, "like a ball bearing rolling in a channel." Those circumstances are largely responsible for its longevity.

It may, however, meet its maker in a different way: Intense external winds can shear the top off a storm, sapping it of its strength. And as it happens, just such winds buffet the Great Red Spot. Historically, the storm has been more than a match, but as it gets smaller, those winds could eventually prevail.

It's also unclear how the diminishing tempest will interact with lesser storms in its path, though Simon says that in recent years it appears to be absorbing them more easily. That could either weaken or strengthen the Great Red Spot, depending on which direction they're spinning.

"Those are the sorts of things we're going to be monitoring over the next few years," she says. But when — or even if — they'll have a dramatic effect on the spot, "your guess is as good as mine. It could be 20 to 30 years; it could be 200 years." Or, alternatively, the storm could settle into equilibrium at a stable size and outlive us all.

THOUGH SCIENTISTS are learning more and more about the Great Red Spot, it remains enigmatic. In 2024, Simon published a study in *The Planetary Science Journal* that found that the storm's size oscillates, aside from its long-term shrinking, squeezing in and out like a stress ball. And in 2021, a study in *Science* set the spot's depth as much deeper than anticipated, at around 300 miles. But the processes powering it are still poorly understood.

And size isn't the only thing in flux. Its name notwithstanding, the spot has ranged in color over the years, displaying an ever-shifting mix of deep red, fiery orange, and even pale beige. As with so much else, no one knows the source of these breathtaking hues. But one clue came in 2019, when researchers found a way to recreate the spot's color spectrum in the lab. Based on their findings, the storm may be a product of atmospheric ammonia breaking down under solar radiation.

For the next official update on proportions, astronomers await the annual data delivery from Hubble (though amateurs keep continuous tabs).

The Great Red Spot probably isn't in imminent danger of disappearing, but weather on the outer planets can be notoriously fickle. Neptune's Great Dark Spot, first spotted in 1989, vanished unexpectedly before the next scheduled observation in 1994.

If the granddaddy of all storms were to someday follow a similar road into oblivion, the view from Earth would lose some of its celestial magic. "Everybody grew up with a picture in some textbook somewhere of Jupiter with the Great Red Spot," Simon says. "For it to suddenly be gone would just be strange." — CODY COTTIER

NASA, ESA, A. SIMON (GODDARD SPACE FLIGHT CENTER) AND M.H. WONG (UNIVERSITY OF CALIFORNIA, BERKELEY)

BY TONY DAJER

THEO COBB

Missing the Point

APPENDICITIS OR JUST A STOMACH BUG? EVEN TODAY, IT CAN BE A TRICKY DIAGNOSIS — WITH POTENTIALLY CATASTROPHIC RESULTS.

The 10-year-old boy, freckled, stocky, central-casting New England Irish, looked unsettled.

"Brian's never sick," his mom explained. "But he's been throwing up since yesterday, with bad stomach cramps. He's never sick. I got some ginger ale into him yesterday, but he puked all last night. No better today, so it was time for the ER." She paused to stroke his clammy forehead. "He's trying. Aren't you, Bry?" Brian nodded, barely.

The boy had no other medical problems. The vomiting had started along with the belly cramps; he couldn't remember which came first. Vital signs were normal except for a slightly elevated heart rate and a low-grade fever of 100.4.

"Where does your stomach hurt most, buddy?" I asked.

His cheeks flushed red. "Kinda everywhere," he finally answered, then added, "Down there."

"OK," I said, "I'm going to tap first, then press gently. If anything hurts, I'll stop."

Gentle percussion is the best way to localize inflammation of the peritoneum, the two-layer membrane that lines the intestines and overlying abdominal wall. Tapping my right middle finger against the left, I probed around Brian's belly. Both lower quadrants seemed equally tender. To tell which was worse, I carefully pressed my palm into the right.

I was thinking of my young patient's comfort in an uncomfortable situation. I would come to regret my words.

"Ow," he said, the sound escaping like a sigh.

"Sorry," I whispered, then tried the left. "Here?"

"Same," he said.

"When I press here," I said, continuing to press on the left, "does that make it hurt on the right?"

"No. Just left," he exhaled.

A switch tripped in my head. This wasn't Rovsing's sign — a hallmark of appendicitis — where pressure on the left causes pain on the right. The boy's belly was equally sore in both lower quadrants, strongly suggesting a widespread process like viral gastroenteritis. Straightening up, I gave his mom a confident look.

"Stomach bug," I proclaimed, and decided against doing blood work. "Vomiting alone can bump white blood cell counts, so blood work probably won't help us tell a virus from anything more serious," I explained. At the time, I was thinking of my young patient's comfort in an uncomfortable situation. I would come to regret my words.

But in the moment, I smiled at Brian. "No needles today, buddy. Do you think you can take some sips of water?" He managed a grin. Mom looked hopeful.

"Let's try. If he can keep fluids down, we'll let you go," I said, hurrying off to face the bustling ER. Good decision, I congratulated myself, to not burden the nurses — or my patient — with a useless IV and blood draw.

An hour later, Brian smiled wanly, proud he had kept two cups of water down. His abdominal exam was unchanged: mildly tender in both lower quadrants. Still, I determined it was safe to send him home. "On one condition," I emphasized. "I'm back on shift in the morning and need to recheck him. Do you have transportation?"

"I have a car," his mom assured me.

"Excellent. See you back here at 8 AM. And if anything worsens tonight, even if you think you're imagining it, please bring him right back, OK?"

"Got it," she told me.

At 8 AM the next morning, there was no sign of Brian. At 8:30, I called Brian's mom.

"Hi, it's Dr. Dajer. I was expecting you in the ER. How's Brian?"

"Um, he's lying down," she said.

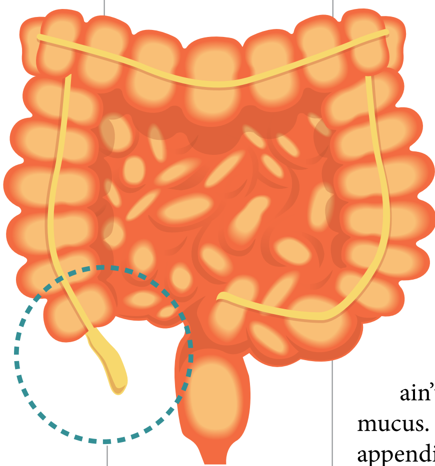
"But no worse? Drinking water, ginger ale? Anything hurting?"

"A bit. No, I don't think so," she answered noncommittally.

"OK," I ventured. "Let's keep a close eye on him. If he gets any worse — anything that worries you — please bring him back."

Four hours later he shuffled into the triage nurse's station. This Brian looked completely deflated, not the plucky kid eager to go home I'd seen the night before. Grimacing, he folded both hands gingerly over his stomach. Damn it, I swore to myself. Appendicitis after all.

A disease that can kill a healthy person in a week, appendicitis will afflict 1 in 14 people at some point in their lives — mostly children and young adults, but no age is exempt. Often mistaken for "the stomach bug that's going around," it's also a top contender when it comes to causes of medical malpractice lawsuits. Why? Because it can cause pain where it isn't. The classic story is discomfort that starts around the mid-abdomen then migrates down to the right to a spot called McBurney's point; the problem is up to half of cases don't follow that script, deceiving even the most thorough and conscientious of doctors.



Dangling from the base of the right colon, the appendix is a hollow tube whose function remains controversial. You can live a long and happy life without one, but some research suggests it may have a role in maintaining healthy gut flora. Surprisingly variable in length (up to nearly 10 inches) it can lie tucked behind the right colon, in the pelvis, or even all the way on the left. Trouble typically starts when a pellet of stool corks its opening. Besides unpredictable length, the pain-where-it-ain't trick stems from its propensity to secrete mucus. Mucus builds up, stopping blood flow to the appendix and causing it to balloon. This distention triggers a visceral pain reflex felt around the belly button or in the pit of the stomach.

As pressure builds, blood supply continues to dwindle and vomiting may occur. (Vomiting after pain onset suggests appendicitis; vomiting before pain points to gastroenteritis.) Bacteria multiply and invade the appendiceal wall, igniting local inflammation. At that point, pain usually migrates to the right lower quadrant where the now-hot appendix usually lies. By 24 to 72 hours, gangrene can weaken the wall, allowing feces from the colon to spill into the once-sterile peritoneum. Prompt diagnosis is hampered by cases where the upper abdominal pain does not migrate, or the pain starts diffusely and never localizes.

An appendix lying in the pelvis is doubly deceptive. Distention triggers the first phase of pain in the periumbilical (around or behind the belly button) or epigastric (just under the ribs) regions, but the migration is dampened because the pelvis has fewer nerve endings to signal inflammation. It gets worse: After perforation, especially in healthy young adults, a pelvic abscess can irritate the colon and cause diarrhea, clinching its mimicry of "nasty stomach bug."

For such an old disease — and despite modern ultrasound and CAT scanning — the misdiagnosis rate remains stubbornly high, with potentially catastrophic results. (This is personal for me: A close relative, a healthy 40-year-old, was discharged from an ER with a narcotic prescription for "gastritis."

You can live a long and happy life without an appendix, but some research suggests it may help to maintain healthy gut flora.

THEO COBB

Two days later, a ruptured appendix almost ended her life.) A 2021 review of over a million ER visits, published in *Annals of Emergency Medicine*, pegged the miss rate at 10 percent (though this particular statistic may be slightly high due to COVID-related care delays). An earlier study in the *Journal of Emergency Medicine* of young women presenting to ERs with subsequently confirmed appendicitis found one-third of cases were initially overlooked. As for me, Brian's tenderness on the right and left lower quadrants had not fit the "classic" (and dangerously limited) mental model of appendicitis.

Dashing to order labs and antibiotics, then call the surgeons, I told Brian's mom the revised diagnosis. Not pleased, she eyed me and asked, "Will he be OK?"

"I think so," I replied, then added, "I'm sorry. I probably should have ordered the blood work."

While an elevated white count can occur in both gastroenteritis and appendicitis, a normal count would have been reassuring, while a very elevated count might have made me think twice. Albeit imperfect, it's a time-tested gauge of disease severity.

This is personal for me: A close relative was discharged with "gastritis." Two days later, a ruptured appendix almost ended her life.

"Yes, you should have," she said, and walked back to her son.

The surgeons removed Brian's gangrenous, perforated appendix and washed the pus out of his abdomen. After three days of IV antibiotics, he went home on oral medication. Unfortunately — but not uncommonly after a perforated appendix — a wound infection brought him back a week later. That required another five days of IV antibiotics.

Days later, when Brian was home, I called his mom. "How's Brian doing?" I asked, still chagrined. I was torn between leaving her alone and hoping not to sound too guilty. "Well enough," she replied curtly. "Going back to the hospital was terrible."

Mea culpa. There are no cost-free apologies in medicine. The blood tests might not have changed anything, but due diligence counts. Yes, Brian's mom had promised to bring him back. But as an insightful professor of mine once said, it is never the patient's fault. D

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

EMILIE LE BEAU LUCCHESI

GEORGE III (right) reigned for nearly six decades, but during his episodes of madness, he was confined to a building once located at Kew Palace (above).

Diagnosing History

PINNING DOWN THE SOURCE OF HISTORICAL FIGURES' MALADIES, LIKE THE ROOTS OF KING GEORGE III'S INFAMOUS "MADNESS," IS ALWAYS INTRIGUING. BUT MEDICAL HISTORIANS SAY IT'S NOT JUST TRICKY TO MAKE A DIAGNOSIS — IT'S ALSO UNIMPORTANT.

At the time of the American Revolution, Great Britain's king was fighting his own battles. King George III had long suffered from physical and mental ailments that seemed to come and go in episodes. In 1765, for example, it was reported he had flulike complaints that led to a period of depression. In a second, far worse bout in 1788-89, physical symptoms were accompanied by more extreme, even manic, mental health symptoms and behaviors.

The king's equerry, Robert Greville, wrote a diary of the time period, labeling it a "Journal of His Majesty's most serious and afflicting Illness." The king would talk for hours, sometimes until he foamed at the mouth; Greville recounts an instance when he talked incessantly for 19 hours straight. He hallucinated — later episodes would include conversations with his dead children — and became uncharacteristically violent and cruel to his family and staff, leading doctors to restrain him with a straitjacket. Recurrences of the illness followed in 1801 and 1804, and the monarch never recovered from his final bout in 1810, dying in isolation in 1820.

In his journal recounting George III's illness, Greville described the monarch's excessive talking fits and hallucinations.

In 1969, two researchers suggested a diagnosis for his mysterious ailments: In their book *George III and the Mad-Business*, Ida Macalpine and Richard Hunter argue the king's symptoms were consistent with porphyria, a blood disease. They cite the king's insomnia, racing pulse, and stomach and limb pain as evidence. Other historians agreed. And, they theorized, because royal physicians used arsenic-contaminated medicines to treat the king's ailments — a toxin that would have exacerbated his porphyria — the treatment must have sparked a neurological reaction.

But in recent years, a new diagnosis has been offered. A 2011 article in *Clinical Medicine* argued that bipolar disorder more accurately fit the king's symptoms, with author Timothy Peters of the University of Birmingham in the U.K. claiming that the researchers behind the porphyria theory cherry-picked the king's symptoms in order to make it fit the diagnosis. Other scientists have agreed that porphyria was likely not the cause of the king's madness due to the disease's rarity and the fact that

CLOCKWISE FROM TOP: MISTERVLAD/SHUTTERSTOCK; ALLAN RAMSAY/WIKIMEDIA COMMONS/PUBLIC DOMAIN; ROYAL COLLECTION TRUST

DEPICTED here on his deathbed in 1820, George III suffered several bouts of illness during his reign. Some episodes were dramatized in the 1994 film, *The Madness of King George.*

other members of the royal family never displayed the same symptoms. Simon Wesseley, Regius Professor of Psychiatry at King's College London, further suggests that Macalpine and Hunter sought to remove the stigma of mental illness from the royal family with their diagnosis of a blood disease. We will likely never know the true diagnosis of the "Royal Malady." But some medical historians say that's just fine.

WHEN HISTORIANS of medicine examine a past medical event or an ailment specific to an individual, the surrounding situation, the event, and the culture around it can be more interesting than an actual diagnosis.

"Most medical historians would argue it's a mistake to pinpoint the cause of the disease in the past. Learning what caused it doesn't tell us much at all," says Richard Keller, chair of the department of medical history and bioethics at University of Wisconsin School of Medicine and Public Health.

George III first suffered flulike complaints in 1765, with more serious mental symptoms occurring in the 1780s and later.

When teaching his introduction to history of medicine course, for example, Keller says he relies on a 2008 article from *Bulletin of the History of Medicine* in which historian Alisha Rankin used estate inventories to examine the troubled health of a 16th-century German duchess.

"This is a woman who complained of lifelong ailments. The symptoms are all over the map," Keller says.

A modern diagnosis of the duchess's disease is unlikely — nor, Keller says, is it needed. Instead, Rankin used the estate inventories to consider the duchess's material culture and what resources she had available to her. Rankin also examined the recipes the duchess's physicians prescribed for her (or her servants) to make in her home. That approach, Keller says, brings a greater wealth of information.

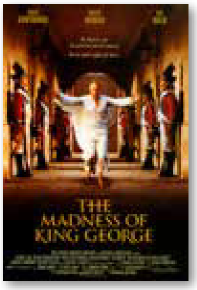
"What it gives us insight into is what it's like to be a person of privilege with chronic illness in the 16th century, which would be very different from someone who was poor," Keller says. "It also tells us about the position of women guiding their own health care."

WHETHER King George had porphyria or bipolar disorder isn't what's significant, says Naomi Rogers, a professor in the history of medicine and of history at Yale School of Medicine.

"It's clear that King George was mad or understood to be mad," Rogers says. "I would say that medical historians would be very interested in what that meant at that time."

King George's madness prompts historians to cast a wide net with questions about what mental illness meant at that time period, how people understood it, and how people with mental illness were treated.

The added benefit of a king's medical crisis is the possibility of records and other archives that give insight into the perspective at the time. Keller says that medical historians would be interested in palace records like inventory lists, physician notes, and personal diaries of court members.



"It could tell us how the king's madness changed the operations of the palace," Keller says. "You'd have to compare that over a long haul, a decade or two. That might indicate how the palace is adapting to that situation."

Such records could also give insight into what medical care providers at the time considered best

FROM LEFT TO RIGHT: DE LUAN / ALAMY STOCK PHOTO; RETRO ADARCHIVES / ALAMY STOCK PHOTO

POPULAR period show *Bridgerton* occasionally addresses King George's illness for dramatic effect. But how did mental illness impact the real royal household of that era?

practices. As the king, George would have had access to the kingdom's most prestigious physicians. Rogers says physicians used arsenic to combat a variety of ailments, so their records might reveal how they understood arsenic as a drug.

Similarly, physician records could also reveal which symptoms or ailments were medicalized. "If he often yelled, seemingly irrationally — how did people talk about it? Was it seen as a royal expression of displeasure? Was it seen as a sign of madness?" Rogers asks.

Although such records would likely be unavailable for commoners with mental illness, Keller says the impact of the king's madness could be measured by how society treated people with mental illnesses. At the time of King George's reign, Keller says people experiencing psychosis were treated inhumanely and even displayed in cages, like zoo animals. The 1800s started the asylum era in which people with mental illnesses were institutionalized.

"That's a really remarkable artifact about George's madness," Keller says. "He's the most prominent person in England suffering from madness at a moment when how the medical profession treats madness is changing."

AS SCIENTIFIC improvements allow researchers to determine which pathogens caused which pandemics, Keller cautions that scholars should avoid getting into small details when there are larger insights that could possibly add to our modern understanding of what transpired.

Keller gives the example of a 2011 study in *The Proceedings of the National Academy of Sciences* in which researchers were able to extract DNA from teeth of victims buried in a medieval plague pit. The scholars were then able to confirm that a variant of *Yersinia pestis* was the culpable pathogen.

"That's cool, in a gee-whiz kind of way," Keller says. But what caught his attention was a newspaper article about the study which noted the graves were dug in advance of the pandemic's onset. The advance burial preparation indicated the medical and government authorities had the ability to recognize contagion. They understood the English Channel was not a barrier that could prevent the plague from spreading from France into England. And they understood the disease to be lethal enough to cause mass deaths.

"That tells you so much more about medieval society than what actually caused the pandemic," Keller says.

In this sense, Keller says it's not what in particular caused King George's madness that should be the

PLAGUE PITS have given medical historians insight into medieval society, which may be more compelling than confirming what caused the plague.

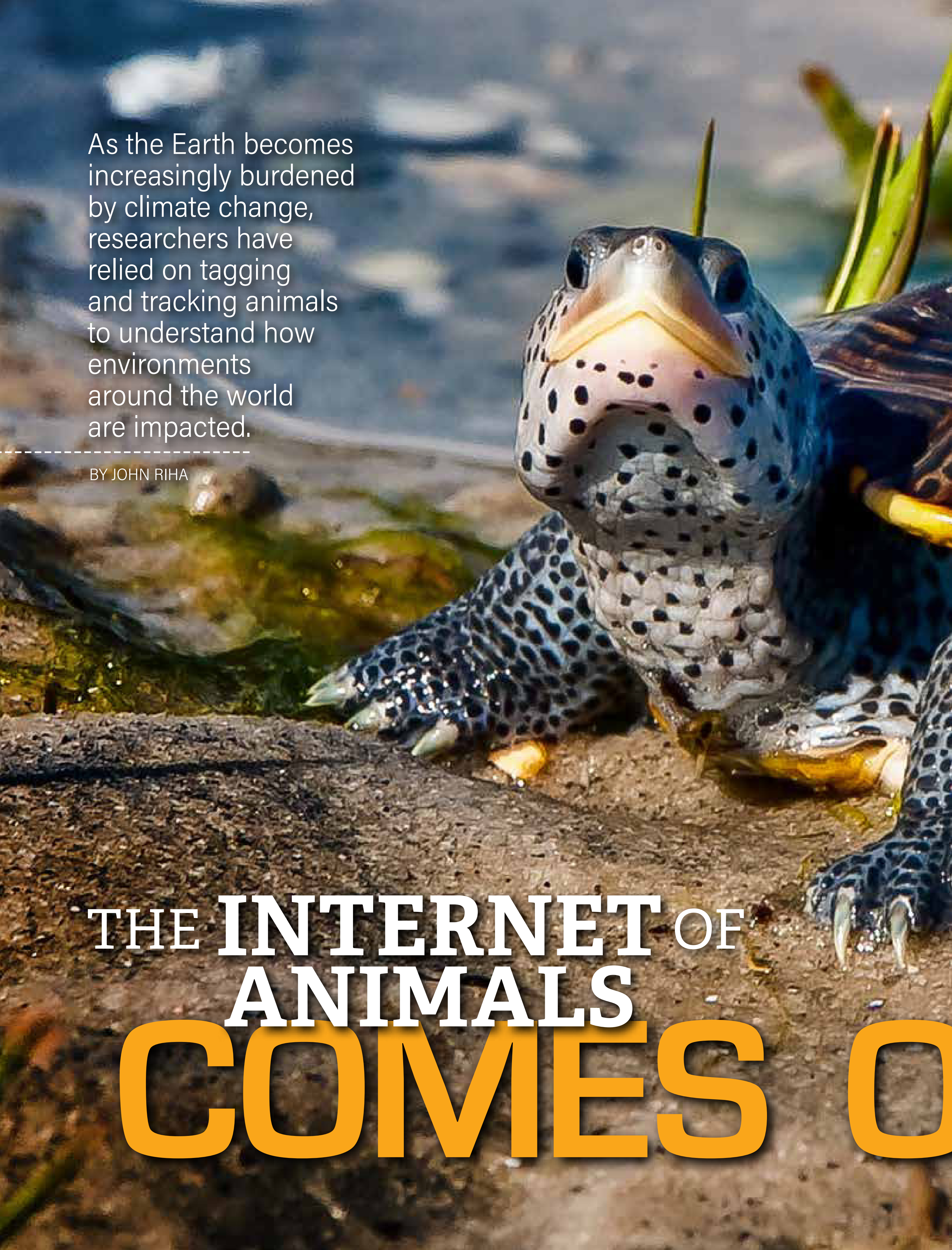
subject of scrutiny. Rather, documentation as to how the palace reacted could help decode how political leaders continued during George's times of incapacitation. Physicians' notes could determine which ailments were medicalized and which weren't seen as symptoms in need of treatment. And diaries could help researchers interpret what mental illness meant at the time, how a king's struggle might have differed from a commoner's, and how such struggles altered — if at all — the way physicians regarded mental illness.

Although many people would feel more satisfied by a diagnosis, Rogers agrees that it should not be the focus of a medical historical investigation. Emphasizing what ailed the rich and famous of yesteryear might seem insightful, but she says that would miss an understanding of the medical, political, and social context in which the event occurred.

"It's not the way of doing the history of medicine," Rogers says. ◼

We will likely never know the true diagnosis of the "Royal Malady." But some medical historians say that's just fine.

***Emilie Le Beau Lucchesi** is a journalist and author of the nonfiction books* Ugly Prey, This is Really War, *and* A Light in the Dark. *She holds a Ph.D. in communication from the University of Illinois-Chicago.*



As the Earth becomes increasingly burdened by climate change, researchers have relied on tagging and tracking animals to understand how environments around the world are impacted.

BY JOHN RIHA

THE INTERNET OF ANIMALS COMES O

DIAMONDBACK TERRAPINS, which often inhabit salt marshes, face habitat destruction from sea level rise. In this critical moment, researchers have turned to satellite monitoring to see how the species responds.

OF AGE

Meg Lamont and her team make their way through the swampy edges of a salt marsh that nestles in St. Joseph Bay on Florida's panhandle. The summer sun beats down from a pale blue sky, and the shallow water is so warm it's almost hot. The air is heavy with the ripe smell of seawater. Prickly black needlerush and cordgrass scrape against their shins as they tromp through the muck. Nevertheless, the team is chatty and upbeat, full of enthusiasm for the work ahead. They're going to tag terrapins.

Lamont, a research biologist at the U.S. Geological Survey Wetland and Aquatic Research Center, is an expert on the habitat and movement patterns of coastal and marine vertebrates in the Gulf of Mexico. The current project she is leading involves finding diamondback terrapins, *Malaclemys terrapin*, the only turtle species in North America that lives exclusively in river estuaries.

The team will capture dozens of turtles, record biological data such as the size and sex of individuals, then glue small transmitters to their backs. Once released back into the wild, the tagged turtles will be monitored via the transmitters and orbiting satellites.

"Getting data for imperiled species like terrapins can be challenging," says Lamont. "They live at the boundary between pure marine and pure terrestrial environments, which is highly susceptible to environmental changes like sea level rise. It's a complex environment, so they're a good indicator species for what's happening around here.

"I love diamondback terrapins," she adds. "They're small, beautiful turtles. But they do bite!"

The process of attaching electronic sensors to animals and then monitoring data that the sensors provide, such as an animal's whereabouts, is interchangeably called biotelemetry, animal telemetry, and biologging. Writing in a 1965 issue of *Bioscience* magazine, researcher L.E. Slater defined the fledgling field of biotelemetry as "the instrumental technique for gaining and transmitting information from a living organism and its environment to a remote observer." Although the technology of biotelemetry has advanced exponentially since then, the description still holds true.

The information that Lamont and her team gathers will add to an ever-increasing stream of animal-provided data that is filling the gaps in what researchers and climate scientists understand about Earth ecology and how to mitigate the effects of climate change. Data about the movements of diamondback terrapins, for example, is essential for establishing conservation strategies designed to protect their fragile habitats.

"Animal telemetry is so critical to our understanding of how animals behave and react to their habitats," says Lamont. "The data benefits environmental managers in so many ways."

Lamont joins a chorus of biologists and researchers extolling the virtues of modern biotelemetry. Advances in computer science, microprocessing, and battery technology are opening new doors on how animals can inform us about planet ecology.

"It's the golden age of animal-tracking science," says Roland Kays, director of the Biodiversity & Earth Observation Lab at the North Carolina Museum of

PREVIOUS PAGE: JASONONDREICKA/SHUTTERSTOCK. THIS PAGE: MAGICBLOODS/SHUTTERSTOCK

BIRD BANDING is one of the oldest forms of animal tracking. Research groups use tiny aluminum bands engraved with a number sequence, pictured above (along with an old banding kit).

Natural Sciences. “These kinds of data are super important for seeing where animals live and what are the conditions that they can live in, what temperatures can they survive at, what type of habitat, et cetera, because we’re seeing that the planet is changing very quickly.”

Today’s biotelemetry includes a mind-boggling array of ingenious devices and methodologies, from bees outfitted with minuscule radio transmitters to animal-tracking satellites that follow the movements of crocodiles in Costa Rica to fluorescent nanoparticles used to monitor the behavior of aquatic insect larvae.

“Animals are describing the world they’re moving through, along with weather data, what types of vegetation, and how the land is being used,” says Martin Wikelski, director of the Max Planck Institute of Animal Behavior in Radolfzell, Germany. “The diversity of the data we’re getting from these remote-sensing devices is nothing short of amazing.”

THE ORIGINS of animal telemetry can be traced back hundreds of years to European nobles who marked their trained raptors with silver bands stamped with the monarch’s name. Occasionally, a cherished bird would take off and be discovered some distance away; a falcon belonging to Henry IV of France, for instance, went rogue during a hunt and was found a day later in Malta — a distance of over 1,300 miles.

These early peregrinations made interesting stories, but it wasn’t until the late 19th century that the scientific community began to experiment with tagging fish and banding birds as a way to track movements and estimate the populations of various species. In the late 1880s, Thomas Fulton, a member of the Scottish Fishery Board, attached small metal tags to various fish species in an attempt to gather information on population growth and feeding habits. His tags offered rewards to fishermen who caught tagged fish and returned them with notes on the time and place of capture.

Because an aluminum band was relatively easy to attach to a bird’s leg, bird banding became a popular research activity pursued by both avian enthusiasts and biologists in the early 1900s. Professional and amateur birders flocked to banding organizations and clubs, many supported by natural history museums, zoos, and universities.

For the first half of the 20th century, tagging and banding

Advances in computer science and technology are opening new doors in biotelemetry and allowing animals to inform us about planet ecology.

CLOCKWISE FROM TOP LEFT: MLORENZ/SHUTTERSTOCK; USGS (2); TOM O’CONNELL/EESC BIRD BANDING LAB

Nine Argos satellites now monitor about 13,000 animal transmitters, providing data for more than 2,000 individual research projects.

proceeded with enthusiasm but without much technological innovation. It still required the laborious process of capturing animals, tagging them, then releasing them back into the wild. Data could only be obtained if animals could be recaptured or if citizens reported any found markers.

The war years, however, ushered in the development of a new technology that would begin to change the game of wildlife monitoring — radar. Radar had revealed not only the whereabouts of ships and planes but also the movements of migratory flocks of birds, even during the night. Taken along with manual tagging and weather science, post-war wildlife researchers were beginning to assemble a multidimensional view of planet ecology.

The modern age of biotelemetry got a jumpstart in the late 1950s with the development of electronic tags. This first generation of radio transmitters included tiny batteries and antennas fixed to collars and fitted on animals big enough to carry the weight — foxes, rabbits, deer, and badgers were prime candidates. The movements of individual animals could now be mapped, although a limited range of 100 yards or so often meant intrepid researchers had to traipse through underbrush with handheld antennas to pinpoint their targets.

In the 1960s and 1970s, scientists began to explore the idea that biotelemetry data could be retrieved by orbiting satellites, then retransmitted to receiving stations around the globe. That meant animal locations and movements could be tracked over long distances and periods of time. By the mid-70s, the French Space Agency (CNES) was collaborating with NASA and the National Oceanic Atmospheric Administration (NOAA) to create Argos, a polar-orbiting satellite system designed to monitor animal movements along with meteorological and oceanographic data.

For researchers in the latter part of the 20th century, analyzing weather data would lead to a deeper understanding of the planet's changing climate. Meteorological information provided by high-flying satellites and ground-based weather stations began to paint a picture of a planet that was inexorably heating up.

That technology has limitations. From their high-altitude positions, satellites observe whole swaths of land, providing broad spatial data that lacks fine detail. Weather stations provide nuanced information about local meteorological conditions, but they're static — fixed in place — and only able to furnish data about a limited geographical area. For researchers hungry for more data, there were still huge

ARGOS-4 is a recent addition to the Argos system, launched in 2022 on GAzelle, a commercial satellite operated by General Atomics.

COURTESY OF THE CLS GROUP

gaps in what they could observe.

But climate scientists realized they had another powerful analytical tool at hand. The biotelemetry data being relayed by satellites — used to track animal migrations and estimate population vitality — was also giving detailed information about conditions in areas that orbiting satellites and fixed weather stations couldn't cover. Fitted with transmitters and released into their natural habitats, tagged animals were providing granular climate data that began to fill in the gaps.

In the Antarctic Ocean, for example, southern elephant seals (*Mirounga leonina*), tagged with transmitters that record water temperature and salinity, roam deep under the sea ice, gathering data from a virtually unexplored environment. Researchers use the elephant seal data to track the rate at which sea ice is melting — a vital measurement of climate change. And that's just the tip of the iceberg. Currently nine Argos satellites monitor about 13,000 animal transmitters or "platforms," providing data for more than 2,000 individual research projects.

"Animals can be our best observers for a changing climate because they are very biologically-fine-tuned mobile weather stations," says Diego Ellis-Soto,

TAGGING WILDLIFE helps reseachers study species' migration, survival rate, and more. Here, a U.S. Fish and Wildlife Service biologist bands a black-footed albatross on Midway Atoll, Northwestern Hawaiian Islands.

FROM TOP: USGS; LADD IRVINE, MARINE MAMMAL INSTITUTE, OREGON STATE UNIVERSITY

"Animals can be our best observers for a changing climate because they are very biologically-fine-tuned mobile weather stations."

a climate and biotelemetry researcher at the University of California, Berkeley. Ellis-Soto notes that gaps in weather data from sprawling oceans and far-flung areas of the globe hinder effective climate research. "In order to get a better understanding of say, how warm is it going to get by 2050, we need to have a better understanding across the board and across all regions in the world where this is happening. Animals are giving us this critical information."

ADVANCEMENTS IN tagging technology have allowed researchers to gather information on an ever-increasing variety of species and habitats.

AQUATIC ANIMALS like seals and sharks, when tagged, provide critical insight on the ocean's temperature, salinity, and currents through their movements.

ZARUBA ONDREJ/SHUTTERSTOCK

Minnesota-based Advanced Telemetry Systems (ATS) is one of about a dozen companies worldwide that make tags designed for mammals, fish, birds, reptiles, and insects. At ATS, researchers can find tracking collars for monkeys with sensitive skin, backpacks for eagles, and transmitters a mere 3.38 millimeters (that's only about 0.13 inch) in diameter that can be injected into juvenile salmon using a hypodermic needle. ATS offers more than 4,000 tracking products and produces about 50,000 transmitters annually. The cost of a single device ranges from $200 for a simple radio transmitter to several thousand dollars for a sophisticated, weatherproof GPS designed to last months in harsh conditions.

For researchers setting up a tracking project, choosing a method usually involves a trade-off between size, cost, the number of transmitters required, and the transmitting power of the device. Biologists typically try to use transmitters that are less than 5 percent of the body weight of the host animal to ensure its freedom of movement and survivability. Guidelines from various watchdog groups, such as the National Park Service's Institutional Animal Care and Use Committee, make sure that researchers maintain high standards when capturing and tagging animals.

The process of attaching tags to animals is as unique as the animal itself. Catching turtles and gluing transmitters to their hard shells is relatively straightforward. Tagging a great white shark in the open ocean, however, requires a well-funded expedition and a seaworthy research vessel. A typical method involves locating a shark, capturing it with a baited hook, then wrestling a thrashing animal that may weigh upward of 2,000 pounds onto a specially designed submersible platform. With the platform raised out of the water, researchers scurry to clamp a tracking device to the shark's dorsal fin while assistants remove the hook and pump water through its gills to keep the animal breathing. With device attached, the shark is released back into the sea.

Tagging bumblebees may be less dramatic, but it's no less complex. Bees are captured and evaluated for potential — big bees are easiest to work with and better able to fly with transmitters attached. They're immobilized by gently flattening them under a thin netting, then their backs are carefully shaved to remove any furry body hairs that might keep the adhesive from sticking. After tiny radio transmitters are glued to their backs, they're released.

Today's technology offers a smorgasbord of sensor and transmitter capabilities. In addition to positional data, birds can be outfitted with accelerometers, magnetometers, gyroscopes, barometers, and air speed indicators. Marine sensors detect salinity concentrations, temperature, current direction, pressure, and light levels. Sensors can record the heart rate, respiration rate, even the stomach pH of individual animals. Solar-powered batteries keep instruments running indefinitely.

Satellite technology is keeping pace. The Argos system has begun launching nanosatellites: small, shoebox-sized satellites that use advanced microprocessing to send and receive data. Five nanosatellites were launched in 2024, with a goal of 25 satellites

BIOTELEMETRY has benefited from leaps in technology, and now, we can see what animals are telling us about the Earth's climate as data from around the world is compiled online.

FROM LEFT: VASILEIOS KARAFILLIDIS/SHUTTERSTOCK; RAINERVONBRANDIS/ISTOCK/GETTY IMAGES PLUS

to be in orbit in 2025.

"These additional satellites open Argos to the way we are studying species," says Thomas Gray, a manager for Woods Hole, Inc., a U.S.-based company that helps facilitate Argos projects. "With our nine satellites, we still had information gaps of three to six hours between satellite passes. With the new satellites, we'll shrink that information gap to 10 or 15 minutes.

"Today we track between 6,000 to 8,000 animals at any given time. But with the new system, we'll have the capacity to support 2 million active transmitters at any time," says Gray. "It's quite exciting from a climate change perspective and it's going to be a significant leap in our understanding of the environment as a whole."

EXPANDING technology has brought biotelemetry and climate science into the realm of big data, where vast streams of information are linked and made available via readily accessible databases. The evolution has acquired its own tech-chic moniker — the Internet of Animals or IoA.

The fastest-growing IoA databases come from citizen scientists. Apps such as eBird and iNaturalist let anyone with a smartphone take a photo or record a vocalization of an animal, have the app identify the species, log the location, and download the result to databases that are available to professional researchers and other citizen scientists. More than 100 million bird sightings are contributed annually to eBird, and iNaturalist has nearly 200 million observations covering almost a half-million different species.

Publicly accessible data-sharing platforms, such as WildlifeInsights.org and Movebank.org, act as repositories of professional research, harnessing artificial intelligence algorithms to manage animal-tracking data from projects all around the world. The vast scope of citizen science combined with meteorological data and biotelemetry research is beginning to create a real-time portrait of ever-changing planet ecology.

The vast scope of citizen science and biotelemetry research is beginning to create a real-time portrait of ever-changing planet ecology.

But Martin Wikelski believes that animals can tell us even more.

In the volcanically charged mountains of central Italy, Wikelski works with reptile experts and veterinarians capturing four-lined snakes (*Elaphe quatuorlineata*), a large non-venomous species native to the rugged region. Using precise surgical techniques, the team inserts tiny sensors into the snakes' abdomens and closes the incisions with sutures that will eventually dissolve. The sensors are designed to record and transmit information about movements, body temperatures, and respiration rates. The hope is that once a baseline of the snake's physiology and behavior is established, anomalies will be early warning signals of imminent earthquakes.

"As an animal, what you do in life is basically predict the future, because your survival depends on it," says Wikelski. "Animals are constantly interacting with the environment. And if you have interacting senses, then you have novel properties that we often call a sixth sense. So animals are made to predict the future, and that ability is what we'd like to capitalize on."

Ellis-Soto agrees that animals are vital harbingers of planet ecology. "We have really great technological advances that allow us to track almost all animals on Earth. And not just does that help us understand where species are thriving and where they're struggling, but also what is the environment they're encountering and how is that affecting them and ultimately us? This calls to a greater appreciation on studying animals, and also that a healthy planet means a healthy life for us humans." D

John Riha *is a journalist and fiction writer living in Oregon. His latest novel is an environmental thriller,* Incident 395.

A FEARSOME assortment of megafauna lived in Australia around 60,000 years ago, including the lizard *Varanus priscus* (front left) and the marsupial lion *Thylacoleo carnifex* (front middle).

PALEO-PROTE

AFTER YEARS OF STUDYING THE FOSSILIZED MEGAFAUNA OF ANCIENT AUSTRALIA, PALEONTOLOGIST **LARISA DESANTIS** SETS HER SIGHTS ON PROTECTING MODERN MAMMALS FROM CLIMATE CHANGE.

BY SARA NOVAK

When the Aboriginal people first landed in Australia 60,000 years ago, a menacing gang of megafauna were waiting to greet them. Within the group were fierce apex predators like *Thylacoleo carnifex*, a marsupial lion with a similar build and bigger brain than a modern lioness. Less abundant but more formidable was *Varanus priscus*, a monster lizard rivaling a hippo in girth.

Fast forward 30,000 years, and humans had wiped out many of Australia's most sizable fauna — or so researchers once thought. Through the work of Vanderbilt University paleontologist Larisa DeSantis, we're learning that these massive beasts may have been done in by Australia's aridification, rather than human hunting, as the continent's already-arid forests transformed into swaths of desert shrubs and grasses.

DeSantis has spent her career studying these mega-sized species, satiating a fossil fascination that started in her childhood, at the La Brea Tar Pits in her hometown of Los Angeles.

Growing up with epilepsy and experiencing around 30 to 40 seizures a day, DeSantis found solace in science. At age 9, when she became the national poster child for the Epilepsy Foundation of America, she had no clue she was paving her path to paleontology. The experience involved advocating for the Americans with Disabilities Act (ADA), which became law in 1990, culminating in a 1989 meeting with President George H.W. Bush in the Oval Office.

CTOR

FOSSIL TEETH, **including those of the kangaroo *Macropus titan* above, are covered in isotopes, scrapes, and scratches, which tell paleontologists about the diets and environments of ancient animals.**

Now running the Dietary Reconstructions and Ecological Assessments of Mammals Lab at Vanderbilt, also known as the DeSantis DREAM Lab, DeSantis studies ancient creatures' ecological and evolutionary responses to climate change. She recently met with *Discover* over video chat to explain how fossils reveal the diets and habitats of mammals from the past, and how they help protect mammals in the present.

Q Ecological research, or research into the interactions between organisms and their environments, often focuses on climate change — tracking the effects of temperature and precipitation over time. How can fossils contribute to that research?

LD: Ecological research focused on climate change normally has to be done over long periods of time, for 10, 20, 100 years to understand its impact. But there's this other perspective that comes from using the fossil record to see how mammals responded to the glacial and interglacial periods of the past.

When we did work at a site called Cuddie Springs in New South Wales, Australia, which we published on in *Paleobiology* [2017], we assessed the impacts of aridification on mammal ecology. We compared the diets of extinct Australian

FROM TOP: LARISA DESANTIS; AMY TOENSING/GETTY IMAGES

DESANTIS SAYS that the fossil record provides a preview of the effects of climate change, today and in the future, for animals like the koala, the Tasmanian devil, and the quokka.

CLOCKWISE FROM TOP: N MRTGH/SHUTTERSTOCK; TAHSEENAMJAD/SHUTTERSTOCK; JAMES_STONE76/SHUTTERSTOCK; FRIENDLY STUDIOS/SHUTTERSTOCK

megafaunal herbivores like *Diprotodon*, a wombatlike animal the size of a rhino, from their peak 570,000 to 350,000 years ago to a period of decline 40,000 to 30,000 years ago by analyzing fossilized teeth. We found that, due to climatic shifts, their diets changed dramatically before they died out, indicating that warming temperatures changed the foods they could consume. Before they went extinct, they essentially stopped eating things like saltbush, a resource that — once it gets too dry, if there's not enough water available — animals can't eat.

Using a dental analysis of creatures from half a million years ago, we saw that the semi-arid climate allowed for diet variability in terms of vegetation, while another analysis of specimens from 40,000 to 30,000 years ago showed a much more restrictive diet. So basically, it looks as if they were having to compete for more-similar resources right before they went extinct.

Q So fossils help researchers reveal the impacts of climate change, without requiring them to witness those impacts themselves. Why would researchers want to know about the effects of aridification on megafauna from thousands of years ago?

LD: Understanding the diets of these megafauna as they neared extinction provides insights into the potential impacts that aridification will have on large herbivores in climates that are similarly changing today. Australia has a long history of aridification, and it's a canary in the coal mine for what could happen in arid places around the world.

Q What tools can paleontologists use to understand climate change in the past, and how can we use this knowledge to shape the present and future?

LD: Chemical signatures called stable isotopes provide clues into what the climate was like when fossilized organisms were alive. Isotopes and scratches on teeth show what they were eating, and comparing fossils from different time periods demonstrates dietary changes based on climate.

We can also see where certain species survived in the past based on the fossil record. For example, our research published in the *Journal of Zoology* [2020] shows that the quokka, the groundhog-sized marsupial that now primarily survives on Australia's Rottnest and Bald islands and in coastal forests in Western Australia, lived throughout Western Australia thousands of years ago.

Our research suggests that quokkas have the potential to survive in other habitats in addition to dense forests. The same is true of other species like the Tasmanian devil, which is currently being reintroduced to other parts of the continent. The species has been on mainland Australia in the past and could potentially survive there in the future. Expanding their habitat outside Tasmania could provide an insurance plan for a species that is rapidly declining.

Q You contend that arid-adapted animals are profoundly impacted by climate change. Why is that?

LD: It's a common misconception that arid-adapted animals in Australia and other parts of the world do just fine as the climate dries out. On the contrary, arid-adapted animals are sometimes even more vulnerable to climate change than their cooler-climate relatives.

Research into the arid-adapted marsupial lion shows that it went extinct toward the end of the Pleistocene era, about 30,000 years ago, and its disappearance was a direct response to a changing climate, as it was unable to survive without patches of dense forest that enabled it to ambush prey.

Similarly, the Australian wildfires of 2019 and 2020 devastated millions of acres of eucalyptus forests, dooming the continent's population of koalas, which live in arid conditions and feed almost exclusively on eucalyptus. When eucalyptus forests decline, we expect koalas to also decline, because they're so tied to those environments. As the continent continues to dry out, animals like koalas will have no place to go.

Q Your fascination with fossils started in childhood, at the La Brea Tar Pits. What was it about them that you found so intriguing?

LD: I was always interested in the sciences, and growing up in Los Angeles, I visited the La Brea Tar Pits often. I loved fossils from a young age, particularly saber-toothed cats, but it wasn't until college that I began to explore paleontology more deeply.

All these years later, I'm still fascinated with the La Brea Tar Pits, saber-toothed cats, and what eventually caused their demise. Now we know exactly when everything went extinct at La Brea, which was around 13,000 years ago, during a dramatic environmental shift with tons of fire activity. These intense fires, we were able to show in our research in *Science* [2023], probably had a dramatic impact on the herbivores and carnivores at La Brea.

ALONGSIDE THE animals of ancient Australia, DeSantis also studies saber-toothed fossils from the La Brea Tar Pits.

HARRISON MCCLARY © VANDERBILT UNIVERSITY

Q You've mentioned that the passage of the ADA, signed into law by President Bush in 1990, had a huge impact on your life. Can you discuss why?

LD: When I was in the eighth grade, I wanted to go to marine science camp on Santa Catalina Island off the coast of Los Angeles. The camp included a week of snorkeling and learning about marine life. My school refused to let me go out of fear I would have a seizure in the water and drown.

I remember crying in my room because I was so upset that I couldn't go. But my parents fought hard for me, and with the ADA, they finally had a legal leg to stand on. In the end, the school was forced to make a "reasonable accommodation," amounting to an adult chaperone standing in the water. I basically had a swim partner that was with me at all times just in case I had a seizure.

That week of camp turned out to be an eye-opening experience for me and my love of science. To this day, I can visualize swimming with the Garibaldi fish and the seal that approached us underwater. A few years later, after a mix of medication and luck, the seizures vanished, but that experience was very important to who I became.

Q You tried for a long time to avoid becoming a paleontologist. Why was that, and what finally changed your mind?

LD: After the ADA was passed, I was full steam ahead, interested in political science and law. But I realized I was too sensitive for it. It was just so hurtful to see some people's political viewpoints.

When I took a class on paleobiology, it reignited my kindergarten brain. Still, as much as I loved paleontology, there weren't very many jobs in it, and I wanted to find a career that could make an impact on the planet. I went on to study natural resource management at the University of California, Berkeley, and then environmental management at Yale University, but in the back of my mind, I couldn't shake my love of fossils, volunteering as a fossil purveyor, even driving a traveling museum exhibit — a 38-foot Winnebago full of dinosaur fossils. I looked like Ms. Frizzle, and I loved it.

Starting in the early 2000s, papers were being published looking at the impact of climate change on organisms of the

WILDFIRES IN 2019 and 2020 showed that aridification is surprisingly severe for arid-adapted animals in Australia, including koalas. DeSantis says that similar lessons are also learned from the fossil record.

UMOMOS/SHUTTERSTOCK

past. While the field of conservation paleobiology — using paleontological data to prevent species extinction and habitat destruction — wasn't fully formed yet, the foundations were there. At the University of Florida while pursuing my Ph.D., I was finally able to merge my interests together, asking questions about ecology using the fossil record.

Q Paleontology and the geosciences have traditionally been fields with few jobs and even fewer for women. Your particular journey speaks to this. Can you discuss why?

LD: When I interviewed for my first job, I was asked by a dean — someone who knew not to ask these questions — if I was married, what my husband did, and if I planned to have children. I had worn my wedding ring even though I had been told by other women to take it off because it opened the door to such inquiry.

The following year, I got the call from Vanderbilt University about a potential job. I was 38 weeks pregnant at the time, so my husband and I packed a car seat, hospital bag, and made one last stop at the obstetrician to make sure I wasn't going to have a baby en route to Tennessee.

At Vanderbilt, I gave one of my best talks because I was so winded from pregnancy that I had to speak slowly. Normally my brain moves faster than my mouth, which can make it hard for people to keep up. There too, I could really see people's true colors. One person drove me right to the loading dock in the back of the science building where I was interviewing so I wouldn't have to walk a far distance. Still, another person proceeded to power walk me from the parking deck to the room as some sort of a cruel joke. I learned early on that the expectations for me as a woman were different than they would be if I were a man. Even today, the biggest challenge is infiltrating the boys' club at the faculty level.

ARID-ADAPTED ANIMALS ARE SOMETIMES EVEN MORE VULNERABLE TO CLIMATE CHANGE THAN THEIR COOLER-CLIMATE RELATIVES.

But things are changing, and I get a lot of my strength from meeting with other women in the field, discussing the experiences we've had. There are a lot of amazing women at the top of their game, and it's been exciting to watch. D

This Q&A has been compiled from a combination of interviews and has been edited for length and clarity.

***Sara Novak** is a frequent* Discover *contributor.*

LIVING IN THE

A HUNDRED YEARS AFTER THE DEVELOPMENT OF QUANTUM MECHANICS, PHYSICISTS STILL GRAPPLE WITH EXPLAINING THE WEIRDEST YET MOST FUNDAMENTAL WORKINGS OF THE UNIVERSE.

JURIK PETER/SHUTTERSTOCK

QUANTUM CENTURY

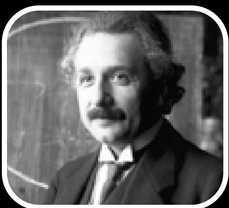
BY DAN FALK

NOT EVERYONE CAN PLAY BILLARDS at the championship level, but everyone gets how the game works: A player uses a wooden cue to strike the white cue ball, which rolls along the felt tabletop until it strikes another ball, or perhaps more than one ball; eventually (if you're good at it) one or more balls drops into a pocket. Isaac Newton, had he felt the urge, could have written a perfectly good handbook for billiards, since all of the relevant physics upon which the game operates is contained in the laws of motion that he worked out back in the late 17th century.

THE QUANTUM CONTINUUM

1900

Max Planck proposes that energy isn't transferred continuously, but rather comes in tiny, discrete bundles, known as quanta.



1905

Albert Einstein discovers the photoelectric effect, in which a particle of light (photon) strikes a metal surface, releasing a photo-electron whose energy is given by its emission from the metal by the light.

1913

Niels Bohr develops a model of the atom in which electrons orbit the nucleus, but only at specific energy levels. The electrons absorb or emit photons to jump between energy levels.

It would be great if the whole universe worked according to those laws — and many nonscientists assume that they do. But as physicists discovered toward the end of the 19th century, the universe is not that simple. In particular, atoms, molecules, and subatomic particles don't seem to obey the same rules of the billiard table, or indeed much of the observable world. The first hint that something was amiss came in 1900, when pioneering German physicist Max Planck realized that the radiation emitted by hot objects, known as blackbody radiation, couldn't be explained by Newton's laws — not even with the help of the laws of electromagnetism, which Scotland's James Clerk Maxwell published in 1865. In what Planck described as an "act of desperation," he proposed that energy does not flow continuously, but rather in tiny, discrete chunks, or quanta. The theory earned Planck a Nobel Prize, and further theoretical successes followed. Eventually — 100 years ago this summer — another German physicist, Werner Heisenberg, came up with his own Nobel-winning achievement: a complete mathematical framework for the theory we now call quantum mechanics (in contrast to the "classical" mechanics of Newton and Maxwell). Physicists could use quantum mechanics to explain all manner of atomic phenomena, and over the ensuing decades it became entrenched as one of the two great pillars of modern physics, alongside Albert Einstein's theory of gravity, known as general relativity.

But quantum mechanics is also weird — so weird that, a century later, physicists and philosophers are still arguing about what the theory actually means. Among its oddities is the straight-up bizarre phenomenon known as quantum entanglement, in which a measurement made in one location can instantly influence the quantum state of an entangled partner in another location. Of all the peculiarities of the quantum world, entanglement "is the hardest one to explain, because there's no good classical analogy," says Tara Fortier, a physicist at the National Institute of Standards and Technology in Boulder, Colorado. "It's not magic. It's just that we're not used to it."

Quantum computers (top) and MRI scanners (bottom) wouldn't exist without quantum mechanics. We wouldn't have lasers, solar cells, or LED screens either.

Entanglement does not mean that information can be known about the state of the system in two locations instantaneously. That would violate a physical law that states that information cannot travel faster than the speed of light. Only the internal state of the system can be affected instantaneously. "This is a very subtle idea," Fortier explains. "I stress this point to clarify a common misconception that quantum mechanics can be used for faster than speed of light communication. It cannot."

QUANTUM mechanics can be most easily "seen" or "perceived" mathematically. Mathematics is like a sixth sense for understanding quantum physics, Fortier notes. "It allows us to predict that which we cannot experience with our limited human senses. When particles are 'entangled' it just means

LEFT FROM TOP: HUGO ERFURTH/WIKIMEDIA COMMONS/PUBLIC DOMAIN; FERDINAND SCHMUTZER/WIKIMEDIA COMMONS/PUBLIC DOMAIN; BAIN NEWS SERVICE, PUBLISHER/WIKIMEDIA COMMONS/PUBLIC DOMAIN

that the dynamics of two particles are coupled together. The mathematical equation that defines the coupled dynamics of a quantum mechanical system can be independent of the particles' individual locations."

Also, these dynamics only describe the internal state of the system, not the systems as a whole (much like a tone recorded from a piano does not tell you much about the color or size of the piano). As a result, what happens to the internal state of one particle can be experienced instantaneously by the internal state of another particle, if the two are entangled. This is regardless of where they are, or how far apart they are. This is weird for non-physicists because it is outside the realm of our physical experience, Fortier acknowledges. "But just because we haven't experienced it … doesn't mean it isn't physically possible."

Weird as it may be, quantum mechanics has been incredibly successful. Some of its predictions have been confirmed to a staggering 12 decimal places, corresponding to an accuracy of 1 part in a trillion. As Brian Greene put it in his 2020 book *Until the End of Time*: "Trumpets should blare and the species should take a bow" in honor of quantum mechanics, which "represents a triumph of human understanding." And it's everywhere: Everything in the universe, including us, is made of atoms, and quantum mechanics is what ultimately dictates how those atoms behave. The theory explains all of chemistry, right down to the layout of the periodic table. "It's fundamental to the way that everything is," says Fortier. "All the matter that we interact with is the way that it is because of quantum mechanics."

CLOCKWISE FROM TOP: AUDIO UND WERBUNG/SHUTTERSTOCK; NA/WIKIMEDIA COMMONS/PUBLIC DOMAIN; NA/WIKIMEDIA COMMONS/PUBLIC DOMAIN; NOBEL FOUNDATION/WIKIMEDIA COMMONS/PUBLIC DOMAIN; JUICE FLAIR/ SHUTTERSTOCK

THE QUANTUM CONTINUUM

1924

Louis de Broglie shows that particles of matter, like light, can be described as waves. The heavier the particle, the shorter its wavelength, if the velocity is constant. This wave-particle duality would play a central role in the development of quantum mechanics.

1925

Werner Heisenberg heads development of "matrix mechanics" to formulate a rigorous representation of quantum mechanics.

1926

Erwin Schrödinger proposes a version of quantum mechanics that is described by "wave-function." The Schrödinger equation describes how this function evolves over time. Max Born later discovers that Schrödinger's wave must be squared to

THE QUANTUM CONTINUUM

describe the probability of finding the electron in any one location and that probabilities are truly random.

1927
Heisenberg proposes his "uncertainty principle," stating that it's impossible to know a particle's position and its momentum at the same time.

1928
Paul Dirac uses quantum mechanics to show that a particle just like an electron, but with a positive charge, could exist. The positron — the first antimatter particle to be studied — was detected in 1932.

1935
Einstein, together with **Boris Podolsky** and **Nathan Rosen**, publishes a paper describing what's now called the "EPR paradox," laying the groundwork for the phenomenon known as entanglement. Einstein was skeptical of entanglement, referring to it as "spooky action

And it's changed our lives: Without quantum mechanics, we wouldn't have semiconductors and the computer revolution they enabled — along with devices like lasers, LED screens, MRI scanners, and efficiently functioning solar cells. Meanwhile, quantum information theory has evolved into a discipline in its own right, with applications in communications, cryptography, and quantum computers. Ken Wharton, a physicist at San Jose State University, even points to quantum mechanics as anchoring our best hopes for fighting climate change: Without an understanding of quantum mechanics, he says, we couldn't have developed two of the technologies that offer our best chance at a renewable-energy future: photovoltaic cells for harnessing solar energy, and nuclear power. "So maybe quantum mechanics is going to let us save the planet."

Of all the peculiarities of the quantum world, entanglement is the hardest to explain.

HEISENBERG was just 23 when, seeking relief from his hayfever, he withdrew to the small, barren island of Helgoland in the North Sea in June of 1925. Aside from any medical benefits, he knew the island's isolation would allow him to work undisturbed on a problem that Danish physicist Niels Bohr had invited Heisenberg to help solve the previous autumn. Bohr had written down a series of equations that predicted the wavelength of radiation emitted by various gases when heated. The equations worked, but there was no overarching theory to explain Bohr's key assumption: that electrons circle the atom's nucleus in precise orbits, then suddenly make a (quantum) leap. Heisenberg pondered the problem, finally experiencing a late-night eureka moment, which he later described in writing: "Suddenly I no longer had any doubts about the consistency of the new 'quantum' mechanics that my calculation described. … I had the feeling that I had gone beyond the surface of things and was beginning to see a strangely beautiful interior, and felt dizzy at the thought that I now had to investigate this wealth of mathematical structures that Nature had so generously spread out before me."

Heisenberg's breakthrough involved using mathematical tools called matrices to represent an electron's allowable orbits. Eventually, with input from his colleagues Max Born and Pascual Jordan, Heisenberg wrote down the rules for a whole new kind of mechanics. Newton's laws still held for large objects like billiard balls and planets, but in the microworld these new quantum mechanical laws would take over. Heisenberg's version of the theory would become known as matrix mechanics. Just a year later, in 1926, Austrian physicist Erwin Schrödinger worked out an equivalent formulation using equations that describe waves; his version is called wave mechanics. (Schrödinger's method proved easier to use, since the physics of waves was already well understood.)

But no sooner had Heisenberg, Schrödinger, and the others set down the rules for this new theory than critics began to point out just how peculiar it was. For starters, it appears to spotlight the act of observation: The theory predicts the probability of obtaining some particular result (for, say, the position or speed of a particle) when you measure it, but it says nothing at all about what the particle is doing up to that moment. Until a measurement is made, the theory says the particle is in a superposition of states, described by Schrödinger's wave function. The act of observation was said to collapse the wave function so that the particle is seen to be in just one state.

While we might not worry too much about, say, an electron being in two states at once, physicists were concerned about the implications of quantum effects scaling up so that they impacted the world we can see and touch. Schrödinger's now-famous thought experiment involving a cat in a box made exactly this point. (See next page.)

"The question is, what should we think about this special role that measurement seems to play?" says

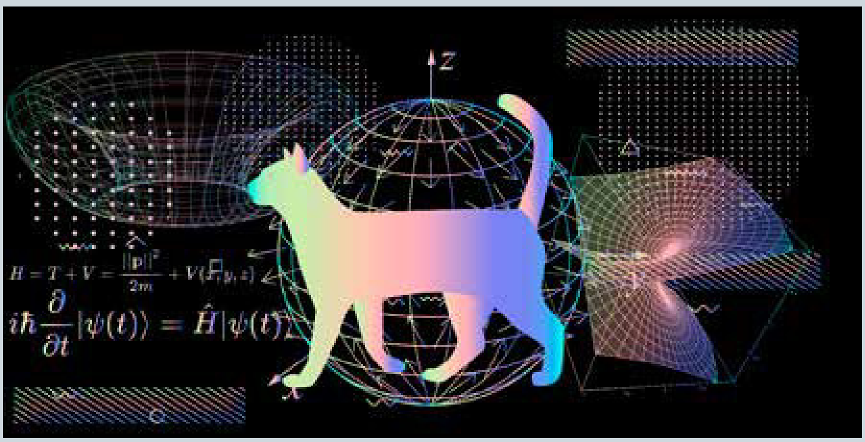
FROM TOP: NOBEL FOUNDATION/WIKIMEDIA COMMONS/PUBLIC DOMAIN; YURKOMAN/SHUTTERSTOCK

Emily Adlam, a philosopher of physics at Chapman University. “Is wavefunction collapse a real physical process? And if so, can we identify in physical terms when it happens? Or is wavefunction collapse just some kind of illusion?” Either way, we'd prefer a theory “that doesn't treat observers as a sort of external, magical force that's not part of the physical world.”

Einstein shared this concern. He believed in what philosophers call realism, that is, belief that the world exists regardless of whether anyone is looking at it. Once, as he was walking in Princeton University with his biographer, Abraham Pais, he pointed to the moon and said, “Do you really believe the moon is not there when you are not looking at it?” He was similarly perturbed by the probabilistic description of nature that quantum mechanics offered, famously declaring that God doesn't play dice.

And there's more: According to Heisenberg's uncertainty principle, a key component of quantum theory developed in 1927, certain quantities can never be known with precision: The more accurately one measures a particle's speed, for example, the less certain we become regarding its position. Quantum mechanics seems to render the world as inherently blurred, a bit like an impressionist painting.

And then there's the mother of all quantum peculiarities: entanglement. The idea was first described in a 1935 paper by Einstein together with physicists Boris Podolsky and Nathan Rosen. They predicted that, under certain conditions, two or more particles can be described by a single wave function. At first that may sound harmless enough,



THE CAT IN THE BOX

IN THE INTEREST of historical accuracy, it's worth noting that Schrödinger did not intend for people to take his live/dead cat scenario seriously. He proposed it as an absurdity, a criticism of then-current thinking regarding quantum theory. But that criticism has adopted a life (and death) of its own ever since. Put simply, Schrödinger's Cat asks us to imagine a sealed box containing a cat, a radioactive material, a vial of poisonous gas, a hammer, and a Geiger counter. If a radioactive particle decays, it triggers the Geiger counter which releases the hammer, smashing the vial and killing the cat. (Remember, it's just a thought experiment!) But suppose quantum mechanics says that, after one hour, there's a 50 percent chance of the decay having taken place. Until we open the box and look at the cat, all we can say is that the cat is in a superposition of being both alive and dead — a strange state of affairs indeed. — DF

LEFT TO RIGHT: CYBERMAGICIAN/SHUTTERSTOCK; NOBEL FOUNDATION

THE QUANTUM CONTINUUM

at a distance”; instead, he argued that quantum mechanics must be incomplete.

1935
Schrödinger puts forward his now-famous thought experiment involving a cat. He was trying to highlight the apparent absurdity of quantum effects scaling up to everyday size. It was one thing for an electron to be in two states at once, but what could it mean for a cat to be alive and dead at the same time?

1948
Richard Feynman (above), Julian Schwinger, and **Shin'ichirō Tomonaga** develop quantum electrodynamics, a theory that explains how light and matter interact, based on quantum mechanics as well as Einstein's theory of special relativity. It is among the most precisely tested theory in all of physics.

1952
Building on earlier work by **Louis de Broglie, David Bohm** develops pilot wave theory, also known as the de Broglie–Bohm theory. This is an interpretation of quantum mechanics in which

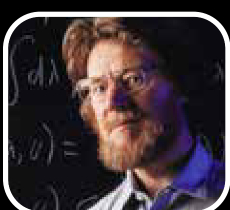
particles follow precisely defined paths, even when unobserved.

1957

Hugh Everett proposes an interpretation of quantum mechanics in which each possible outcome of a measurement is equally real, describing a distinct universe. This view, later popularized by Bryce DeWitt, is known as the Many Worlds Interpretation of quantum mechanics.

1960

The **first laser** is built based on a quantum mechanical process (shown by Einstein) to emit narrowly focused beams of light at a single wavelength. Lasers are now used in optical disc drives, barcode scanners, chip manufacturing, surgery, and many other applications.



1964

John Stewart Bell showed how the idea of entanglement could be put to the test. His equations, now known as Bell's theorem, show that

but the implications are jarring: It means that if we measure the properties of one member of an entangled pair of electrons, for example, we instantly gain information about the other electron, even if it's far away. There's a correlation, as physicists put it, between the two sets of measurements. This stands in contrast with the more mundane correlations we might find classically. If you know a drawer contains a left glove and a right glove, and you pull out the left glove, you've instantly learned the identity of the remaining glove — but there's no mystery, because the two gloves were always whatever handedness they were, even before you looked at them. With quantum entanglement, it's as though the glove suddenly becomes either right or left when you look at it — at random — and yet, lo and behold, the other glove will just happen to be its partner.

Entanglement appears to violate what physicists and philosophers call locality — the idea that you can explain what happens at any one location just by considering the forces present at that spot. Going back to the billiards example: If you see the 8-ball move, you can be sure its motion is purely the result of being struck by another ball; the motion of balls on a different table is of no consequence. But if the universe is nonlocal, maybe the balls on some faraway table somehow do matter. Einstein felt this couldn't be right, dismissing such interaction as "spooky action at a distance." The details are a little tricky: Einstein had shown that no signals can travel faster than the speed of light, and indeed it turns out that quantum entanglement, weird as it is, can't be used for faster-than-light signaling. Even so, this ability to spookily gain instant knowledge about faraway things, is utterly unlike anything in classical physics. And yet, it's real: Einstein didn't live long enough to see the proof, but by now many experiments have confirmed that entanglement is a real, observable phenomenon: The 2022 Nobel Prize in physics went to Alain Aspect, John Clauser, and Anton Zeilinger for their experimental work in showing that entanglement between two particles separated by long distances is as strange as quantum mechanics predicted.

One idea is that entanglement is somehow responsible for space and time existing in the first place.

IN THE DECADES that followed the development of quantum mechanics, physicists and philosophers squabbled about what the theory actually says about the universe, arguing about its interpretation. The default view, reflecting the work of Bohr and Heisenberg and the idea that wave functions somehow collapse when observed, came to be known as the Copenhagen interpretation, after the city that was home to Bohr's research institute. But Copenhagen was never the only game in town. An idea put forward by France's Louis de Broglie in the 1920s and further developed by American-born David Bohm, known as pilot wave theory (or de Broglie-Bohm theory, or Bohmian mechanics), preserves something of the flavor of classical physics: It says that underneath the seemingly probabilistic movements described by quantum mechanics, particles in fact follow precisely defined, fully deterministic paths. (The probabilities haven't gone away, but now can be seen as merely reflecting our ignorance of exactly where things are and how they're moving.) Pilot wave theory is an example of a so-called "hidden-variables theory," meaning that beneath measurable quantities like position and momentum there were hidden variables that obeyed precise rules. Pilot wave theory will appeal to anyone put off by Copenhagen's inherent fuzziness — but its precision comes at a price. Pilot wave theory is inherently nonlocal, meaning that the very spookiness that bothered Einstein is baked into the theory itself.

And then there's the view that many would deem the most mindboggling — the so-called Many Worlds Interpretation, or MWI, which goes back to the work of American physicist Hugh Everett in the 1950s. In the Many

FROM TOP: VCHAL/SHUTTERSTOCK ; PETER MENZEL/SCIENCE SOURCE

THE COLLIDER DETECTOR at Fermilab was developed to identify and study particles that make up the universe. The detector discovered the top quark in 1995.

Worlds view, we're asked to take the quantum wave function at face value. If it describes an electron as being here and also there, we just accept that it really is in both places at once. In the Many Worlds view, wave functions never collapse. Every time a quantum measurement allows for multiple results, all of those results happen, but in separate universes. (In the case of Schrödinger's cat, we're asked to imagine an array of universes in which the cat is alive, and an array of universes in which the cat is dead.) It may sound like science fiction — indeed, some physicists believe it carries too much metaphysical baggage to be taken seriously. Aside from encouraging us to picture a vast, possibly infinite array of unseen universes, MWI also seems to sweep the issue of quantum probabilities under the rug.

"What do you mean by probability," asks Lucien Hardy of the Perimeter Institute for Theoretical Physics in Waterloo, Ontario, "in a theory where everything that can happen definitely does happen?" But a growing number of prominent modern physicists, including Max Tegmark, David Deutsch, and Sean Carroll, believe the Many Worlds view is actually the most reasonable way to think about quantum mechanics.

And then there's an equally counter-intuitive idea known as "retrocausality" — the notion that causality doesn't always flow from past to future. Let's go back to quantum entanglement, and Einstein's concern about the properties of particle A being correlated with those of some distant particle B. If you believe in retrocausality, the conundrum goes away: The measurement of A can now be thought of as causing a correlation at some earlier moment before A and B had separated, and this has an effect on

LEFT TO RIGHT: TRACY MARC, FERMILAB; ELIF BAYRAKTAR/SHUTTERSTOCK

THE QUANTUM CONTINUUM

the statistical correlations between entangled particles are stronger than any "local" hidden variables theory could account for. Beginning in the 1970s, experiments have shown that Bell was right — and that "spooky action at a distance" is real.

1970s

Based on quantum mechanics, the **Standard Model** of particle physics is developed. The model describes how fundamental particles, classed as quarks and leptons, interact via four physical forces.

1972

A patent is filed for the first **magnetic resonance imaging** (MRI) scanner, developed later in the 1970s. MRI machines use magnetic fields and radio waves, enabled by semiconductor circuitry.

1995

The top quark, the heaviest of the particles in the Standard Model, is discovered at **Fermilab.**

2012

The Higgs boson — the latest particle of the Standard Model to be discovered — is revealed by experiments at the Large Hadron Collider.

B. How crazy is retrocausality? San Jose State's Wharton and his colleague Huw Price believe it has merit. They point out that while the apparent flow of time is real enough for humans, there's nothing in the laws of physics that favors one time direction over the other. And Wharton emphasizes that you can't exploit retrocausality to go back and kill your grandfather — so the paradoxes of time travel are avoided. "It's weird," he says, "It's crazy. But it's not a paradox."

EVERY INTERPRETATION of quantum mechanics contains unfamiliar elements that challenge our traditional views of how the universe works. It's possible, perhaps even likely, that we'll have to let go of one of the "big three" cherished assumptions about nature — reality (the idea that the universe exists whether anyone is looking at it or not), locality (the idea that what happens at A is independent of what happens at B), or causality (the idea that time always flows from past to future). "Without a doubt, what is going on underneath quantum mechanics is going to be weird in some ways," says Adlam. "So it's a kind of a pick your poison situation: Which kind of weirdness is more acceptable to you?"

A long-standing hope is that new insights will come when physicists manage to reconcile quantum mechanics with gravity – a quest that has been underway for decades, with no obvious clear-cut pathway to success. When and if that breakthrough happens, perhaps the quantum world will be revealed in a new light. Hardy, for example, suspects all of the current interpretations of quantum mechanics are missing something. "My belief is we have to go beyond quantum theory to a new physical theory, and then a new interpretation may suggest itself," he says.

The Many Worlds view asks us to picture a possibly infinite array of unseen universes.

One idea – still speculative, for now – is that entanglement is somehow responsible for space and time existing in the first place. In this view, space and time are no longer seen as fundamental, but rather as emergent phenomena that are born thanks to quantum effects happening "down below," so to speak. Perhaps a shake-up is on the horizon — one that might be as jolting as the one that rocked the world of physics a century ago.

"There will be another revolution," says Wharton. "I have no idea when it will come. But we're not done yet." D

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BILLION PHOTOS/SHUTTERSTOCK

BY OLIVIA FERRARI

A Dose of Dance

WHAT HAPPENS IN OUR HEADS WHEN WE DANCE? NEUROSCIENTISTS HAVE ASKED, AND NEW APPROACHES ARE ANSWERING, REVEALING HIDDEN BRAIN BENEFITS.

The dancers sprawled on stage, backs arched, with their shoulders and feet supporting their stretched bodies. Taking deep, shuddering breaths, they trembled and swayed in time with the music — a dark, droning tone typical of butoh, an avant-garde style of dance invented in Japan in the 1950s.

Less typical of butoh were the brain scanners that sat atop the dancers' scalps, and the brain scan visualizations that swelled behind the dancers' bodies in real time.

The performance, which took place in February 2023 at the University of Houston, Texas, was a collaboration between researchers and artists to capture what happens in our brains when we dance. According to the team, the performance was the first time that researchers have synchronously recorded and visualized brain activity from five performers at once.

Constantina Theofanopoulou, a neuroscientist from the Rockefeller University in New York and a flamenco dancer, helped develop the team's approach for deciphering and displaying the dancers' brain scans, explaining that the performance is one of many recent attempts to understand dance's impacts on the brain. Research thus far has shown that dance provides plenty of different brain benefits for dancers of different styles and skill levels, from better body perception to improved memory. By strengthening the brain's connections, it combats cognitive decline. And by extending the pleasure cycle, it coordinates activity between brain regions, and possibly between

Dance provides plenty of different brain benefits for dancers of different styles and skill levels.

FROM TOP: MOLESKO STUDIO/SHUTTERSTOCK; ALBERT M. SANCHEZ

VIRGINIA TECH neuroscientist Julia Basso (left) uses mobile EEG methods to monitor the brain activity of synchronized dancers.

brains, indicating its strength as a social and therapeutic tool. Whether performed by professionals or amateurs, dance is increasingly used in therapy and medicine, where even more benefits could be discovered.

RHYTHMS IN our bodies, like heartbeats and brain oscillations, are integral to our identity as humans. Our impulse to dance is no different. Dancing is so ingrained in who we are that some scholars believe that the ability could've arisen as many as 1.8 million years ago, when the anatomy of our ancient ancestors transformed to allow for better bipedal coordination, control, and balance. But despite the significance of dance, neuroscientists struggle to understand its influence on our brains.

That's because determining what happens in the brain during dance has long been logistically difficult. Until recently, research looking to link brain activity with dance has required research participants — both skilled and amateur dancers of specific styles — to slip inside cramped brain-scanning machines, where they would perform salsa hand movements or tango foot movements while the rest of their bodies remained stationary.

"Scientists were hoping to find the brain network of dance, but they realized that they have to make the technology work first," Theofanopoulou says.

Determining what happens in the brain during dance has long been logistically difficult.

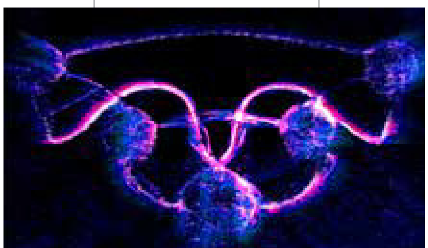
Comprising the regions of the brain that are activated and connected by dance, the brain network of dance is most active when the whole body is in motion. But movement and sweat can disrupt mobile brain-scanning methods, detaching their machinery and affecting their accuracy. This is especially true of mobile electroencephalography (EEG) methods, which use small, scalp-attached sensors to measure electrical impulses in the brain.

Setting out to solve these issues, Theofanopoulou and her team developed a mobile scanning method to track dancers' brain activity with minimal disturbances due to movement. Their EEG approach, which involved the specialized fitting and fastening of sensors, as well as the special selection of movements (nothing too sharp or too sudden), managed to record the butoh dancers' brain activity at an impressive millisecond resolution.

Publishing a paper that outlined their approach in *BioMed Central Neuroscience* in November 2024, Theofanopoulou and her team even considered what hair products the dancers used to optimize their EEG technology. The result is a more accurate method for mobile brain scanning, which could support new breakthroughs in the science of dance.

DESPITE LOGISTICAL obstacles, past research has revealed some scattered information on the impacts of dance on the brain. Since the 1990s and 2000s, studies have shown that music stimulates the cerebellum, which controls coordination and movement, as well as the brain's pleasure centers. And adding movement to music only intensifies those sensations. In 2022, a review in

RAY MEESE FOR VIRGINIA TECH (2)



IN THE BUTOH study, abstract scenes, shapes, and brains were used to visualize dancers' brain activity, which was monitored by Theofanopoulou (below) using a unique mobile scanning method.

the *American Journal of Dance Therapy* found that dancing — not necessarily in a choreographed way, but just moving to music — increases serotonin in the body, potentially boosting mood and reducing stress in the moment.

Some research suggests that our powerful pleasure centers respond especially well to dance because it extends the pleasure cycle. While this cycle normally includes phases of wanting, liking, and satisfaction, it is possible that dancing prolongs the liking phase and weakens the satisfaction one, drawing out the pleasure cycle and sustaining positive emotions for longer.

Katharina Conradi, a dance teacher and a dance therapist based in the Netherlands, helps people use different types of dance to process grief and other heavy emotions, and says that they often feel "lifted up" after dance therapy sessions. She credits this lift to the release of tension that dance provides in the brain and body at the same time. In fact, it's possible that this simultaneous release is essential to the benefits of dance therapy, which is associated with improved physical and mental health, especially for people dealing with psychological trauma.

"This form of therapy is very successful because it combines the thinking and the physical together," Conradi says. "It's always an … integration."

DANCE CONNECTS so many parts of the brain that some neuroscientists say it has a whole-brain effect, activating not only the cerebellum and motor areas, but also the parts of the brain that perceive sensory information, control cognition and emotion, and process rhythm, creativity, and sociality. Some scientists suspect that coordination among these parts of the brain has a kind of synergistic effect that makes us feel good.

"There [are] so many different things going on," says Julia Basso, a neuroscientist at Virginia Tech, whose work concentrates on the connection between the brain and the body. "[Dance] is so complex in what it offers that you get the social, you get the rhythmic, you get the creative, you get the cognitive, all in one setting."

Over time, engaging repeatedly in choreographed dance even changes the structure of the brain, strengthening connections between brain regions. Studies show that professional dancers have higher connectivity in areas of the brain that are associated with motor and sensorimotor activities. These improved connections can result in a better ability to coordinate one's own body, and to efficiently integrate internal and external information on the fly.

People who dance also have some specific mental abilities that are sharper than those of people who don't. Studies have shown that experienced ballet and contemporary dancers have a strong memory for complex motion sequences, while expert hip-hop dancers have a talent for rotating images in their minds, potentially indicating superior spatial processing. Dancers also possess a more accurate sense of proprioception, or the positioning of their body and body parts, according to a 2022 study in *Scientific Reports*.

Because of the positive effects dance has on brain connectivity and flexibility, dance therapy can be a powerful tool, especially for elderly people. Though the therapeutic potential of dance and dance therapy are still being tested, some studies suggest that learning to dance choreographed sequences improves memory and attention abilities over time, decreases the risk of dementia, and strengthens motor skills in people with Parkinson's disease. Dance-training programs involving new and increasingly difficult choreography also promote neural plasticity more than other types of physical activity, according to research published in *PLOS One*, which is important for healing and protecting the brain as it ages.

FROM TOP: BADIE KHALEGHIAN, FROM THEOFANOPOULOU ET AL. 2024. BMC NEUROSCIENCE (3); DOUGLAS ADESKO

"Dance can be a really important way to support the aging process," Basso says, "because it keeps our mind growing and fresh."

WITH ITS special sensors and scientific steps, Theofanopoulou's mobile scanning method was designed to be used to better understand dance therapy's effects on neurodegenerative diseases like Parkinson's, expanding the existing research to reveal the effects of different levels of involvement and intensity — essentially different doses of dance — on treatment outcomes. But that's not all. It was also designed to untangle dance's ability to bring people together.

In the past decade, dozens of studies have shown that our brains can align when we collaborate, and particularly when we collaborate with friends, family, or romantic partners. Now, some scientists are starting to scrutinize the brain activity of dancers, suspecting that when our bodies work as one, our brains do, too. "Dance [could enhance] what's called interbrain synchrony," Basso says, "so that when we dance with other humans … our brain rhythms [could] actually synchronize with one another."

While the recordings from Theofanopoulou's butoh performance are still being analyzed, she says that the real-time visualizations of the dancers' brain activity are expected to show signs of synchrony, something that other scientists are also working to find. Projected behind the dancers as they performed, the visualizations appeared as abstract scenes and shapes, and as 3D brains, that shifted and surged according to the degree of similarity between the dancers' brain oscillations.

Though the mechanisms of this plausible alignment of brain activity remain unsettled, it's possible it occurs as a result of the shared motions, as well as the shared concentration and commitment, that are involved in moving together to choreography. Dancing with a partner requires the coordination of the body, the breath, and the heartbeat, and involves the synchronization of the dancers' senses of sight, sound, touch, and rhythm. Brain activity is therefore only one of many bodily functions that may align as dancers match their moves.

ACCORDING TO Basso, dance may bring people together, boosting social connectivity and mood, through interbrain synchrony. But dance may also build bonds through neurochemistry. Studies suggest that synchronized activities — dance as well as making music — can create social ties by releasing endorphins. Some scientists believe this is why dance arose, spread, and persisted in humans in the first place: as a form of interpersonal coordination that promotes positive feelings and helps us stick together as a complex social species.

The social power of dance is also seen in the activity of individual brain cells: Neuroscientists believe that the mirror neurons that activate when we mimic others may also activate when we watch them dance, unconsciously preparing us to dance, too. Not only that, but matching others' moves in dance and dance therapy may explain the enhanced empathic abilities seen in expert dancers over time, since increased activity in mirror neurons is linked to the ability to perceive and anticipate others' movements as well as their emotional states.

In Conradi's dance therapy practice, group dance can be especially empowering. "The whole idea of being together … can be by itself healing," she says. "Because then you don't need to think, and you are supported by others."

Dance promotes positive feelings and helps us stick together as a complex social species.

OF COURSE, Theofanopoulou's butoh performance cannot solve all of the mysteries of dance's impacts on the brain. But Theofanopoulou believes that the cognitive benefits of dance are clear, and will only become clearer with future applications of the performance's methodology.

Improving our mood and keeping us sharp, the evidence suggests that dance is a mechanism for fighting cognitive decline and bringing people together. "We need to believe this convincing evidence," Theofanopoulou says, "and have dance work as medicine." ◘

__Olivia Ferrari__ is a New York City-based journalist with a background in research and science communication.

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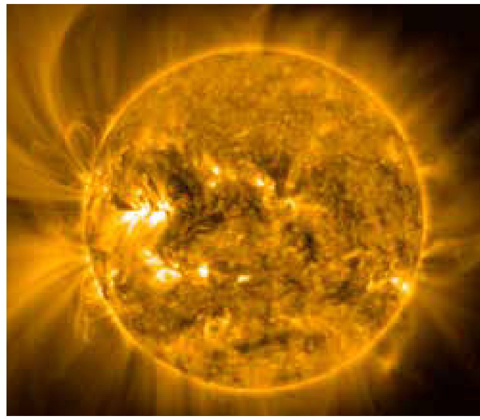

FROM LEFT: NASA/JOHNS HOPKINS APL/ED WHITMAN (3); TOP RIGHT: NASA/JOHNS HOPKINS APL/STEVE GRIBBEN; BOTTOM RIGHT: ESA/ROB

TOUCHING THE SUN

In April 2009, *Discover* shined the spotlight on an up-and-coming NASA project poised to undertake the daring mission of studying the Sun. The mission envisioned new breakthroughs in solar research by flying through the Sun's blazing outer atmosphere, the corona. Researchers were determined to accomplish this feat by constructing a spacecraft — then known as the Solar Probe Plus — suited to withstand intense solar heat and radiation. The probe would monitor various details like magnetic fields and solar wind emanating from the corona.

Almost a decade after the project was featured in *Discover*, it would eventually launch in 2018 under a new name: the Parker Solar Probe — named for solar physicist Eugene Parker, who first proposed the existence of solar wind in the 1950s. Since its launch, the probe has been orbiting closer to the Sun every year; in 2021, it made history as NASA announced that it had flown through the corona for the first time, facing temperatures of over 2 million degrees Fahrenheit as it sampled particles and magnetic fields.

Thus far, the mission has demystified many of the Sun's properties that have long puzzled astrophysicists. Among its various discoveries, the probe observed an abundance of "switchbacks," S-shaped reversals in the Sun's magnetic field that are being closely followed for their role in accelerating solar wind. Researchers are still chiseling away at the Sun's mysteries — one of the burning questions being why the corona is hotter than the photosphere, the visible surface of the Sun.

The probe's measurements, researchers anticipate, could bring them one step closer to deciphering the "coronal heating problem."

THE PARKER SPACE PROBE recently made its closest approach to the Sun last December, flying 3.8 million miles from its surface and reaching a record 430,000 mph.

The historic mission will conclude in 2025, having orbited the Sun 24 times during its seven years in space. Once the probe's fuel runs out, it will be flipped around, unable to make adjustments to protect itself with its carbon heat shield. Most of its components will be completely melted by the Sun. However, a few parts — including the heat shield — will survive and be left orbiting the Sun for over a billion years. D

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