SCIENTIFIC AMERICAN

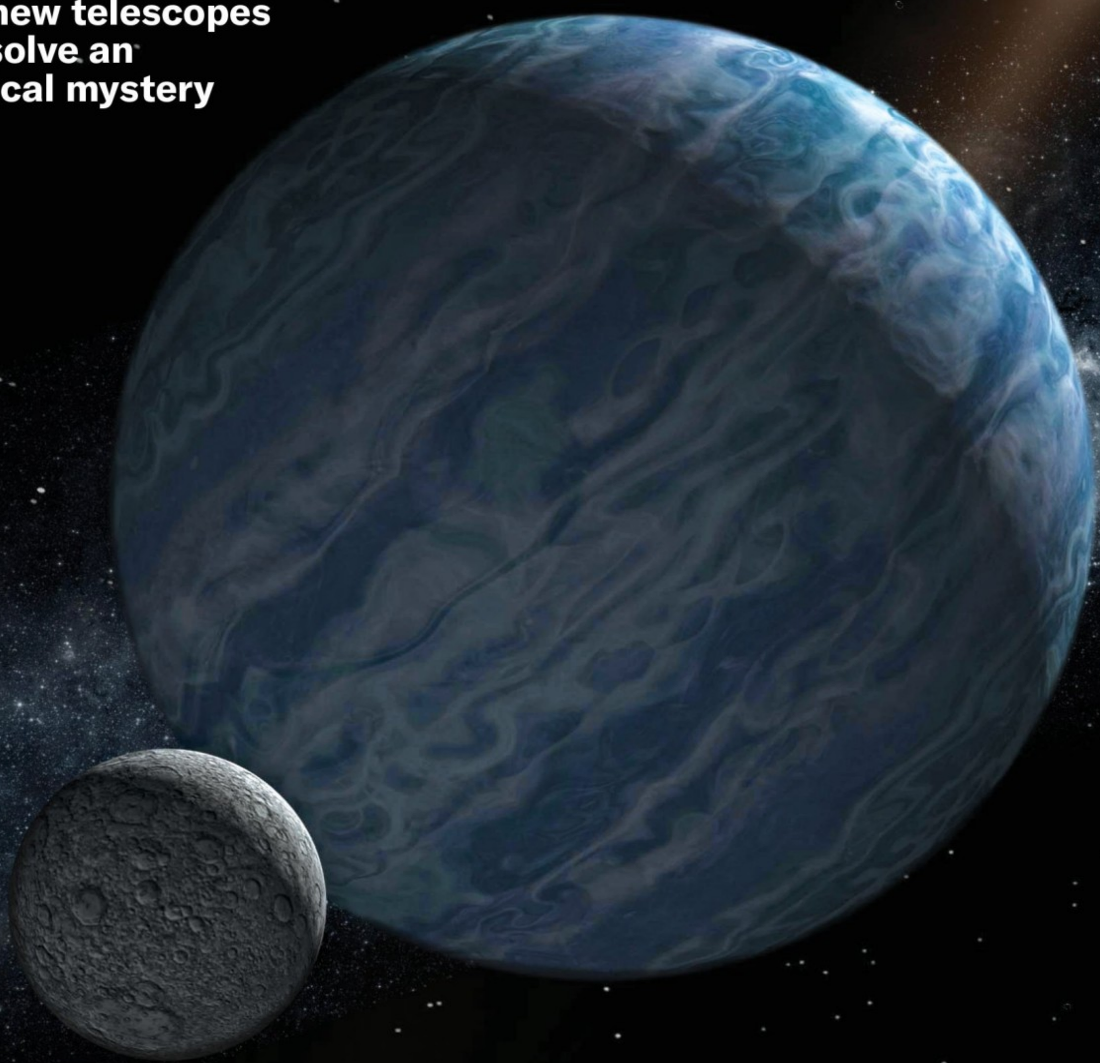
The Evolution of Joking

How to Control Dreams

New Bat Viruses

The Search for Planet Nine

Powerful new telescopes will soon solve an astronomical mystery



JANUARY 2025
SCIENTIFICAMERICAN.COM

SCIENTIFIC AMERICAN®

[January 2025]

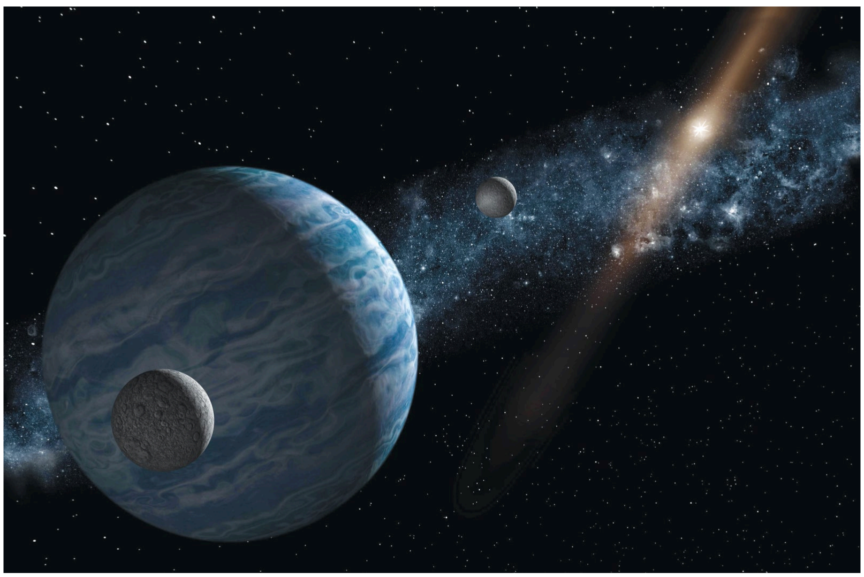
Features

- ## If Planet Nine Exists, We'll Find It Soon
  If there's a hidden world in the solar system, a new telescope should find it
- ## Great Apes Joke Around, Suggesting Humor Is Older Than Humans
  Studies of great apes hint at why and when clowning behavior evolved
- ## The Next Viral Pandemic Is Coming. Here's How We Can Stop It
  A new combo of climate and habitat crises, along with immune system stress, is driving more bat-borne viruses to afflict us
- ## Could Inducing Lucid Dreams Treat Insomnia and Nightmares?
  "Engineering" sleeping consciousness could reduce nightmares, treat insomnia—and even induce specific dreams just for fun
- ## How the Vagus Nerve Could Influence Physical and Mental Health
  The healing potential of the brain's most interconnected nerve intrigues researchers
- ## NASA's Europa Clipper Spacecraft Aims for Jupiter's Most Intriguing Moon
  For the first time, we are sending a spacecraft to explore an alien ocean world—a moon that might host life today

We May Be on the Brink of Finding the Real Planet Nine

If there's a hidden world in the solar system, a new telescope should find it

By Robin George Andrews edited by Clara Moskowitz



Ron Miller

Most astronomers would love to find a planet, but Mike Brown may be the only one proud of having killed one. Thanks to his research, Pluto, the solar system's ninth planet, was removed from the pantheon—and the public cried foul. How can you revise our childhoods? How can you mess around with our planetariums?

About 10 years ago Brown's daughter—then around 10 years old—suggested one way he could seek redemption: go find another planet. "When she said that, I kind of laughed," Brown says. "In my head, I was like, 'That's never happening.'"

Yet Brown may now be on the brink of fulfilling his daughter's wish. Evidence he and others have gathered over the past decade suggests something strange is happening in the outer solar system:

distant subplanetary objects are being found on orbits that look sculpted, arranged by an unseen gravitational force. According to Brown, that force is coming from a ninth planet—one bigger than Earth but smaller than Neptune.

Nobody has found Planet Nine yet. If it's really out there, it's too far and too faint for almost any existing telescope to spot it. But that's about to change. A new telescope, the Vera C. Rubin Observatory in Chile, is about to open its mechanical eyes. When it does, it should catch millions of previously undetected celestial phenomena, from distant supernovae to near-Earth asteroids—and, crucially, tens of thousands of new objects around and beyond Pluto.

If Brown's hidden world is real, Rubin will almost certainly find it or strong indirect evidence that it exists. "In the first year or two, we're going to answer that question," says Megan Schwamb, a planetary astronomer at Queen's University Belfast in Northern Ireland—and, just maybe, the solar system will once again have a ninth planet.

Pluto was discovered in 1930 and always seemed to be a lonely planet on the fringes of the solar system. But in the early 2000s skywatchers found out that Pluto had company: other rime-coated worlds much like it were popping up in surveys of that benighted frontier. And in 2005, using California's Palomar Observatory, Brown—an astronomer at the California Institute of Technology—and two of his colleagues spied a far-flung orb that would change the way we perceive the solar system.

That orb was Eris. It was remarkably distant—68 times as far from the sun as Earth. But at roughly 1,500 miles in diameter, it was just a little larger than Pluto. "The day I found Eris and did the calculation about how big it might be, I was like, 'Okay, that's it. Game's up,'" Brown says. Either Eris was going to become a new planet, or Pluto wasn't what we thought.

> Finding a ninth planet would be huge. Such a discovery could change what we know about our solar system's past.

In 2006 officials at the International Astronomical Union decided that to qualify as a planet, a body must orbit a star, must be sufficiently massive for gravity to squish it into a sphere and must have a clear orbit. Pluto, which shares its orbital neighborhood with a fleet of other, more modest objects, failed to overcome the third hurdle. Pluto became a "dwarf planet"—but its demotion didn't make it, or its fellow distant companions, any less beguiling to astronomers.

Pluto and Eris are members of the Kuiper belt, a roughly doughnut-shaped torus of icy shards left over from the solar system's formative days. There are countless worlds just like them, known as trans-Neptunian objects, but they are very hard to see.

Still, in the early 2000s Brown, along with his two co-discoverers of Eris, Chadwick Trujillo of Northern Arizona University and David Rabinowitz of Yale University, found their fair share. They announced one of these, named Sedna, in 2004. The closest it gets to the sun is 76 astronomical units, or AU (1 AU is equivalent to the average Earth-sun distance), which is so mindbogglingly far-flung that a person standing on it could obscure the furious light of the sun with the head of a pin. Back then, it was the most distant object ever detected in the solar system. In fact, it resides beyond the Kuiper belt and was viewable only as a fuzzy little dot shifting between the stars. Some refer to Sedna as an extreme trans-Neptunian object, or ETNO. Though poorly defined, ETNOs are key players in the saga of Planet Nine, which is also referred to as Planet X. "Sedna was our first clue to Planet Nine, although we didn't recognize it at the time," Brown says.

In 2014 Trujillo (then at the Gemini Observatory in Hawaii) and astronomer Scott S. Sheppard of Carnegie Science in Washington, D.C., published a paper on Sedna and another remote object called

2012 VP_{113}, whose closest approach to the sun was a staggering 80 AU. Both dance back and forth across the heliopause—the putative boundary of our solar system that separates the magnetized wind of the sun from the gas and dust found between stars, beyond which interstellar space begins. “Those two objects are in a class of their own,” Sheppard says. They seemed inexplicable.

Sedna and 2012 VP_{113} (along with a few other, similarly odd objects) are on orbits so stretched out and distant that the gravitational influence of something had to have positioned them there and paved their strange orbital highway around the sun. But what was that something? At these distances the immense gravitational fields of the giant planets, including Neptune, don’t have any significant effect on them; the only thing that should be influencing their orbits is the sun.

“Those objects are in a dead zone,” Sheppard says. He and others figured an invisible gravitational actor had to be invoked to explain these aberrant wayfarers. In 2014 Sheppard and Trujillo suggested that Sedna, 2012 VP_{113} and company may have those outlying orbits thanks to a hidden planet—one anywhere from two to five Earth masses in size—that is pulling at them and gradually changing the shapes and positions of their original orbits over time.

The best way to find out if that’s true is to use these ETNOs and their orbits “as gravitational probes of the outer solar system,” Sheppard says. The idea appealed to Brown, who took Sheppard and Trujillo’s 2014 study down the halls of Caltech to astronomer Konstantin Batygin. Whereas Brown is more of an observer of the night sky, Batygin is a theorist, someone who wants to know why the cartography of the solar system is the way it is. “I take deep joy in taking on observational puzzles,” he says. “For me, the thrill is in putting the calculations out there and battle-testing them with data.”

Brown and Batygin ruminated on six ETNOs and noticed something weird was going on. Unlike the eight known planets, whose orbits are approximately circular and are oriented along the same flat plane, known as the ecliptic, these six objects—including Sedna—had elliptical orbits and were tilted about 20 degrees with respect to the ecliptic. The six also made their closest approaches to the sun in the same region of space. They were all too far out to be within Neptune's gravitational reach, but something appeared to have crafted their orbits.

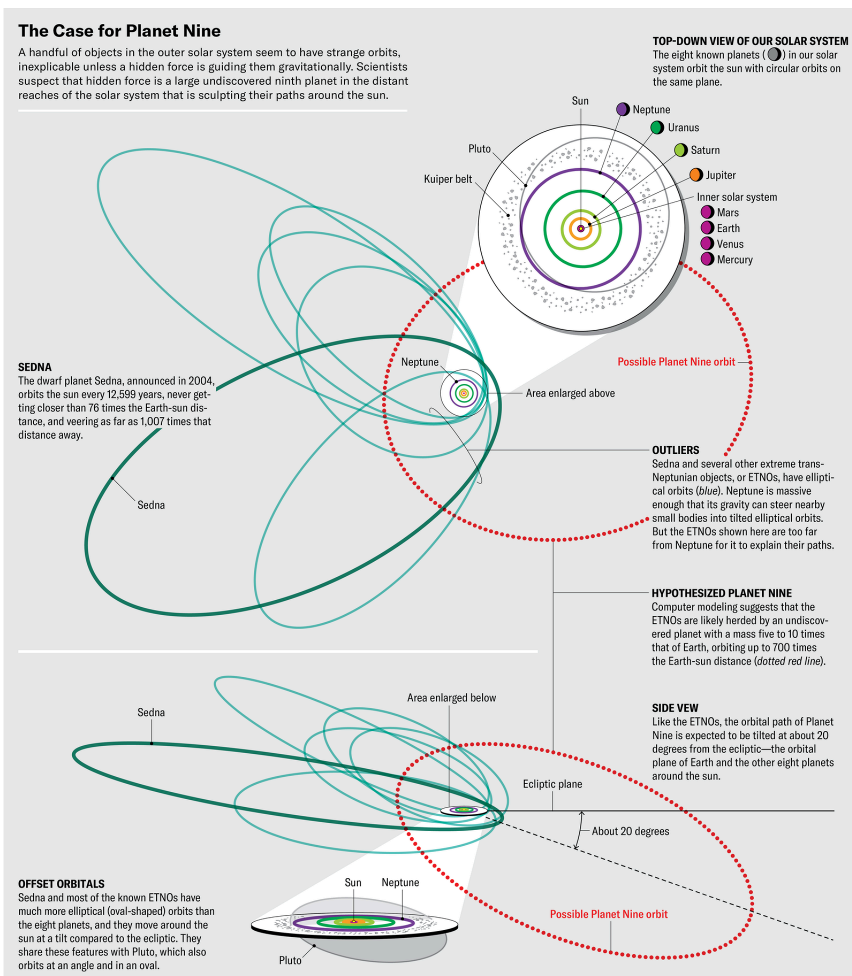
Brown and Batygin's computer models suggested the only reasonable possibility was a hidden planet with a mass five to 10 times that of Earth orbiting as far as 700 AU away. This world, perhaps one exiled from the warmer confines of the solar system during its chaotic earlier years, managed to cling to the sun's gravitational ropes. And as it whirled through the distant darkness, it wielded its own gravitational influence on those passing six orbs, herding them into similar, strange new orbits.

Since Sedna's discovery in 2004, the notion of a huge, incognito planet had come up on several occasions. But Brown and Batygin's 2016 paper announcing their calculations was a clarion call: We are confident that Planet Nine is out there. Now all we need to do is find it.

The hunt for a missing planet is inherently peculiar. "How many planets are in the solar system?" Schwamb asks. "This should be an easy question, right? But it's not!"

Finding a ninth planet would be huge. Beyond consoling those in the public who still mourn Pluto's demotion, such a discovery could change what we know about our solar system's past. Any objects in, and beyond, the Kuiper belt are "relics left over after planet formation," Schwamb says. "They tell us about that hidden history that basically has been erased from the solar system." Did planets manage to form that far from the sun, or did they migrate out there? Most orreries of planets moving around other stars include a mini Neptune of some variety. “It is very odd that we don’t have one,” she says.

If it exists, Planet Nine is big compared with Earth—Brown’s best guess is that it hovers around seven Earth masses. But it’s so far away that it’s beyond the detection capabilities of most telescopes. In general, observatories have a choice: have a wide field of view to see more of the night sky in one go or a big mirror to collect more light from a smaller area and see distant, faint objects. Space is rather expansive, so trying to zoom in on one minuscule patch of it in the hope of finding a single object is extremely unlikely to succeed.



Jen Christiansen; Source: Caltech/R. Hurt (IPAC) (*ETNO and Planet Nine orbital reference*)

Many astronomers—not just Brown, Batygin, Sheppard and Trujillo—have tried looking. Several more ETNOs have been found, including the Goblin (discovered around Halloween 2015), Farout and FarFarOut—more gravitational probes for Planet Nine hunters to study. But to date, Planet Nine itself has eluded them.

There is, of course, a chance that they can't find it not because Planet Nine is stealthy but because it doesn't exist. Over the past decade various alternative hypotheses have sprung up to try to explain Sedna and its cohort's weirdly clustered orbits.

One possibility is that there is a Planet Nine but not the canonical one; instead it's something considerably punier—Mars-size—and it sits elsewhere on the solar system's outermost boundary. In 2017 Kathryn Volk, an orbital dynamics researcher at the University of Arizona, thought the orbits of various trans-Neptunian objects hinted at the presence of a Mars-esque world within the Kuiper belt. Additional observational data on other distant objects has since undercut her team's hypothesis, and although the possibility of a Mars-like Planet Nine has come up at astronomy conferences, Volk is now skeptical. "Much like the more standard Planet Nine, they're probably both wrong," she says. "I don't think any of the existing predictions are correct."

In 2020 scientists suggested that an icy ring of primordial debris, if massive enough, could also be sculpting the orbits of several ETNOs. Brown notes that we see inclined frosty rings around other stars, but those rings are thought to be held in place by the gravitational influence of another hefty planet, making this a more complicated explanation than Planet Nine alone.

It's also been suggested that perhaps a passing star or a rogue planet zipping through space could have dragged Sedna and its friends onto their weird orbits long ago. In 2019 researchers even wondered whether a tiny black hole might be the culprit. When I raise this possibility to Brown, he grins. "I have it!" he says. He disappears for a moment, then reemerges holding a sphere about the size of a volleyball. “This is a seven-Earth-mass black hole. One of my students 3D-printed it for me.”

Brown chuckles. “What we know is that there is a seven-Earth-mass object out there. What it is, we don’t know,” he says. “It could be a planet. It could be a black hole. It could be a cat or a burrito. All of these are possibilities—some make more sense than others.” He puts down his tiny black hole. “A planet is a really mundane explanation.” After all, he says, we see planets like that on distant orbits around other stars all the time.

Trujillo is a little more circumspect when considering alternative explanations. Sure, he says, they could be right; those theories deserve to be explored. “We still don’t really know how Sedna and the other ETNOs got out there,” he says. But the fact remains that “an undiscovered large planet is a real possibility.”

Though not as adamant as Brown, Batygin is certainly bullish. In astrophysics, “most theories are wrong,” he says. “The most surprising thing I’ve encountered over the course of the past eight years for this particular problem is that there hasn’t been a compelling other alternative.”

Arguably, the greatest challenge to the Planet Nine story is the suggestion that Sedna and company may not have strange orbits at all. Astronomers cannot see every region of space clearly. If an observatory is afflicted by bad winter weather, then data will be lacking for that corner of the night sky. ETNOs also spend most of their unfathomably long orbits so far from Earth that they glint in sunlight only when they reach their closest approach to the sun. Then there’s the Milky Way. Our solar system is perched on one of the arms of our spiral galaxy, and when we look inward, all we see is starlight. It’s beautiful but bothersome to astronomers. “Nobody finds [trans-Neptunian objects] where the Milky Way is,” says Samantha Lawler, an astronomer at the University of Regina in Canada. “You’re looking for a small, fuzzy, moving dot, and when there are so many stars in the background, it's harder to find them." Because astronomers know about only a small number of Kuiper belt objects and ETNOs, some scientists skeptical of the Planet Nine hypothesis think we simply do not have enough information to know whether worlds like Sedna really are on strange orbits or just look like they are for the moment.

> "Each year we don't find [Planet Nine], the probability of it actually existing goes down dramatically." —Mario Jurić
> *University of Washington*

Think of it this way: imagine you're in the dark, and you have a flashlight. You shine it on one patch of the floor ahead of you, and you see a handful of marbles in that one spot. (That's Sedna and friends.) With that information alone, you may think there must be a special reason those marbles are in that spot. But there could be plenty of other marbles all over the floor—and if you could see all those other marbles, you would realize that the first seeming cluster of them isn't a cluster at all. Instead it's just a random group of marbles on a floor covered in haphazardly placed marbles. The problem is that, for now, your flashlight isn't bright or wide enough to let you see the rest of them.

This misperception is caused by what's known as an observational bias. To see whether the case for Planet Nine was afflicted by one, Lawler and her colleagues turned to the Outer Solar System Origins Survey (OSSOS). Between 2013 and 2017, OSSOS used the Canada-France-Hawaii Telescope to scan eight patches of the night sky and ultimately identified more than 800 new Kuiper belt objects. Eight objects had average distances from the sun greater than 150 AU, making them ETNOs—the kinds of objects that could be used as gravitational probes for Planet Nine. And their orbits were not clustered at all.

If a giant hidden planet is influencing these eight objects, they should exhibit the same type of clustering as those being used to invoke Planet Nine. But they don't. The OSSOS data cannot rule out Planet Nine, but they do suggest that what may look like clustered orbits sculpted by an invisible world could, in fact, be an illusion. Authors of another bias-checking study, using the Dark Energy Survey, came to the same broad conclusion in 2020. "Why say there's something more complicated if you can't rule out the null result?" Lawler says. "That's our argument."

The soon-to-open Vera C. Rubin Observatory stands atop the Cerro Pachón mountain range in Chile. NOIRLab/NSF/AURA/F. Bruno

The crux of the debate is that we are dealing with small-number statistics: there are too few known trans-Neptunian objects for astronomers to confirm one way or the other. "The agnostic perspective now is that we do not have enough data either way," says Pedro Bernardinelli, an astronomer at the Institute for Data Intensive Research in Astrophysics and Cosmology at the University of Washington. "I am fairly convinced that it's probably not there. But I also think it's silly to not search for it."

Thankfully, that search is about to get a lot easier.

In May 2024 a nearly 7,000-pound, car-size camera was moved from its construction site in California to a mountaintop in Chile. After a 10-hour flight and a several-day, winding, bumpy drive to an 8,700-foot-high peak in the Cerro Pachón mountain range, the 3,200-megapixel camera—the world's largest—arrived without a single scratch. Like the prize jewel for a monarch's crown, the $168-million camera was then almost ready to be set in place within the nearly finished Vera C. Rubin Observatory.

The observatory will see its first light sometime in early 2025. Thanks to its enormous field of view, Rubin will take images of the entire night sky viewable from the Southern Hemisphere night after night—and its house-size nest of mirrors will gather up remarkably distant starlight, meaning nearly everything that shimmers or shifts about will be photographed.

Rubin—a venture funded by the U.S. National Science Foundation and the Department of Energy—is named after the late, great astronomer who, by looking at the way stars and galaxies stuck together more than could be explained by the gravity of visible matter alone, uncovered compelling evidence for dark matter. Her namesake is aptly set to find a cornucopia of concealed objects, from faraway collapsing stars to millions of asteroids and even a bunch of interstellar objects in our own solar system.

The Kuiper belt, whose population and structure are only vaguely known, stands to be greatly illuminated by Rubin. After nearly four decades of searching, astronomers have found about 4,000 objects out there. "With Rubin, it should go up to about 40,000," says Mario Jurić, an astronomer at the University of Washington. I bring that up with Brown, who laughs. "Ah, who cares about those?" he says with a grin. But ultimately, he has his eyes on Planet Nine. And, he says, Rubin is probably going to find it.

Here's how: To fulfill Rubin's myriad science objectives, astronomers are putting together a strategy for the observatory's survey of the night sky, which will essentially be automated. Astronomers can't just ask for time on Rubin as they do on other telescopes. Instead algorithms will process Rubin’s nightly images to produce catalogs, which will then be released to the community.

For solar system science, astronomers will see a list of moving objects—those known and those previously unidentified—with orbital parameters based on the current crop of Rubin observations. Researchers seeking Planet Nine can then use the newly discovered trans-Neptunian objects to see whether the case for the planet is stacking up or collapsing.

When lots of ETNOs have been found, Brown says, it will become clear whether the clustered orbits one would expect to be caused by a hidden planet—like those of Sedna and company—are present. And because Rubin will see the entire southern sky, any observational bias will be quickly ruled out. “If the clustering is there, Planet Nine is there,” Brown says.

It’s also possible that among the moving objects Rubin detects will be Planet Nine itself. If it’s more like Uranus or Neptune—a hydrogen-enveloped orb with plenty of ice—it will reflect a lot of light, making it easier to spot. (Even in that best-case scenario it would probably look like a pinprick of light in a Rubin image.) Pessimistically, Batygin says, “it’s a bare rock”—a superdark world, practically invisible. “Undeniably, that would suck. But that might be the reality of it. We’ll get what we’ll get, and we won’t get upset. Well, some of us will get upset.”

If it’s hanging out in front of the Milky Way, that would be “the nightmare scenario,” Bernardinelli says. “It will be very hard to find.” Jurić notes that Rubin’s software will do its best to subtract that bright conflagration of starlight, revealing, he hopes, anything concealed within it. Will that work? Jurić thinks so, “but you don’t know until you try it,” he says.

Worst-case scenarios aside, astronomers expect that the mission to find Planet Nine will be over in a few years. In just one, Earth (and

Rubin) will have circled the sun once. Only inclement weather will prevent us from seeing what's out there; a bad winter month may take one month of full-sky coverage away, but the telescope should be able to capture it the next year.

"Each year we don't find [Planet Nine], the probability of it actually existing goes down dramatically," Jurić says. And after a couple of years, the existence (or nonexistence) of Planet Nine will be, to most astronomers, unequivocal. Rubin is "the ideal planet hunter," Schwamb says. "I don't think there's any other telescope in the world that could manage to do this."

Most astronomers are happy to wait and find out what Rubin reveals. Schwamb, whose Ph.D. adviser was none other than Mike Brown, treads carefully. "I will be pleasantly excited if there is a planet," she says. "I will not be so surprised if there isn't one."

But Brown and Batygin have never been surer. In a 2024 study, they analyzed the orbits of 17 trans-Neptunian objects, each with a bizarre feature: their closest approaches to the sun can get as near as Jupiter. Objects that cross Neptune's orbit like that should get ejected from the solar system, so how can these objects on these orbits exist today? Something is grabbing orbs that linger at the very edge of the solar system and putting them on orbits that take them far closer to the sun than they would otherwise get, the scientists surmise.

Their study used virtual re-creations of the solar system and tried to see what kinds of objects had the gravitational influence to sculpt these orbits—including passing stars, the Milky Way itself and Planet Nine. According to the researchers, the versions of reality without Planet Nine make no sense. This outcome is "the strongest statistical evidence yet that Planet Nine is really out there," Batygin says.

If the planet does exist, there’s a good chance that Brown and Batygin might not find it first. Rubin may detect it autonomously, Jurić says, whereupon another group of astronomers reading the data will confirm that it is genuine. Alternatively, Rubin’s software might not detect it automatically, but an astronomer may find Planet Nine by using their own software to go through the imaging data or by perusing a list of moving objects that Rubin found but did not autonomously flag as Planet Nine candidates. Batygin, ever the theorist, says the discovery is what matters most, regardless of who claims it. “I just want to know the answer,” he says.

If Planet Nine is real, “my instant reaction might be relief,” Brown says. He admits that should he not be the one to first cast eyes on it, he would feel an initial gut punch of frustration. “I would love to discover it,” he says. But he’d be satisfied if he and his colleagues were proved right all along, and he met his daughter’s challenge of redemption—and he would be thrilled that the history of the solar system would change, once again, partly because of his research.

“There’s a very good chance that we could be sitting around studying Planet Nine in just a couple of years’ time,” he says. Every telescope, on Earth and in space, might be zeroing in on its secrets. Whatever it’s like, Brown says, “it will be the best planet in the solar system.”

Robin George Andrews is a volcanologist and science writer based in London. His most recent book is *How To Kill An Asteroid* (W.W. Norton, 2024). Follow him on X @SquigglyVolcano

---

https://www.scientificamerican.com/article/if-planet-nine-exists-well-find-it-soon

Great Apes Joke Around, Suggesting Humor Is Older Than Humans

Studies of great apes hint at why and when clowning behavior evolved

By Erica Cartmill edited by Kate Wong

Tim O'Brien

One sunny afternoon in San Diego, three-year-old Aisha played outside while her father sat nearby. Her father wasn't paying much attention to her, so Aisha took a toy and waved it at him. When he didn't respond, she redoubled her efforts, gently bonking him on the head with the toy. She looked at her dad's face expectantly, but to no avail. Aisha then waved the toy in her dad's face and brushed it across the top of his head, making it harder and harder for him to ignore her. Finally, he gave in and watched while she swung on a swing.

Like most three-year-olds you might know, Aisha could be a handful. Unlike those three-year-olds, Aisha is an orangutan. She is 11 now, and she and her family live at the San Diego Zoo. Throughout her childhood, Aisha spent her days playing, eating, sleeping and frequently bugging her parents. Aisha's behavior toward her father probably sounds familiar. You're likely to see similar behavior from a bored toddler and her father in a supermarket checkout line. Where does this urge to bug, mess with, or tease others come from? Is the similarity between Aisha's behavior and that of a human child merely a superficial resemblance, or is it the result of deep commonalities in the way we play, learn and think?

Over the past several years my colleagues and I have been studying teasing in humans and great apes to figure out why—and when—this behavior evolved. Teasing exists in a gray area between play and aggression. It can sometimes lead to bullying and ostracism. But it can also be loving and even endearing. For humans, playful teasing—which includes clowning, pranking and joking—provides a wonderful space to learn about social relationships. It can test those relationships by gently stretching the boundaries of social norms and seeing what one can get away with. And it can advertise the strength of those relationships to others (imagine watching a group of friends playfully insult one another). We think much the same is true for the other great apes. Although scholars have traditionally viewed humor as a uniquely human trait, our findings suggest that it has surprisingly deep roots.

I first started thinking about the origin of humor in 2005, when I was researching orangutan communication for my Ph.D. I was at a zoo studying how orangutans use gestures to communicate. One day, I witnessed a fascinating interaction that I didn't know how to categorize or analyze. An infant orangutan was dangling from a rope over her mother, who was lying on her back in a pile of straw. The infant extended a large piece of bark toward her mother, and her mother reached for it. At the last second, the infant pulled the bark back out of her mother’s grasp. Her mother lowered her hand. The infant offered the bark again. This “here, take it—oops, just kidding” behavior happened a few more times until the infant dropped the piece of bark.

> Young children find repetitive jokes incredibly entertaining. The humor centers on something unexpected happening. Peekaboo!

To my surprise, the mother then picked it up and started doing the same thing back toward the infant. This role reversal was intriguing. Now it wasn’t just a tolerant mother going along with her daughter; it was a game—or maybe a *joke!* It had the core features of a joke: a setup (the offer) and a punch line (the withdrawal). Sure, it wasn’t a great joke—it wouldn’t appear in anyone’s stand-up routine—but it seemed like the kind of joke a toddler might enjoy.

Young children find repetitive physical jokes incredibly entertaining. The humor centers on a moment of surprise: something unexpected happening. And yet these interactions are typically repeated over and over. The unexpected moment becomes an expected part of the game. Peekaboo!

This kind of expected surprise is the basis of a lot of humor. Jokes often involve a conventionalized setup (“knock knock ...,” “what’s the deal with ...,” “did you ever notice how ...,” “what’s the difference between ....”). The framing primes the listeners for a punch line, letting them know they should listen to the language that follows in a less literal way.

Children begin creating these unexpected moments before their first birthday, even before they say their first word. Vasu Reddy, a psychologist at the University of Portsmouth in England, calls these interactions “clowning” behaviors and highlights three common types: offer-and-withdrawal, disruption of others’ activities, and provocative noncompliance (intentionally doing something that violates a norm or rule). A human infant might offer an object and pull it back at the last second, just as I saw the infant orangutan do. They might demonstrate noncompliance by putting a shoe on their head like a hat instead of on their foot, smiling as they do so. An infant's primary motivation for clowning seems to be engagement with others, not violation of rules. These are playful social behaviors; youngsters frequently laugh while clowning and look toward the faces of the adults for a reaction.

The exchange between the infant and mother orangutan wasn't immediately relevant to what I was researching at the time, but it stuck in my mind, along with other instances of teasing that I occasionally observed while studying gestural communication in this species. Eventually my research focus shifted, and I got more and more interested in the cognition that drives communication. I began to think about those teasing interactions I had witnessed. They weren't necessarily part of the communication systems I had been studying, but they involved understanding the minds of others. It occurred to me that those behaviors could provide an interesting lens on the evolution of social intelligence.

Orangutans and humans are both great apes, along with chimpanzees, bonobos and gorillas. Members of this group have many things in common. We have big brains and long childhoods. We laugh, mourn, get jealous and hold grudges. We recognize ourselves in mirrors and understand that others can know things we don't. Great apes have well-developed social intelligence; we're very interested in other individuals, and we spend a lot of time playing with, learning from, fighting over, getting even with, and befriending them. Could playful teasing have evolved as part of this intense interest in the goals, feelings and relationships of others?

Getting at this question would require systematically observing the great apes for the presence of teasing behaviors, something that, to my knowledge, no one had done before. In early 2020 I assembled a team of students, postdocs and colleagues—including Isabelle Laumer, Johanna Eckert and Sasha Winkler, all then at the University of California, Los Angeles, and Federico Rossano of the University of California, San Diego—to conduct this research. We initially planned a series of hands-on studies in zoos, but the world had other plans. Like humans, the other great apes are susceptible to COVID, so at the height of the pandemic, the primate research community paused all research that involved interacting directly with great apes. We decided to carry out a video-based study instead. Using footage of orangutans, gorillas, chimpanzees and bonobos in zoos in the U.S. and Europe, we identified social interactions that appeared to contain a mix of playful and annoying elements. We explicitly avoided any cases of pure aggression or pure play so we could focus on the gray area in between.

A juvenile orangutan pulls her mother’s hair.
Björn Vaughn/BPI/BOS Foundation

Social cognition is difficult to study, particularly in animals as complicated as great apes. Researchers studying humans can use questionnaires to ask people what they think about others’ intentions or beliefs. But studies of nonhuman apes and human infants must measure subjects’ thinking without language—for example, by observing and coding natural interactions or by measuring the behaviors individuals produce when presented with sounds, images or puzzles.

We developed a coding system for teasing that builds on those used to study ape communication. Behavioral coding systems are the most common way to study interactions between animals or people when you are observing them from a distance. They consist of a set of codes (basically, labels) and a set of rules about how to apply those codes. Systematic application of the codes according to the rules turns messy real-world interactions into quantifiable variables that can be analyzed statistically. It also can be used to confirm that behaviors seen by one person are also seen by others, giving researchers a way to bolster the reliability of their observations. This approach helps to ensure that the phenomenon is not merely in the eye of the beholder.

In developing our coding system, we made sure to include things such as the identity of the teaser and target, the teaser's actions, whether the teaser waited for a response from the target, whether there were any repetitions of behavior, and whether interactions were primarily one-sided or reciprocal. We also coded for elements of play, including facial expressions, gestures, relaxation, and evidence of mutual enjoyment (for instance, both parties willingly continuing an interaction). Three of us worked together to code categories, apply them, discuss them, revise them, and apply them again. We repeated this process several times until we were happy with the coding system we had developed and satisfied that we were all applying it in the same way.

Our final coding system identified five main characteristics of playful teasing: a provocative behavior, a mainly one-sided provocation, an element of surprise (such as the teaser approaching the target from behind), a look from the teaser toward the target's face, and repetition or elaboration of the provocative behavior. Very few of the examples we observed had all five of these traits, but 129 examples had at least three of the five.

> Playful teasing provides a relatively low-risk environment in which to develop and refine your social prediction skills.

The most difficult teasing characteristic to define, and arguably the most important, was the presence of provocative behavior. It was reliably coded the same way by different people, so we knew it could be identified, but it was hard to put into words. We ultimately decided that the best definition was “something that was difficult for the target to ignore.” This could involve the teaser doing something very slowly or very quickly directly in front of the target. It could involve shaking or pounding on something the target was sitting on. It could even involve the teaser leaning into the target’s face until they were almost touching. These behaviors have very different forms, but they are all things that would be difficult to ignore.

The four kinds of great apes we studied live in very different social groups and natural environments in the wild. Orangutans are largely solitary and spend most of their time up in the trees. Gorillas live on the ground in social groups made up of one adult male and multiple adult females and young. Chimpanzees and bonobos spend time both in the trees and on the ground, and they live in big communities composed of multiple males and multiple females. But whereas chimpanzees have male-dominated societies with relatively high levels of aggression between adults, bonobos live in mostly matriarchal societies and tend to respond to conflict not with fighting but with sex.

Despite these profound differences in their ways of life, all four species playfully teased one another in largely similar ways. They poked, hit, pushed, pulled and tickled one another. There was a lot of swinging and waving of arms, legs and objects. A teaser might grab another’s hand or foot to stop their activity. Sometimes apes hid under objects when teasing, popping a hand out to pull someone’s hair or somersaulting into another individual while inside a burlap sack. On one occasion, a juvenile chimpanzee named Azibo approached his mother while she was grooming another chimpanzee and smacked her on the back, then retreated and looked at her from a safe distance. The juvenile repeated the provocation multiple times. The mother ineffectually swatted the air in response, gently grabbing toward Azibo while continuing to groom the other ape. This kind of behavior is different from regular play. When two apes play, the interaction is more symmetrical. They approach each other and stay together while they interact, or they chase each other. Azibo's repeated provoke-and-remove-to-a-safe-distance pattern is playful, but it is also provocative, a characteristic of teasing.

Young apes were more likely to tease than adult apes, but adults teased, too. In another interaction Azibo had a stick that he was using to try to get into a feeder. Every time the youngster tried to insert the stick into a hole in the feeder, an adult named Sandra blocked his attempt by covering the hole or by grabbing the tool and then dropping it on the ground. Sandra didn't want the tool for herself; she just wanted to tease Azibo.

Teasing actions were used in ways that appeared specifically intended to elicit a response from the target. Apes weren't just treating others as part of the environment; they were expecting an interaction. During and after teasing actions, apes looked at the target to gauge their response. They then repeated their actions or elaborated them. A poke might turn into a hair pull. Waving a toy might turn into a bonk on the head.

This provocative, persistent, escalating teasing seems incredibly irritating, but the responses of other apes were almost never aggressive. Targets tended to ignore teasers or try to gently shrug, wave or shoo them away. Sometimes they responded positively, reciprocating with play, an embrace or teasing of their own. Other times they just got up and left. Apes were typically relaxed before teasing began, and teasing did not agitate either the teaser or the target. Although teasers were trying to goad their targets, they were doing it in a low-stakes way. Playful teasing most likely happens during periods of boredom, not stress. Think of kids in the back seat on a road trip—that's an ideal environment for teasing.

The presence of playful teasing in all four of our great ape cousins suggests that it benefits them in important ways. We can look to this behavior in humans to see how it might be advantageous. Playful teasing provides a rich opportunity to learn about others' minds. The teaser has to predict the target's response and adjust their behavior based on how the target is likely to respond. Things that might be received well by a close friend would not be by a stranger. You can call your best friend a slut, a punk or a weenie, and they might playfully insult you back, but you are unlikely to get the same response from your boss or a tax auditor. Even within close friendships, someone's response might vary from day to day or from hour to hour depending on the person's mood and your previous interactions. Learning to predict how others will respond to you is a critical skill for highly social animals like humans and other apes. Who will have your back if you get into a fight? Who will give you the benefit of the doubt if your actions or intentions are ambiguous? Playful teasing provides a relatively low-risk environment in which to develop and refine your social prediction skills.

Being able to predict and understand the goals, intentions, knowledge and desires of others is the basis for human language and culture. Although nonhuman apes do not have language, they do share some of these foundational skills—and playful teasing provides a window onto them. Most animals play, but playful teasing may offer an opportunity to move from physical to mental play: from playing with bodies to playing with minds.

We're only just beginning to understand teasing and how it relates to social cognition in creatures other than humans. Can apes predict whether someone will be surprised? My colleagues and I are using methods such as eye tracking to study what apes pay attention to when watching others interact. Do apes get excited when they anticipate a strong reaction in a social interaction? We're using thermal imaging to measure changes in blood flow around the eyes and ears—a physiological sign of excitement—when we expect a social scene may be funny, scary or exciting to an ape. We're still collecting and analyzing data for these projects, but a small pilot study using thermal imaging with bonobos suggests at least some apes get excited when they see another ape get tickled, for instance. By combining biological measures such as eye position and blood flow with behavioral measures such as an ape's preference for different partners in a game, we can develop a more complete picture of how attention, memory, mood and prediction combine when apes are thinking about others.

Although playful teasing has been systematically studied only in humans and other apes, we suspect that other animals do it, too. If it provides a way to build, test and show off relationships, as well as an opportunity to practice predicting others' behavior, then we might expect it to evolve in other highly social animals with big brains, few predators and long childhoods. Parrots, dolphins, elephants, whales and dogs are all good candidates. Our group is studying a few of these nonprimate species, but it will take many more observers to get a clear understanding of what playful teasing looks like across the animal kingdom. To get more people involved, we recently surveyed zookeepers in more than 100 zoos, and we are now collecting stories about animal teasing from folks around the world. If you have stories or recordings of animals playfully teasing you or other animals, we invite you to share them on our website: www.observinganimals.org/teasing.

Getting a big picture of playful teasing across the animal kingdom will inform how we study the origin and evolution of this behavior. Already observations of teasing in all the great ape species suggest the roots of human humor may go back 13 million years or more to the last common ancestor of Aisha the orangutan and the bored child in the checkout line. They may not get a Netflix comedy special, but teasing apes provide strong evidence the first joke is far older than the early human who extended a hand in the firelight and said, "Pull my finger."

Erica Cartmill is a professor of anthropology, cognitive science and animal behavior at Indiana University Bloomington. She studies the evolution of cognition and communication.

---

https://www.scientificamerican.com/article/great-apes-joke-around-suggesting-humor-is-older-than-humans

| Section menu | Main menu |

How to Stop the Next Viral Pandemic

A new combo of climate and habitat crises, along with immune system stress, is driving more bat-borne viruses to afflict us

By Jane Qiu edited by Josh Fischman

Black flying foxes, abat species, shed the Hendra virus.
Doug Gimesy

At 4:30 on a chilly morning in Australia, headlights burned through a dark forest in central Woodford, a small rural town 50 miles north of Brisbane, Queensland. Hundreds of flying foxes—magnificent fruit-eating bats with big eyes, fluffy coats, and a wingspan nearly that of an eagle—had just returned from foraging and dangled on tree branches like gigantic Christmas ornaments. Below them, rather incongruously, a large plastic sheet covered the ground. It had been placed there by a team of ecologists to collect urine and feces that the animals dropped.

The scientists, from Griffith University in Brisbane, were probing bat droppings because of a grave human-health concern: plagues now come at us from the skies. Viruses carried by the world's only flying mammals, bats, have infected people. In the past decades a series of viral attackers—many of them deadly—have been found in or linked to bats: Marburg, Ebola, Hendra, Nipah, SARS-CoV-1, MERS-CoV and, most recently, SARS-CoV-2. COVID, the disease that last virus causes, has killed more than seven million people across the world. Bat-derived viruses seem to threaten our health with disturbing frequency.

But why bats? And why now? After decades of searching for clues and putting together puzzle pieces involving evolution, ecology and climate, scientists have come up with a good answer. Bats have evolved a unique immune system that lets them coexist with a horde of otherwise harmful viruses, a development that seems tied, in surprising ways, to their ability to fly. But when people destroy their habitats and food and trigger disturbing changes in climate—all of which have coincided recently—bats' immune systems can be strained to the breaking point. The animals can no longer keep viruses in check. Their burgeoning population of microbes rains down on other animals and eventually infects people.

The search for further evidence to bolster this hypothesis, as well as early warnings of bat-virus outbreaks, had brought the Griffith team to Woodford last year. The investigators were looking for signs of nutrition problems or biomarkers of impaired immunity in the bats, among other indicators. Alison Peel, one of the ecologists, carefully transferred puddles of bat urine from the plastic sheet into test tubes. Then she felt something hard land on her back. "Great, I just got hit by bat poop," she said with a grimace. The first light of dawn began filtering through the dense forest canopy.

The team will be spending several years in the field, trying to pick out causes of virus shedding that can be easily obscured in a wild environment. "Such long-term studies are extremely hard but absolutely critical," says James Wood, an infectious disease ecologist at the University of Cambridge, who has been working on Hendra-like viruses in African bats in Ghana and Madagascar. The basic links between environmental stress on bats and increased spread of disease were documented in 2022, in a landmark paper in *Nature*. It connected climate variability, deforestation and food shortages over a quarter of a century to pulses of heightened virus infections in bats, other animals and people.

In Queensland, Australia, large groups of black flying foxes hang from trees.
Doug Gimesy

One of the authors of that paper was Raina Plowright, an infectious disease ecologist at Cornell University who has been studying flying foxes and viruses for two decades. The interwoven nature of these causes, she says, means that any public-health intervention to prevent future pandemics will need to tackle the whole environmental tapestry, not just pull on a single thread. “Halting deforestation and climate change will help address the root cause,” she says.

On a March evening in 2006, Plowright was in the bushland in northern Australia’s Nitmiluk National Park when she felt that something was not quite right. She had set up a finely meshed net under the forest canopy to capture flying foxes, then sat back and stared at the sky. Plowright, a graduate student at the time, was waiting for what she called a flying river of animals—hundreds of thousands of them rushing from their roosts to feed as the sun went down—letting out a cacophony of high-pitched calls. “It’s absolutely spectacular," she says. "They are the wildebeests of the Northern Territory."

But that twilight was eerily quiet. Plowright could barely find a trickle of flying foxes, let alone a gushing river. It was extremely unusual. "Where have the bats gone?" she recalls wondering.

Plowright was part of a team trying to understand why flying foxes had been spreading the Hendra virus to horses and people. Hendra had killed two humans at that point, and it had killed and sickened many more equines, threatening an industry worth several billions of dollars to Australia. The scientists' job was to periodically measure the extent of virus infection in wild bats and monitor their health.

When the researchers finally managed to capture a few bats, they realized all was not well. The animals were skinny and in bad shape; it looked as if they had not been eating. "The bats were basically starving and in really poor health," Plowright says. And even though it was just after the mating season, none of the captured females was pregnant. The team couldn't detect any Hendra genetic material in the animals—which is notoriously tricky to do—but nearly 80 percent of the bats had immune system antibody proteins against the virus. That was nearly twice the level measured the year before, and it meant the bats had caught the pathogen. "It was the first clue that nutritional stress may have a role in an increased susceptibility to virus infection," Plowright says.

Hendra, the virus that Plowright and others were tracking, had made its fearsome debut on the outskirts of Brisbane, in the state of Queensland, in September 1994. On a breezy spring afternoon a thoroughbred mare named Drama Series started to look sickly while grazing at a paddock near Hendra, a sleepy area known for its racehorses. Drama Series deteriorated precipitously, and she died two days later, says Peter Reid, the equine veterinarian who treated her.

Within a few days a dozen more horses fell ill; most of them had shared a stable with Drama Series. Some soon died, and the rest were euthanized to prevent possible transmission to humans. But it was too late, Reid says. Within a week flulike symptoms descended on Drama Series' trainer, who eventually succumbed to respiratory and kidney failure.

Around the same time, another outbreak killed two horses in Mackay, 600 miles north of Brisbane. But the cause remained a mystery until their owner died 14 months later. Medical examinations showed that the cause of his death—and that of his horses—was the same viral pathogen that launched the deadly attacks in Hendra.

Researchers spread a plastic sheet under a flying fox roost in Queensland to collect urine and feces samples.
Doug Gimesy

The same virus in two deadly outbreaks 600 miles apart: this context gave scientists an ominous clue to the pathogen's source. "We started to consider the possibility that the virus was transmitted by a flying animal," says Linfa Wang, an infectious disease expert who was then at the Australian Animal Health

Laboratory (now known as the Australian Center for Disease Preparedness).

But which animal? Scientists decided to focus their attention on insects, birds and bats. These creatures were the airborne members of a long list of wild animals, including rodents, snakes and marsupials, that field researchers had been trapping and another team of molecular biologists, including Wang, had been analyzing. Their goal was to pinpoint the source of the disease. Wang, now at Duke–National University of Singapore Medical School, says the work soon paid off. Blood samples from all four of the flying fox species in Australia had antibodies to Hendra. In the ensuing years, the team managed to isolate the virus from a bat and obtained the full sequence of its genome.

That discovery focused attention on bats as virus carriers, and scientists have since discovered dozens of bat-borne pathogens. They learned, for instance, that bats are vectors for the Nipah virus, which killed around 100 people and led to the culling of one million pigs in Malaysia in 1998–1999. In the aftermath of SARS in 2005, Wang and his colleagues in China, Australia and the U.S. reported in *Science* that bats might also be the source of the new contagion.

These discoveries posed a conundrum. Nipah, Hendra, and other viruses can make humans and other animals sick, often with devastating consequences, yet bats seem to tolerate them well. Wang wanted to understand why. He was shocked when he realized how little was known. “It was like stepping into a void,” Wang says. “Our understanding of bat immunity was almost zero.” It was a void that, beginning in the early 2000s, he and other scientists started to fill.

In 2008 the Australian government gave Wang a coveted blue-sky research grant, one awarded to scientists deemed on a path toward breakthrough discoveries. With around $2 million to spend over five years, he could do whatever he wanted. There was only one thing on his mind. “I wanted to be the first person in the world to sequence bat genomes,” he says. What he didn’t expect was that the effort would lead to a fascinating link between bats’ unusual immune system and their even more unusual evolution.

Of the 6,400 or so living mammalian species, bats are the only ones that can fly. More than one in five mammalian species is a bat—it is one of the most diverse groups in the class, second only to rodents. Bats’ lifespans are extraordinary. Some bats weigh only a few grams but can live as long as 40 years, equivalent to humans living for almost 1,000 years. Despite such longevity, bats rarely develop cancer.

How and when the only flying mammals evolved wings and became airborne is still unclear. The oldest fossils of bats that “have all the hallmarks of a flying creature” are dated to 52.5 million years ago, says Nancy Simmons, a mammalogist at the American Museum of Natural History in New York City, who worked on these exquisitely preserved skeletons from present-day Wyoming. The signs of wings and other flight features on the fossils indicate the animals’ unique path to the skies began to evolve millions of years earlier, and the lineage probably split from other mammalian species before the massive asteroid impact that wiped out dinosaurs and around 70 percent of all species worldwide 66 million years ago.

“The advantages of flight are tremendous because you can cover much larger areas than similarly sized animals that can’t fly,” Simmons says. “It opened up a whole new set of resources that were not available to those that couldn’t fly.” Bats, in essence, became “birds of the night,” occupying many of the same ecological niches as birds but avoiding competition with them by being nocturnal.

A scientist prepares to analyze DNA from flying fox feces samples.
Doug Gimesy

This high-flying lifestyle requires a lot of energy. In flight, some species of bats increase their metabolic rate more than 15-fold. Body temperature can rise from around 95 degrees Fahrenheit to 104 degrees F, and their heart rates can speed up from a resting pace of 200 to 400 beats per minute to 1,100 beats. From their roost sites, they often travel dozens of miles to feed in one night. Some migratory species can travel up to 1,240 miles from their summer locations to winter ones. The use of so much energy releases a large amount of metabolic by-products, such as damaged DNA and highly reactive chemicals. These substances trigger inflammatory responses similar to those caused by microbial infection. “Bats must have an efficient system to deal with the insults that come with flight,” Wang says. “It’s all about damage control.”

With his blue-sky grant, Wang set out to systematically study how bats were physiologically different from other mammals—a question considered esoteric at the time. By collaborating with BGI, a Chinese genomics company that had already sequenced the genomes of organisms such as rice and the giant panda, Wang and his colleagues got the first chance to read the “genetic book” of two types of bats: a small, insect-eating species (*Myotis davidii*) from northern China and Russia, and a big, fruit-eating black flying fox (*Pteropus alecto*) from Australia. “It was like hitting a jackpot,” Wang says. Writing in *Science* in 2013, the team reported that bats have more genes responsible for repairing DNA damage than other mammals such as mice and humans do—possibly allowing the flying creatures to be more adept at fixing the molecular wear and tear caused by their high metabolism.

There were also some helpful genetic absences. The genetic books of both of the bat species Wang's team sequenced, for instance, have lost several "pages"—genes found in more grounded mammals—that encode certain immune system proteins. These proteins help to detect invading organisms and launch inflammatory responses. This scenario might sound counterintuitive: Wouldn't the lack of those genes make bats more vulnerable to infection? Scientists think not; it's often the immunological overdrive in response to pathogens, rather than pathogens themselves, that kills the host. (A lethal aspect of COVID, early in the pandemic, was a "storm" of immunological overreaction that damaged organs beyond repair.) "This was the first tantalizing clue to how bats deal with infection," Wang says.

A hint about what happens when this delicate infection-control system goes awry came from earlier bat-surveillance studies: when the animals shed more virus, other species started to get sick. In June 2011 a Hendra outbreak hit horses in Australia's eastern states of Queensland and New South Wales. By October of that year about two dozen horses perished, traced to not one but 18 separate transmissions of the virus from flying foxes. "It was unprecedented," says Hamish McCallum, an expert on ecological modeling at Griffith University's Southport campus. There had been only 14 transmission events since the first Hendra outbreak in 1994.

At about the same time, a team led by Peel (who would go on to collect samples in Woodford) uncovered another troubling phenomenon: bats were shedding a whole bunch of viruses other than Hendra. Since November 2010, her colleagues had been collecting urine samples from flying foxes—mostly the black flying fox and the grey-headed flying fox (*Pteropus poliocephalus*)—at their roost sites on a monthly basis. Their studies show that the bat populations usually have a variety of viruses at low levels. But the levels tended to rise in the cold and dry winter months, between June and August, when risks of virus transmission are heightened.

In winter 2011 the levels of eight viruses—including Hendra, its cousin the Cedar virus and the Menangle virus (which can also infect humans)—peaked in urine samples collected from bats in Queensland. This bump did not happen in subsequent winters or in the state of Victoria, where there were no reported cases of Hendra infection in horses, Peel says. “That was when it became clear that flying foxes shed multiple viruses simultaneously in discrete pulses,” says Plowright, who collaborated with both Peel and McCallum for the study. The pulse seemed to coincide with the times when the horses got infected. A rise in virus shedding therefore seems to be a critical step—and a sentinel indicator—for cross-species transmission.

To bat immunologists such as Tony Schountz of Colorado State University in Fort Collins, the level of virus shedding is intricately related to the so-called immunological détente between pathogens and their bat hosts. “It’s a relationship in which the virus and the host effectively say to each other, ‘If you don’t bother me, I won’t bother you,’” he says.

Two strategies are in place to maintain the détente. One typically entails the constant expression of immune system signals that are switched on in other mammals only when the animals are invaded by pathogens. In some bat species, this includes type I interferons (a group of signaling molecules regarded as the first line of defense against viral infection) and heat-shock proteins (which in other animals are induced in response to stress). “Bats are always in a state of ‘ready to fight,’” says Zhou Peng, an expert on bat virology at the Guangzhou National Laboratory in China. “This helps to keep the viruses in check.”

The grey-headed flying fox also carries the Hendra virus, which threatens people and other animals.
Doug Gimesy

The other strategy is to have only minimal inflammation, avoiding the overreactions that can damage organs. Bats show only small signs of tissue inflammation even when infected by viruses, Schountz notes. Such dampened responses can leave bats vulnerable to viruses, but the “ready to fight” immune system components usually take care of the invaders with a more targeted, precise counterattack that goes after the viruses and not the organs they are in. “They never go overboard” in their defenses, Schountz says.

This finely tuned interaction, developed over a long history as bats and viruses learned to coexist, can explain bats’ remarkable ability to harbor viruses without getting sick. “It’s all about yin and yang,” Wang says. “But the balance can be tipped.”

Changes in the environment can do the tipping. That might be what happened to the bats the Griffith team sampled in 2011. Research over decades has shown that food availability predicts virus shedding. Several times a year since 2006, scientists have conducted detailed assessments of environmental conditions within the foraging radius of several flying fox roosts in Queensland. They found that the eucalyptus forests at those sites provided the highest abundance of food resources in late summer—especially highly nutritious pollen and nectar. The amount of food dropped to the lowest point in winter months, when Hendra cases can rise.

What was particularly striking was how well the levels of virus shedding and horse infection correlated with food availability. When food was hard to find, bats tended to shed more virus, and horse infections shot up. But when food was abundant, virus-related problems dropped. The food ups and downs, it turned out, were affected by a pattern of climate variability known as the El Niño–Southern Oscillation (ENSO) in the preceding months or years. ENSO lurches between two states: El Niño, when surface waters in the tropical central and eastern Pacific are unusually warm, results in hot and dry years in Australia. La Niña, when waters are exceptionally cool, leads to wetter weather on land. Recent studies have shown that global warming might have made the switches more intense and more frequent.

In 2011—the year scientists uncovered the big surge of virus shedding and horse infection—Australia was coming out of two strong El Niño years. The drought had created a prolonged food shortage for bats because eucalyptus trees didn’t flower. “There was little nectar around,” McCallum says. “The bats were probably starving.” Food availability during the winter of 2010 hit one of the lowest points during the entire period the scientists studied.

The findings are also consistent with what Plowright saw in the spring of 2006 in Nitmiluk: starving and unhealthy bats, as well as a large number with signs of Hendra infection. That period followed a major cyclone that reduced food availability. Scientists suspect that food shortages and nutrition deficiencies, possibly exacerbated by an increasingly erratic ENSO, might have thrown off the balance of the animals’ immune systems, leading to increased levels of virus infection, replication and shedding.

But ENSO is not the only culprit behind food shortages for flying foxes. The species have suffered from habitat loss for decades. Plowright's team found that 70 percent of the forest that provided winter habitats for the animals was cut down and cleared, mostly for agriculture, mining and urban development, by 1996. Nearly a third of the remaining habitat was gone by 2018—often without proper regulatory approval, Plowright says. Millions more acres are set to be cleared in the coming decade, she adds, making Australia one of the worst deforesters in the world. The 2022 *Nature* paper she co-authored, which highlighted the correlations between environmental changes and fluctuations in virus activity, showed that Hendra shedding was curtailed when there were unexpected pulses of winter flowering in remnant forests. The blooms provided nutrition for the flying foxes, most likely improving their health and ability to keep viruses in check.

Just after sunset, flying foxes take off to feed over the Australian town of Gympie, showing how close the bats live to people.
Doug Gimesy

The overall trend of development and loss of foraging habitat is forcing flying foxes to move into urban and agricultural landscapes. They scavenge foods such as weeds and leaves of shade and ornamental trees, which are less nutritious, hard to digest and possibly even harmful. "It's a choice between you starve and die or you find new sources of food," Plowright says. "They're really just trying to survive." At the same time that urbanization is depriving the animals of nutrition, it is also bringing them much closer to horses and humans. Both trends increase the likelihood of virus transmission. Plowright and her colleagues found that more than two thirds of all incidents of Hendra infection in horses, as of 2010, occurred within the foraging areas of bat colonies in urban settings.

Australia is certainly not alone in driving bats out of their traditional habitats, says disease ecologist Richard Suu-Ire of the University of Ghana in Accra. In Africa, Suu-Ire's team has identified an increasing number of Hendra-like viruses in straw-colored fruits bats (*Eidolon helvum*) and also found that pigs near deforested areas or bat colonies in urban settlements have been infected by those viruses. "It's quite alarming," he says. This aligns with other studies that suggest cross-species virus transmission may happen far more frequently than previously recognized.

It's become increasingly clear that disease emergence from flying mammals is about the alignment of several elements. The virus reservoir, such as a bat colony, has to be infected, and bats have to shed significant amounts of virus. The environment—including factors such as temperature and precipitation level—has to support pathogen survival. And infection victims such as horses and people must come in contact with bats or the virus that they shed. "All of these things have to align to create the perfect storm," Plowright says.

El Niño, global warming and habitat loss have conspired to catalyze this alignment with an increasing frequency. Some researchers suspect the combination might also have contributed to the emergence of COVID, although investigations into the origins of that disease are ongoing. If the link to food shortages continues to hold up, scientists may be able to predict the risk of virus shedding by simulating ecological factors, climate conditions and bat physiology. The environmental connection could also be tested to see how it affects the spread of other bat-borne viruses—especially Nipah, one of the World Health Organization’s top-10 priority diseases for research. Killing up to three quarters of the people it infects and, unlike Hendra, capable of human-to-human transmission, the virus has caused frequent outbreaks in South and Southeast Asia since its emergence in 1998.

The new findings also point at ways to lower the risk of disease emergence. One is to plant tree species that flower in winter when food shortages tend to occur and to do so away from human settlements. This could provide flying foxes with badly needed foraging habitats. Scientists say this could keep the animals healthy and away from urban settings during vulnerable times of the year. “It’s about safeguarding public health through habitat conservation,” McCallum says. And Peel’s team is working to identify biomarkers of deteriorating bat nutrition and health that could serve as early warnings of virus shedding. Those markers will enable researchers to fine-tune computer models that predict habitat changes that elevate the risk of virus spread.

Ultimately disease risks, habitat loss and climate change are all interconnected elements of the same gigantic challenge facing humanity in the 21st century. Yet international initiatives have typically tackled those challenges separately, says Alice Hughes, an ecologist at the University of Hong Kong. For instance, an agreement negotiated during the past three years by WHO member states and set to be finalized in May 2025 includes few provisions that factor biodiversity loss and global warming into its strategies to prevent pandemics. “It’s a missed opportunity,” Hughes says. One hopeful sign is a global action plan that came out of the 2024 U.N. Conference of Parties to the Convention on Biological Diversity. The plan aims to address the connections among environmental degradation, wildlife exploitation and pathogen emergence.

The flying foxes missing from that March evening in 2006 pointed Plowright toward many of the interlaced elements driving elevated disease risks. It's since become abundantly clear that virus transmission is not only about the behavior of bats. It is also deeply tied to the actions of people and our increasingly tortured relationship with nature. Repairing that relationship will require coordinated global action. Such tasks are never easy, but the benefits of success are reduced pandemic risks and improved health for mammals that walk on the ground and fly through the air.

This reporting was supported by a grant from the Alfred P. Sloan Foundation.

Jane Qiu is an award-winning independent science writer in Beijing. She has won a Knight Science Journalism Fellowship, as well as awards from prestigious groups such as the American Association for the Advancement of Science and the Association of British Science Writers.

---

https://www.scientificamerican.com/article/the-next-viral-pandemic-is-coming-heres-how-we-can-stop-it

The New Science of Controlling Lucid Dreams

"Engineering" sleeping consciousness could reduce nightmares, treat insomnia—and even induce specific dreams just for fun

By Michelle Carr edited by Mark Fischetti

Cat O'Neil

I routinely control my own dreams. During a recent episode, in my dream laboratory, my experience went like this: I was asleep on a twin mattress in the dark lab room, wrapped in a cozy duvet and a blanket of silence. But I felt like I was awake. The sensation of being watched hung over me. Experimenters two rooms over peered at me through an infrared camera mounted on the wall. Electrodes on my scalp sent them signals about my brain waves. I opened my eyes—at least I thought I did—and sighed. Little specks of pink dust hovered in front of me. I examined them curiously. "Oh," I then thought, realizing I was asleep, "this is a dream."

In my dream I sat up slowly, my body feeling heavy. In reality I lay silently and moved my eyes left to right behind my closed eyelids. This signal, which I had learned to make through practice, was tracked by the electrodes and told the experimenters I was lucid:

asleep yet aware I was dreaming. I remembered the task they had given me before I went to sleep: summon a dream character. I called out for my grandmother, and moments later simple black-and-white photographs of her appeared, shape-shifting and vague. I could sense her presence, a connection, a warmth rolling along my spine. It was a simple and meaningful dream that soon faded into a pleasant awakening.

Once I was awake, the scientists at the Dream Engineering Lab I direct at the University of Montreal asked me, through the intercom, about my perception of characters, any interactions with them and how they affected my mood on awakening. Even in her unusual forms, my grandmother had felt real, as if she had her own thoughts, feelings and agency. Reports from other dreamers often reflect similar sensations—the result of the brain's striking ability in sleep to create realistic avatars we can interact with. Researchers suspect that these dreamy social scenarios help us learn how to interact with people in waking life.

Many people have had lucid dreams. Typically you are immersed in an experience, then something seems "off," and you realize you are actually dreaming. Often people wake up right after they become lucid, but with practice you can learn how to remain lucid and try to direct what happens. In the lab we can prime sleepers to have lucid dreams by waking them and then prompting them as they fall back asleep. At home you can try waking up and visualizing a lucid dream (most effectively in the early morning), creating a strong intention to become lucid before falling asleep again.

In the past few years scientists have discovered that while someone is having a lucid dream, they can communicate with an experimenter in a control room, and that person can communicate with the dreamer, giving them instructions to do something within the dream. In a landmark paper published in 2021 in *Current Biology,* researchers in the U.S., the Netherlands, France and

Germany provided evidence of two-way, real-time communication during lucid dreams. At two locations researchers presented spoken math problems to sleeping participants, who accurately computed the correct solution. When one team asked, “What is eight minus six?” the dreamers answered with two left-right eye movements. Another team asked yes-or-no questions, and lucid dreamers frowned to indicate “no” and smiled for “yes,” with their movements recorded by electrodes around their eyebrows and mouth.

Sleep researchers are now using emerging technologies to interface directly with the dreaming mind. Meanwhile neuroimaging studies are revealing the unique patterns of brain activity that arise during lucid dreaming. This research could lead to wearable devices programmed with algorithms that detect opportune moments to induce lucidity in people as they sleep. As researchers, we are excited about this possibility because directing, or “engineering,” a dream may allow people to reduce the severity or frequency of nightmares, improve sleep quality and morning mood, and even enhance general health and well-being.

Scientists have known that lucid dreams are real since the late 1970s. In 1980 Stephen LaBerge, then a Ph.D. student at Stanford University, published a paper about the side-to-side eye-signaling method that proved lucidity’s existence. Experts went on to demonstrate that lucid dreamers could control their breathing patterns and muscle twitches, which provided ways for them to communicate with the awake world. Imaging studies revealed more wakelike activity in the brain during lucid dreams than nonlucid dreams. This momentum culminated in the first Dream x Engineering Workshop at the Massachusetts Institute of Technology Media Laboratory, which I led in 2019. LaBerge was there, along with 50 dream scientists from around the world. For two days we explored how we might engineer dreams. We focused on using new technologies to induce lucid dreams in novices and exploring the brain basis and health benefits of lucid dreaming on a larger scale.

Since then, many more researchers have become interested; progress has been quick and revealing. Investigators working in more than a dozen countries have learned how to induce and record lucid dreams with wearable devices and even use the techniques to treat nightmares, insomnia, and other sleep problems.

> Lucid dreamers can communicate with people in the waking world by making eye movements, frowning or clenching their hands.

Treating nightmares is an important goal because they are linked to all manner of psychiatric and sleep disorders, including addiction, psychosis, narcolepsy and insomnia, as well as higher risks for anxiety, depression and suicide. The perils are especially relevant for people with post-traumatic stress disorder who experience nightmares, which for more than half of PTSD patients replay traumatic events again and again, potentially retraumatizing them each time. PTSD sufferers with severe nightmares have more acute symptoms and a fourfold greater risk of suicide compared with people with PTSD who don't experience such dreams.

In a recent study, 49 PTSD patients from nine countries who had long histories of traumatic nightmares attended a week-long virtual workshop with lucid dreaming expert, trainer and author Charlie Morley. To learn how to induce lucid dreams that might heal, participants imagined positive versions of their nightmares in which they engaged curiously with the dream or with threatening dream characters. One patient reported calling out into the dreamscape, "Dreamer, heal my body!" She then experienced roaring in her ears as her body vibrated forcefully. Another patient asked to meet and befriend her anxiety, which led to the emergence of a giant, golden lozenge that evoked her amazement and gratitude. After just one week of training, all the participants had reduced their PTSD symptoms. They also recalled fewer nightmares.

Laboratory studies have yielded similar results. One person with weekly nightmares took part in a study led by one of my lab members, Remington Mallett. While sleeping in an enclosed lab bedroom with more than a dozen electrodes pasted on her scalp and face, this young woman had a nightmare. She dreamed she was in a church parking lot, and an approaching group of people with pitchforks was chanting, “Die, die, die.” She realized she was asleep and dreaming in the lab and that the experimenter was watching from the other room. She gave a left-right eye signal, knowing the experimenter would wake her up. She later said, “In the dream I was aware that you [the experimenters] were there and reachable.” She gave the signal because she knew it would get her out of the dream, and it did. Her nightmare frequency decreased after this lab visit, and four weeks later it was still lower than it had been before the experiment.

Even just the moment of becoming lucid can sometimes bring immediate relief from a nightmare because you realize you are dreaming and that there is no real danger—similar to the relief we feel when we wake up from a nightmare and realize it was just a dream. Often when people become lucid during a nightmare, they decide to simply wake up—an immediate solution. Closing and opening your eyes repeatedly is another way to intentionally wake up from a dream, which could be useful during nightmares when at home, outside a lab.

Lucid dreaming could improve sleep health more generally. For example, we now know that people with insomnia have more unpleasant dreams than sound sleepers, including dreams in which they feel like they are awake and are worrying about not sleeping. In one recent study, insomnia patients underwent two weeks of lucid-dream training that included setting presleep intentions of becoming lucid and visualizing the kind of lucid dream they wanted to have. These practices led to less severe insomnia and less frequent anxiety and depressive symptoms in participants over time. It could be that the increased lucidity made them more aware of the fact that they were asleep, thereby improving their subjective sense of sleep quality. It's also likely that lucid dreaming made their dreams more pleasant; my team and other researchers have shown numerous times that both lucid and positive dreams are associated with better sleep quality, mood and restfulness after waking.

To improve dream engineering, we need to have a clearer understanding of what is happening in the brain during lucid dreams. Recent work in sleep and neuroscience labs is revealing the brain patterns involved.

Our most vivid dreaming takes place during rapid-eye-movement, or REM, sleep—the light phase of sleep when the brain is most active and wakelike, especially when close to the time that a person would usually get up. Lucidity may enhance one of the main functions of REM sleep: to refresh connections between the prefrontal cortex, where our brains control our thoughts and decisions, and the amygdala, where they generate our emotions. Sleep helps us control our emotions every day. When REM sleep is disrupted, the prefrontal cortex becomes less effective at regulating arousal both during sleep and during the subsequent day. This creates a vicious cycle for people with nightmares and insomnia: a night of poor sleep is followed by a worse mood and decreased defenses against stress the next day, leading to another night of disturbed sleep, and so on.

In contrast, lucid dreaming is associated with increased activation in the prefrontal cortex. To have stable lucid dreams, you need to remain calm and attentive, or you will probably wake up from excitement. Maintaining self-control seems to be central to having positive lucid-dream experiences, resolving nightmares, and boosting creativity and mood. That was the conclusion of a recent study by Mallett, who surveyed 400 posts on Reddit to identify exactly when and how lucid dreams are helpful for improving mental health.

We're learning that the real mental health benefits of lucid dreaming seem to come when dreamers can direct the content. Maintaining self-control in dreams is a bit of a learned skill. Similar to mindfulness, the dreamer must practice remaining both calm and focused while in an unpredictable and unstable dream. People can then learn to control dreams by using tricks of attention such as opening and closing their eyes and expecting, or even commanding, an object such as the Eiffel Tower to appear. This skill most likely relies on specific patterns of neural activation and on cognitive practice. To be at once an actor in and director of a lucid dream requires delicate cognitive control and flexibility, but expert lucid dreamers—people who have lucid dreams at least weekly—would probably say "control" is not the most accurate term. It's more of an improvisation, a balancing act of guiding the dream toward desired content while allowing it to arise spontaneously—like a jazz musician suggesting a rhythm or melody but also listening and adjusting to what the other musicians are playing.

To better understand how this improvisation happens, my colleague Catherine Duclos is studying the basic brain patterns of lucid dreaming in expert lucid dreamers in our Montreal lab. The volunteers sleep normally for the first half of the night, but in the early morning experimenters awaken them to place a cap on their head that is used for electroencephalogram (EEG) tests. The cap has 128 electrodes—many more than are typically used in sleep studies. After about 30 minutes, when all the electrodes are well positioned, the subjects return to sleep, intending to have a lucid dream.

Once Duclos has identified patterns of brain-wave activity that occur only in lucid dreams, she can use that information in the lab to try to directly enhance lucidity and control by augmenting activation in the cortex with electrical brain stimulation. After decades of characterizing sleep as an “offline” brain process, scientists now view the sleeping brain as “entrainable”—it is malleable and can be controlled through external stimulation. By applying an electric current of a specific wavelength to the scalp, scientists can modulate the rhythm of the sleeping brain to make brain waves faster and more wakelike in REM sleep or slower as they are in deep sleep.

> One woman having a nightmare produced a left-right eye signal, knowing a researcher watching her would wake her up.

Duclos plans to use transcranial alternating-current stimulation (tACS) to shape brain rhythms so that they are more similar to those in lucid dreams, based on the patterns she finds in the dreams she is recording now. Researchers in prior studies have also attempted to use tACS to induce lucid dreams, with mixed results. We hope the increased resolution of high-density EEG will help.

Another study of expert lucid dreamers will also help clarify how cognitive control works in a lucid dream. Tobi Matzek, one of my Ph.D. students and an expert lucid dreamer, spent four nights in our lab being recorded by EEG. Each night, as early morning approached, we awakened her and presented a 20-minute instruction over speakers in the bedroom, training her to pay attention to what she was experiencing after we woke her and to maintain this awareness when sleeping. She then fell back asleep and became lucid repeatedly. She used control strategies such as calling out requests for desired characters in the dream. In one instance, Matzek said she called for “God to appear as a perceivable form,” and an emerging ball of white light brought with it feelings of euphoria. She awoke in awe.

Matzek had eight lucid dreams, in which she summoned dream figures whom she perceived as having higher levels of self-control and independent thoughts than typical dream characters. (Her dreams described in this article were presented at a recent conference.) This study is showing us how our sleeping brain creates dream characters and just how meaningful fictional and at times otherworldly social scenarios can feel. Lucid dreamers who can conjure up characters rate these dreams as more positive and mystical than other dreams. It’s possible that lucid dreams could create opportunities to visit with lost loved ones, spiritual teachers, or family and friends, but so far we know little about how to generate such experiences or how they might impact waking life.

Matzek and other expert lucid dreamers sometimes ask big questions during their dreams. One night Matzek asked, “Can I experience the creation of the universe?” and she dreamed of being “immersed in outer space, surrounded by stars and planets and other huge celestial objects.... The darkness of space is deep and rich, and every planet and star is superbright.” At one point she felt overwhelmed by the vastness, but a spiritual presence helped her stay calm. The end result, she says, was “absolutely breathtaking.” She felt weightless and was “slowly spinning head over heels as I take in everything around me. Many [stars] are brown and red, and it’s like they’re all glowing. I know that I am actually seeing the universe uncreated, back in time.” Understanding what’s happening inside the brain during these altered states of consciousness could reveal how to induce such mystical experiences on demand.

Dreams are ephemeral, but they feel real and impactful because the brain and body experience them as real. Brain imaging shows that our dreams are read as “real” in the sensorimotor cortex. When we dream of clenching a fist, the motor cortex becomes more active, and muscles in the forearm twitch. Dreaming is the ultimate reality simulator.

Because the body experiences physical reality in sleep, we can use visual cues, sounds, and other sensations—pressure, temperature, vibration—to sculpt the dreamworld. In my lab we use flashing lights or beeping sounds during presleep lucidity training. As we did for Matzek, we wake up participants in the early morning and pursue a 20-minute training: while they lie in bed with their eyes closed, a recorded voice instructs them to remain self-aware and to pay attention to their ongoing sensory experiences. We present the flashing lights and beeping alongside this tracking so the sensory cues will serve as reminders to remain lucid.

When participants go back to sleep, we present the cues again during REM sleep to "reactivate" the associated mind state. Fifty percent of the time, participants have a lucid dream—a higher rate than without the cues. Beeping sounds played during sleep caused one person to dream of shopping in a supermarket: "I was just putting things in my trolley, and I could hear the beeping, and it was like I was getting loads of messages on my phone telling me what to buy in Tesco ... things like, 'Buy some biscuits.'" The cues made their way into the dream and served as reminders to become lucid.

Dream engineers around the world, such as Daniel Erlacher and Emma Peters of the Institute of Sport Science at Bern University in Switzerland, are exploring new types of sensory stimuli to more reliably induce lucid dreams. These cues include subtle vibrations that could be delivered by a wearable headband or smart ring, little electric pulses that cause muscles to twitch, or vestibular stimulation—an electric current sent behind the ears that induces sensations of falling or spinning. These sensations might be more easily detectable by dreamers than flashing lights and beeping sounds, perhaps because dreams already have so much competing visual and auditory content.

Lucid dreamers can communicate with people in the waking world by controlling their sleeping bodies. In addition to making deliberate eye movements, lucid dreamers can frown, clench their hands or control their breathing, and scientists can record all of this in the lab. They can measure respiration with a belt around the torso that detects expansion and contraction of the lungs or with a little sensor on the lip that can track the flow of air in and out of the nose. Kristoffer Appel of the Institute of Sleep and Dream Technologies in Germany has even decoded word messages from lucid dreamers. The dreamers held their thumb out in front of their face, traced letters, and followed the movement of their thumb with their eyes. Dreamers could say, with their eye movements, "Hello, dream." We are learning to converse with lucid dreamers, getting ever more complex messages into and out of the sleeping brain and body to direct and record dreams in real time.

I expect that the mental health applications of lucid dreaming will grow. Achilleas Pavlou and Alejandra Montemayor Garcia of the University of Nicosia Medical School in Cyprus are developing wearable devices programmed with machine-learning algorithms to detect when nightmares are occurring based on bio-signals such as brain activity, breathing and heart rate. My team, along with collaborators at the Donders Institute in the Netherlands and the IMT School for Advanced Studies in Lucca, Italy, is testing a simple EEG headband that can detect REM sleep and deliver the kinds of sensory cues I mentioned earlier to induce lucid dreams. If successful, such dream aids could be made widely available at home. Headbands and watches could help people call for help to escape nightmares—or just help them induce lucid dreams or direct the content for more satisfying dreams.

People could also use these tools simply to have exotic recreational experiences. In 2024 Adam Haar, who recently finished a postdoctoral fellowship at M.I.T., and artist Carsten Höller created an exhibit in a museum in Basel, Switzerland, that welcomed overnight visitors. A bed on six robotic legs created a rocking motion before and during sleep, while a fly agaric mushroom sculpture spun above the bed. In the liminal space before sleep onset, the dreamer was reminded to dream of flying, and rocking motions and flashing red light from the installation seeped through their body and eyelids.

These stimuli were replayed at various moments throughout the night, and the sleeper was then awakened for dream reports. One visitor noted visions of “floating on the sea ... and climbing inside the squishy stalk of a giant mushroom from the bottom and being engulfed in its gravityless squishy innards,” even of being buffeted up from the ground on the wind. In the weeks after, this woman reported “countless flight-adjacent or weightlessness dreams,” such as “gliding in the air along miles of zip line through a Swiss-looking city.”

For lucid dreamers, flying is one of the most sought-after and euphoric experiences. In a 2020 study led by Claudia Picard-Deland of the University of Montreal’s Dream and Nightmare Laboratory, participants used a virtual-reality flight simulation prior to taking a nap and then recorded their dreams for two weeks at home. Playing in the virtual-reality environment for just 15 minutes led to an eightfold increase in flying dreams. And even though the study was not designed to induce lucidity, the experimenters found that flying dreams elevated it. One participant had their first-ever lucid dream: “I succeeded to make myself float a little, then once I realized that it worked, that I had control, I put my hands just like Iron Man at my sides.... I heard a big boom and a constant noise, as if I had plane propellers at the ends of my arms, and I accelerated so fast I couldn’t believe it. I screamed with joy as loud as I could.” The participant marveled at “the quantity of detail of physical sensations that I felt from flying, the intense acceleration, the wind,” as well as seeing, from above, a beautiful city from the future.

Other gadgets may not be far off. Haar developed Dormio during his Ph.D. work at M.I.T. It is basically a glove with sensors that can measure muscle flexion, heart rate and electrical skin activity, all of which change as you drift off to sleep. When Dormio detects that you’ve just fallen asleep, it gives a spoken prompt to influence what you dream about. After a couple of minutes, it wakes you up to recall imagery, and if you follow this process several times, you can engineer brief dreams that have content you desire.

Nathan Whitmore of the M.I.T. Media Lab has developed a phone app to deliver voice training for lucid dreaming, paired with auditory cues presented again during sleep. Initial results with more than 100 participants showed that presleep training brought on lucid dreams. Ken Paller of Northwestern University and Mallett have discovered EEG signatures that seem to precede the onset of lucidity. Such measures could lead to algorithms that detect opportune moments to deliver sensory cues and induce lucid dreams. Pair these with a flying game prior to sleep, and you might be in for a fun night.

Michelle Carr is an assistant professor of psychiatry and addictology at the University of Montreal and director of the Dream Engineering Lab at the Center for Advanced Research in Sleep Medicine in Montreal.

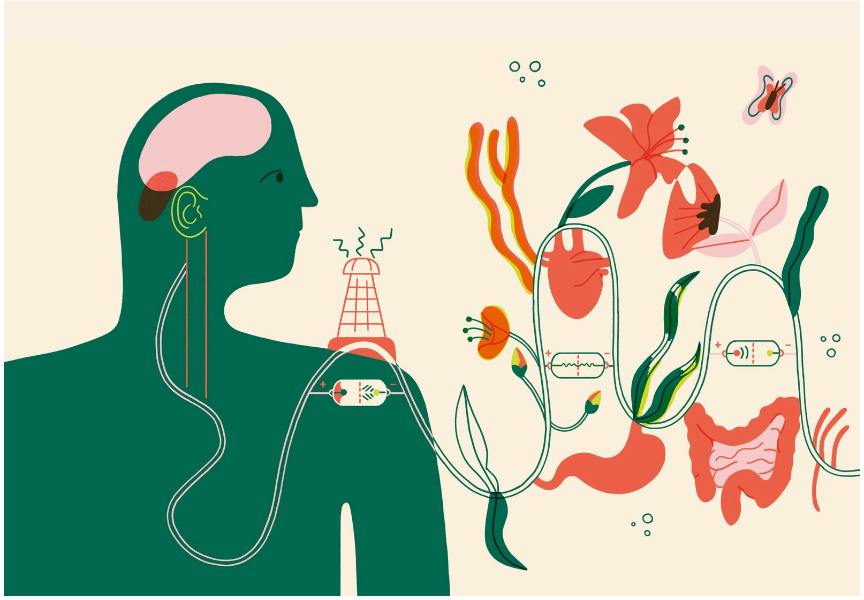
---

https://www.scientificamerican.com/article/engineering-lucid-dreams-could-improve-sleep-and-defuse-nightmares

The Vagus Nerve's Mysterious Role in Mental Health Untangled

The healing potential of the brain's most interconnected nerve intrigues researchers

By Jena Pincott edited by Madhusree Mukerjee



Noemi Fabra

The vagus nerve is a vine of nerve fibers with roots in nearly every organ and shoots in the brain. It helps us detect a racing heart, rising blood pressure, stomachache, discomfort, an overzealous immune system and even alarm calls from microbes in our gut. When it senses trouble, the vagus helps to steady our heart, soothe our stomach, rein in our immune system and calm us down.

Wellness influencers claim we can ice, tone or zap the vagus nerve to fix almost anything—long COVID, headaches, poor memory, extra pounds, the blues. Much of that hype is unfounded. Still, some research on the vagus nerve is intriguing enough—and promising enough—to draw serious scientific attention.

Investigators have long known that activating the vagus with mild electrical pulses can treat some conditions. In 1997 the U.S. Food and Drug Administration approved a vagus nerve stimulation (VNS) device that can be surgically implanted under the collarbone and linked to a wire wrapped around the nerve. It is widely used to treat cases of epilepsy that do not respond to drugs. In 2005 the FDA certified a similar device for treatment-resistant depression, and the agency approved yet another one in 2021 to speed up recovery from stroke. Gadgets that stimulate the vagus nerve from outside the body, such as at the outer ear or neck, have been cleared in many countries, including the U.S., to treat obesity, pain and migraines.

Signaling confidence in the potential of VNS, the National Institutes of Health Common Fund launched a $250-million initiative in 2015 with a second phase in 2022. The program, called SPARC (for Stimulating Peripheral Activity to Relieve Conditions), seeks to map the nerve's individual fibers and circuits and to illuminate their functions. Scientists hope it will enable them to refine existing treatments and find new therapies for other conditions, ranging from inflammatory bowel disease to long COVID. Clinical trials are underway on so-called transcutaneous VNS (tVNS) devices, which are easier to use because they access the vagus from outside the skin, or cutaneous barrier. These tools potentially could be used to treat rheumatoid arthritis, migraine, lupus and chronic fatigue syndrome—and that's just a partial list.

"A truly revolutionary idea can take 20 to 40 years before it's thoroughly adopted," says neurosurgeon Kevin J. Tracey of the Feinstein Institutes for Medical Research in Manhasset, N.Y., "at which point everyone says how we needed that all along." The vagus vine's power may be partly mythical, and the research on it is by no means conclusive or clear. But some scientists say it offers hope for millions suffering from complex, hard-to-treat conditions.

In 1664 English neuroanatomist Thomas Willis named the longest of the brain's nerves the vagus, Latin for "wandering." "We call it the vagus nerve, singular, but there are actually two, one on each side of your body," Tracey says. Each side has up to 100,000 fibers, and each fiber contributes to a specific function: heart rate, breathing, immunity, gut contractions that help to digest food, even speech. About 80 percent of vagal nerve fibers are afferent, reporting to the brain about the state of the body; the rest are efferent, carrying instructions down from the brain. British physiologist Walter Holbrook Gaskell demonstrated in the late 19th century that afferent signals tend to excite, whereas efferent ones quiet.

The first person to zap the vagus with an electric current, using something like a tuning fork pressed against the neck, was American neurologist James Leonard Corning in the 1880s. He was trying to reduce blood flow to the brain to cure epilepsy, but his idea failed. A century later, however, neuroscientist Jacob Zabara of Temple University in Philadelphia found that directly applying an electrical signal to the nerve in a canine could disrupt irregular brain activity, thereby reducing seizures. In 1988 neurologist James Kiffin Penry and neurosurgeon William Bell became the first to implant a VNS device into a human to treat epilepsy.

> When the vagus nerve brings news of dangerous inflammation in the body, the brain sends down signals to soothe it.

The VNS device currently used for epilepsy, which delivers a pulse every few minutes, is a direct descendant of Zabara's invention. A pivotal study demonstrated that it cut the frequency of seizures by 45 percent on average after a year. It is believed to work mainly by stimulating the afferent fibers, the ones leading up to the brain.

The treatment had a remarkable side effect: over time it made people happier. Their mood lightened even if they still had frequent seizures. According to Tracey, when doctors told these patients they could remove the implant, many of them replied, “No, leave it in. It makes me feel good.” This anecdotal evidence prompted the device maker to begin marketing its vagus nerve stimulator as an innovative treatment for depression.

The accidental discovery excited a wave of research to figure out exactly how the vagus nerve impacts mood—a wave that has yet to crest. Scientists now know that the vine carries information about heart rate, digestion and, more broadly, the state of the body to many of the brain regions implicated in psychiatric illness. These afferent signals first reach the brain stem’s hub, the nucleus tractus solitarius, which sorts them and passes them on. One recipient is the amygdala, which helps us process emotions, especially fear, anxiety and stress. Another is the hypothalamus, involved in the release of stress hormones such as cortisol. A third is the ventral tegmental area, which plays a central role in our experience of pleasure, motivation and reward.

Crucially, the downward signals of the vagus help the body regulate some of its inner activity, such as heart rate, to maintain internal equilibrium. When we encounter a threat, “fight-or-flight” hormones raise our heart rate and blood pressure while curbing activity in the gut and intestines. The vagus nerve detects these changes and reports them to the brain, providing real-time feedback. It also facilitates fine-tuning. When stress signals become excessive, the brain sends messages down the vagus to activate the countervailing “rest-and-digest” system. The vine releases the neurotransmitter acetylcholine at its root tips—in the heart, reducing heart rate and blood pressure, and in the stomach, improving digestion. The system relaxes.

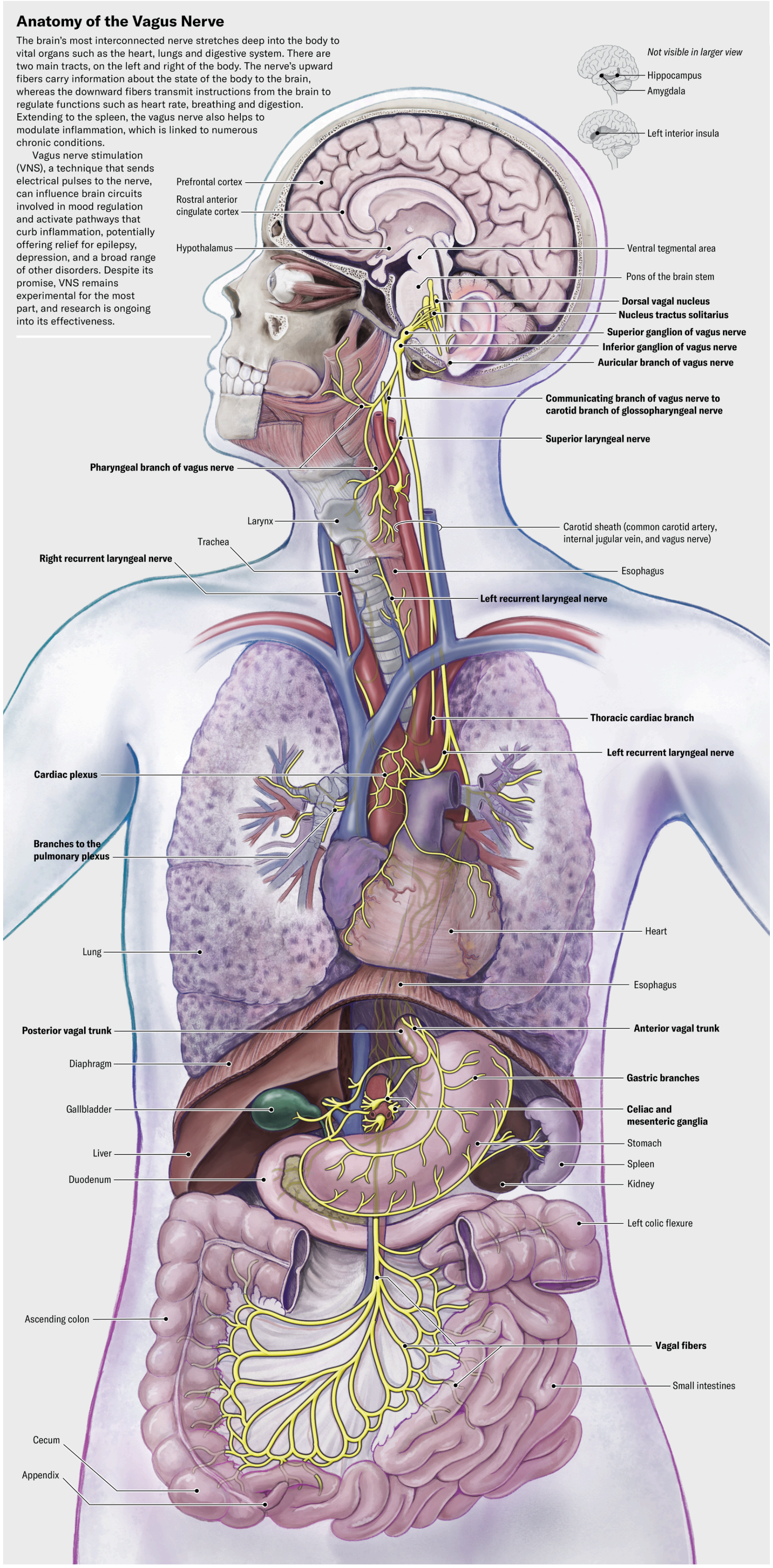
A second serendipitous finding, in the late 1990s, showed that the vagus nerve can do much more than calm the body. Researchers in Tracey’s laboratory were studying a drug to reduce inflammation in the brain. Some inflammation is protective, such as the swelling and redness around a wasp sting that show the immune system is dealing with the venom. But inflammation from an overactive immune system can damage tissues. When the body senses an injury or infection, cells in the spleen release signaling molecules called proinflammatory cytokines into the bloodstream to activate the immune response at the site. If cytokines circulate continuously for months or years—from stress, chronic infection or autoimmune disease—inflammation can cause insidious harm.

To test their anti-inflammatory drug, the researchers injected mice with a toxin that triggered an immune reaction. But there was a mix-up: instead of injecting the toxin into the brain, a member of the lab injected the mice in the abdomen, causing systemic inflammation. Much to Tracey's surprise, the anti-inflammatory drug they subsequently delivered into the brain reduced the inflammation in the body. How did that happen? The blood-brain barrier should have prevented the drug from leaving the brain. "We literally talked about this for months," Tracey recalls. It turned out that the vagus nerve had carried the drug's signal from the brain deep into the body.

Anatomy of the Vagus Nerve

The brain's most interconnected nerve stretches deep into the body to vital organs such as the heart, lungs and digestive system. There are two main tracts, on the left and right of the body. The nerve's upward fibers carry information about the state of the body to the brain, whereas the downward fibers transmit instructions from the brain to regulate functions such as heart rate, breathing and digestion. Extending to the spleen, the vagus nerve also helps to modulate inflammation, which is linked to numerous chronic conditions.

Vagus nerve stimulation (VNS), a technique that sends electrical pulses to the nerve, can influence brain circuits involved in mood regulation and activate pathways that curb inflammation, potentially offering relief for epilepsy, depression, and a broad range of other disorders. Despite its promise, VNS remains experimental for the most part, and research is ongoing into its effectiveness.



Mesa Schumacher; Kevin J. Tracey/Feinstein Institutes for Medical Research (*scientific reviewer*)

Even more astonishing, Tracey found that stimulating the vagus with electricity alone also inhibited inflammation throughout the body—no drugs needed. It was a "life-changing" moment, he recalls. More than half of all deaths from disease are tied to inflammation, including heart ailments, stroke, asthma, diabetes, and autoimmune and neurodegenerative conditions. If exciting the vagus nerve could subdue inflammation without drugs and their side effects, it could mark a breakthrough in treating chronic conditions safely.

Depression seemed like a good place to start. People with depression experience a variety of symptoms, but they share some commonalities: sadness, loss of motivation and social withdrawal. Almost a third of people with major depression also have inflammation. "Cytokines cause depression," Tracey says. "If I inject you with these inflammatory molecules, you will get fatigued and lose interest in things that normally bring you happiness." When people with cancer receive immunotherapy that includes cytokines, he adds, doctors often prescribe prophylactic antidepressants. People who suffer from anxiety and post-traumatic stress disorder also often have inflammation.

Efforts to use vagus nerve treatment to help people with depression took off—and then stalled. The FDA approved VNS in 2005 after several trials found that using it for a year alleviated depression in at least 30 percent of patients. Two years later, however, the Centers for Medicare and Medicaid Services (CMS) announced that it would not pay for the treatment, citing insufficient evidence of efficacy. The treatment costs about $30,000 or more in the U.S., which puts it out of reach for most patients. A 2017 study of 800 people with treatment-resistant depression found that five years of VNS fully cured 43.3 percent of them and reduced symptoms by half or more for 67.6 percent. Following the success of this study, the CMS agreed to reimburse patients participating in a large new clinical trial the device maker launched in 2019.

Optimistically named RECOVER, the trial could establish VNS eligibility for Medicare coverage. Over several years clinicians recruited 1,000 participants with major depressive disorder who had failed to improve with 13 other treatments on average and had a history of attempted suicide—people who would normally be excluded from drug clinical trials. “This study is for the sickest of the sick, a population that VNS studies have never shied away from,” says Charles Conway, director of the Center for the Advancement of Research in Resistant Mood and Affective Disorders at Washington University in St. Louis, who is leading the trial. The study aims to track each patient for five years.

Every five and a half minutes Gina Bolton feels a soft tingle near her throat. For a few seconds her voice enters a higher register. It makes her sound choked and upset, but it means a stimulator the size of a quarter, implanted near her collarbone, is working, she says. The device sends tiny, regular bursts of current—around two milliamps—every few minutes through a wire coiled around a vagus nerve near her vocal cords.

Bolton has had her stimulator since the summer of 2021, when she enrolled in the RECOVER trial. For 30 years she had tried every conventional treatment—psychotherapy, “tons of meds,” transcranial magnetic stimulation (which applies magnetic fields to excite neurons), and even electroconvulsive or “shock” therapy, in which electrodes on her scalp delivered electric current directly to her brain. The effects never lasted. When her son and daughter were young, she’d drop them off at school, forcing a smile and a hello, then retreat to bed. More than once she tried to take her own life.

Several months in, Bolton says, she started to notice a change in her behavior: “I was having emotions.” She realized she could laugh again, and if something sad was happening, she could cry. “Before, I was just numb.” In the summer of 2023, two years after she started VNS, Bolton went off the antidepressants she'd been taking for most of her adult life. The device had replaced the drugs.

But in June 2024, after a year of observing about 500 patients, the RECOVER trial posted mixed results. Many of the patients with depression who were getting pulses to their vagus nerve showed meaningful improvement—but so did those whose devices were not activated. (Participants were not told for the first year whether their device was sending pulses, but Bolton says she could sense them.) Another mysterious ability of the brain and body—the placebo effect—had evidently kicked in.

The result is disappointing but not entirely unexpected, says Sarah Lisanby, director of the National Institute of Mental Health's division of translational research. The placebo response gets in the way of all studies of psychiatric devices, she notes. Further, she adds, research on VNS is scant compared with the decades' worth of evidence supporting electroconvulsive therapy, which alleviates depression in up to three quarters of patients but impairs memory (among other side effects that Bolton found intolerable).

Meanwhile the RECOVER study continues. Conway and other researchers hope its data can be used to predict who would most likely benefit from future VNS work. The study did not track inflammation, but it could turn out to be a key marker. In February 2024, researchers at the University of Montreal published a pilot study on people with depression who had elevated inflammatory markers. After four years of VNS, almost all of them improved significantly as their inflammation decreased. Patients who have known inflammatory disease may be prime candidates for trials in the future.

Scientists, including Charles Raison of the University of Wisconsin–Madison and Andrew Miller of Emory University, have meanwhile identified mechanisms by which inflammation can cause depression. Inflammatory cytokines circulating in the blood can weaken or even breach the protective barrier between blood vessels and the brain. Once inside the brain, they trigger its immune cells, called microglia, to produce further inflammatory agents.

Inflammation in the brain can interfere with the production of neurotransmitters, including serotonin and dopamine, thereby diminishing feelings of well-being, motivation and pleasure. It also reduces the production of brain-derived neurotrophic factor (BDNF), a molecule that helps neurons grow and form connections. When BDNF levels drop, links between neurons weaken. That makes it harder for the prefrontal cortex, the brain region that helps us manage our emotions, to curb alarm calls from the amygdala and for the hippocampus, involved in learning and memory, to recover from a stressful event.

Could the vagus nerve soothe inflammation in the body to break this dismal cycle? Tracey and other researchers have mapped out its anti-inflammatory channels and how they work. When the nerve’s afferent fibers bring news of dangerous inflammation in the body, the brain sends signals back down the efferent pathways. These orders prompt the release of acetylcholine in the spleen, where immune cells reside. Acetylcholine prompts white blood cells called macrophages to reduce their production of proinflammatory cytokines. It may also cue macrophages in the spleen to transform so that instead of destroying infected or damaged tissues as they normally do, they go to the sources of inflammation, including the gut, and help tissues regenerate. In their healing incarnations, macrophages may even repair damage that inflammation causes in the brain and prompt the formation of new neurons and circuits, Tracey says.

With inflammatory disorders—including, Tracey suspects, depression—a disruption in the signals traveling down the vagus can prevent the nerve’s anti-inflammatory function from kicking in.

The pathway may be impaired or the signal too weak, allowing inflammation to become chronic and harmful.

All this knowledge has, however, been hard to convert into treatments. A recent meta-analysis led by Sharmili Edwin Thanarajah of the University Hospital Frankfurt in Germany showed that VNS does not consistently resolve inflammation. And even for the third of people with depression who have proinflammatory cytokines in their blood, VNS might reduce their depression but not their inflammation. Something else is going on.

Depression is a complex and variable condition. “Depressed people may look similar, but they don’t all have the same disease,” Tracey says. This heterogeneity could mean different types of vagus nerve signals might be effective for different people. Some might benefit from signals going down from the brain that curb inflammation and soothe the body, whereas others may benefit more from signals going up.

Neuroimaging offers some clues. Although findings vary with the type of VNS and the regimen used, stimulation of the vagus generally strengthens connections between the prefrontal cortex and the amygdala—which may lead to better control over emotions. It also boosts activity in the left anterior insula, which is associated with emotion processing. Further, a team led by Jian Kong of Massachusetts General Hospital and Harvard Medical School found that when VNS is used to treat depression, it appears to enhance connectivity between the medial hypothalamus, involved in regulating stress responses, and the rostral anterior cingulate cortex, associated with self-referential thinking. This shift may indicate increased integration of emotional and cognitive processes.

Some of these improvements could come from a VNS-induced increase in the neurotransmitters norepinephrine and serotonin, which, in studies of rodents, are associated with enhanced energy and alertness. Animal studies also indicate that VNS boosts BDNF, which helps to restore neural connections lost to stress and depression. Moreover, the treatment appears to replenish other signaling molecules that are frequently imbalanced in depression, such as gamma-aminobutyric acid and glutamate.

But to Conway, VNS's effect on dopamine pathways is one of the most compelling mechanisms. Dopamine is a crucial transmitter involved in motivation and pleasure, and its level in people with depression is low. More than a decade ago Conway and his colleagues used imaging to study how a year of VNS would change the brains of participants with major depression. They found that patients who responded to treatment showed increased activation in the ventral tegmental area, where dopamine is made.

Some surprising new research also indicates that VNS can boost dopamine circuits in the brains of people with major depression. In a 2024 study, Nils B. Kroemer, a neuroscientist at both the University of Bonn and the University of Tübingen in Germany, gave tVNS to patients with depression while they repeatedly pressed a button to elevate a ball, for which they received small rewards. The tVNS significantly invigorated them and increased their drive to get food and cash.

An hour-long session of tVNS paired with a game treats only a symptom of major depression—a lack of desire and motivation. But with a condition that can be so debilitating, any improvement is welcome.

Kroemer believes that for at least some depressed people the lack of motivation may come from reduced sensory input to the brain. Internal signals from the gut and other organs, transmitted up the vagus nerve, give us a sense of drive: a hunger, literally and figuratively. "If the stomach is empty, there seems to be a strong hardwired motivational signal that gets us to explore new options," Kroemer says. But that happens only if the signals transmit—which requires a healthy vagus nerve.

Kroemer and others are investigating the gut microbiome's contribution to motivation and its interactions with tVNS. Gut bacteria and their metabolites send signals up the vagus nerve to the nucleus tractus solitarius and the brain. These pathways modulate the release of neurotransmitters, including dopamine and serotonin, which regulate mental states. The brain also sends signals down the vagus nerve to the gut, influencing aspects of the gut environment such as inflammation and digestion, which in turn affect the composition of resident bacteria. There's some evidence that beneficial bacteria can reduce depression, anxiety, panic attacks and stress, whereas pathogenic microbes may worsen these states. Future interventions may combine tVNS with approaches aimed at optimizing the gut microbiome, such as a fiber-rich diet or specific probiotic combinations.

Few people with depression or other psychiatric disorders have access to VNS outside of a clinical trial (approximately 125,000 patients have received an implant). Instead an increasing number of researchers and clinicians have turned to tVNS, which is cheaper and more convenient.

A surgically implanted device is presumed to be more effective, Conway says, "because it's attached to the nerve and sends a signal 24/7 for certain." Imaging studies also find that implants activate more brain areas than tVNS does. Externally applied VNS has other limitations as well: devices that clip to the ear stimulate primarily afferent fibers, and ones applied at the neck may not efficiently reach the vagus nerve, which is buried deep within.

Most studies with tVNS have been small and limited. A randomized trial led by Kong found that eight weeks of tVNS administered through the ear was as effective as the antidepressant citalopram (Celexa) for major depression. For PTSD, a 2021 pilot study led by Omer T. Inan of the Georgia Institute of Technology and J. Douglas Bremner of Emory University found that three months of twice-daily tVNS self-administered to the neck blocked participants' inflammatory response to memories of traumatic events and reduced stress symptoms by 31 percent compared with people in the control group—prompting the FDA to grant the treatment a “breakthrough device” designation, which accelerates its development and review process. For anxiety, another pilot study, at Leiden University in the Netherlands, showed that “high worriers” had fewer intrusive thoughts after using ear-clip tVNS compared with people who received sham stimulation.

Increasingly, clinicians are combining tVNS with conventional treatments such as antidepressants and cognitive-behavioral therapy. These devices also enable individuals to self-treat many different conditions, including anxiety, stress and even general malaise. There is, however, no consensus on protocol for any given condition; worse, the inability to target specific fibers can lead to unwanted outcomes. Contrary to popular belief, VNS does not have only calming effects. Some pathways trigger arousal, increasing alertness and vigor—or, if overstimulated, jitteriness and anxiety.

Meanwhile SPARC researchers have compiled a massive data-sharing platform that includes detailed maps and models of the vagus nerve, along with other tools, with new submissions being continuously integrated. By leveraging artificial intelligence and other technologies, SPARC teams aim to isolate single fibers and circuits, along with their pathways, and track what they do. The goal is to develop strategies for targeting specific nerve fibers involved in a variety of conditions. The ambitious list includes Crohn's disease, Parkinson's disease, traumatic brain injury and pain management.

In the near future, these technologies could become more personalized. Ongoing developments in VNS involve stimulating multiple contacts along the vagus nerve to activate fibers connected to specific organs while avoiding those that have adverse effects. Emerging “closed-loop” systems could let scientists adjust stimulation parameters based on real-time feedback from the body—responding to signals such as food cravings, heart rate or inflammation.

Some proponents see VNS assuming entirely new forms. Once a neural circuit is identified, it can be targeted in any number of ways: focused ultrasound or tiny implants in various parts of the body, even the brain stem. In 2024 researchers at Columbia University’s Zuckerman Institute identified the precise circuit in the nucleus tractus solitarius and vagus nerve that informs the brain of emerging inflammation in the body and determines the response—essentially, the dial for inflammation, which they proposed controlling with drugs.

As for Bolton, she plans to continue VNS, or its future incarnation, for the rest of her life. She still remembers the exact moment she realized the treatment was working. It was several months into the trial, and she was driving to a check-in appointment. Bolton could feel the device’s intermittent pulse, as well as something else: the beat of the song playing on the car radio. She found herself tapping her fingers on the steering wheel in time with the music. “I had not wanted to be alive for so long,” she says, “and now, suddenly, I realized I did.” The beat went on, and for the first time in years, she found herself singing.

If You Need Help

If you or someone you know is struggling or having thoughts of suicide, help is available.

Call the 988 Suicide & Crisis Lifeline at 988, use the online Lifeline Chat at 988lifeline.org/chat or contact the Crisis Text Line by texting TALK to 741741.

Editor's Note (2/19/25): The graphic in this article was edited after posting to correct the reference to the pons of the brain stem. The text of the article was previously amended on February 4 to better clarify the results of the 2017 study.

Jena Pincott is a freelance science writer and author of several books, including *Do Chocolate Lovers Have Sweeter Babies?: The Surprising Science of Pregnancy* (Simon & Schuster, 2011).

---

https://www.scientificamerican.com/article/how-the-vagus-nerve-could-influence-physical-and-mental-health

| Section menu | Main menu |

NASA’s Europa Clipper Spacecraft Aims for Jupiter’s Most Intriguing Moon

For the first time, we are sending a spacecraft to explore an alien ocean world—a moon that might host life today

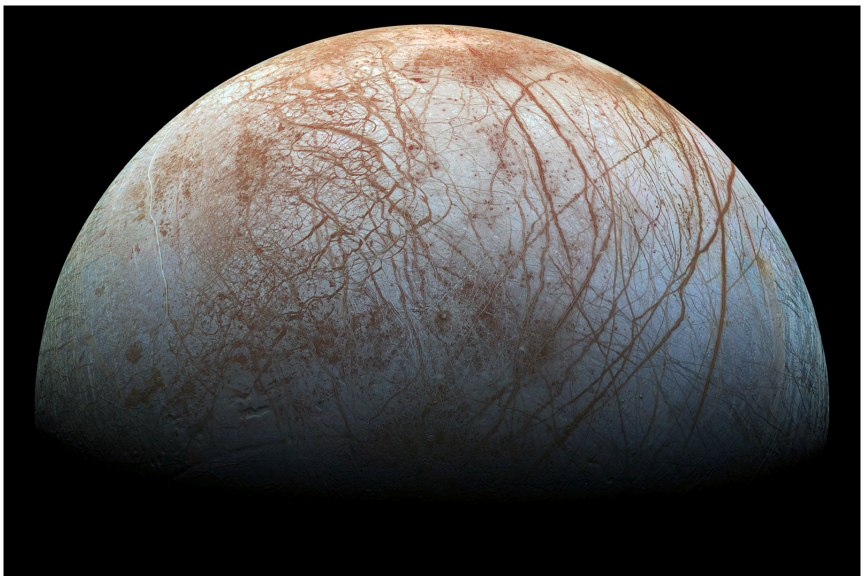
By Nadia Drake edited by Lee Billings & Clara Moskowitz

Chris Wren and Kenn Brown/Mondolithic Studios

From a launchpad at the Kennedy Space Center in Florida, surrounded by flourishing wetlands and within sight of the Atlantic Ocean’s wave-tossed shores, a mission set to explore another water world lifted into a clear blue sky on October 14, 2024. Loosed from our world’s gravitational harbor by SpaceX’s fire-breathing Falcon Heavy rocket, NASA’s Europa Clipper spacecraft is now sailing toward the Jupiter system.

Its target: Europa, an ice-encrusted moon that may offer the best odds humanity will ever get for finding life beyond Earth within our solar system. Europa’s interior may be home to a moon-spanning, briny sea that could possess all the elements needed to craft and cradle life as we know it: energy, chemistry and water. And Europa's hidden ocean is thought to hold more water than all of Earth's oceans combined.

For decades, this moon has charmed alien-hunting space scientists. But sending spacecraft to scout extraterrestrial seas is neither trivial nor for the impatient. Voyages to the outer solar system can take so long to realize that many scientists who embark on these projects know they may not be around to see the mission's end.



Long, sinuous fissures and ridges crisscross Europa in this color composite view from NASA's Galileo probe, hinting at deeper geological activity that has cracked and jumbled the icy moon's surface.
NASA/JPL-Caltech/SETI Institute

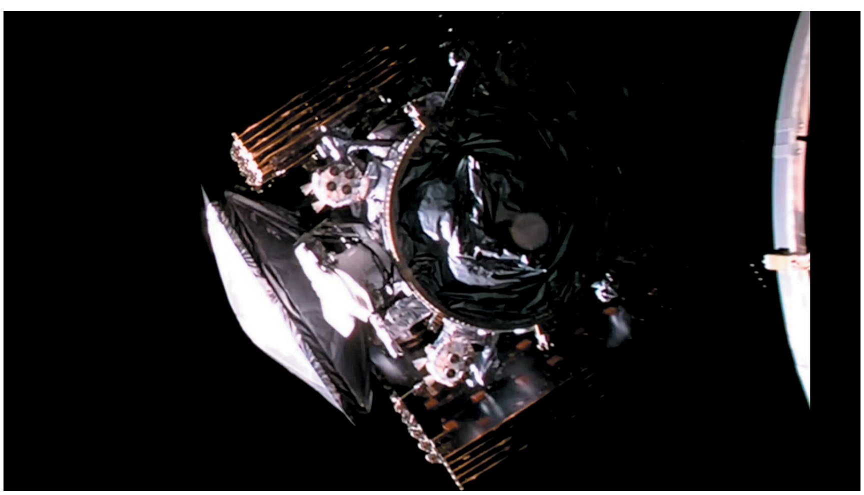
"I often talk about these missions as modern cathedrals—they are generational quests," said Laurie Leshin, director of NASA's Jet Propulsion Laboratory (JPL), which led the construction of Europa Clipper, during a prelaunch briefing. "I'm really proud that as humanity, we choose to undertake these difficult and long-term goals, things like exploring the unknown out at Jupiter."

Clipper's launch, which came after more than 20 years of painstaking preparations, is just the first step in the second half of the spacecraft's $5.2-billion story. Its journey to the outer solar system, hastened by a spiral trajectory that takes advantage of gravitational nudges from both Earth and Mars, will cover 1.8

billion miles and take around six years to complete. Once it pulls into port at Jupiter in 2030, the spacecraft will loop around the giant, storm-wracked planet, charting a course that will carry it by Europa 49 times over four years.

Lit only by faint shards of sunbeams, Jupiter and the rest of the outer solar system's worlds are realms of mystery. But the Clipper mission signifies a dawning era in which this region's subsurface seas will snap into sharper focus. Scientists are now turning their gaze not only to Europa but to other ocean-bearing icy moons such as Saturn's Titan and Enceladus—each of which could be habitable (and inhabited) today.

"It's a movement toward exploration of a whole new class of objects, ocean worlds, that we didn't realize were a thing a couple of decades ago," says JPL's Robert Pappalardo, Europa Clipper's project scientist. "And we're going to be exploring, in-depth, what this type of world is like, a type of world that might be the most common habitat for life that exists, not just in our solar system but in the galaxy."



A camera on the spacecraft's rocket booster (*right*) offered one last look at NASA's Europa Clipper (*left*) before the probe departed on its multiyear interplanetary journey.
NASA TV/SpaceX

If our solar system is any guide, such small, icy satellites greatly outnumber planets, and they could transform our ideas about where life might thrive. Clipper's goal is to learn whether Europa really is a habitable world—to confirm that, as most every space scientist is already convinced, an ocean is truly tucked away underneath the moon's crust, where it has perhaps brewed biology's raw ingredients for billions of years. The mission's personnel suspect they'll find a life-friendly sea, but until the spacecraft arrives and does the work, no one knows for sure.

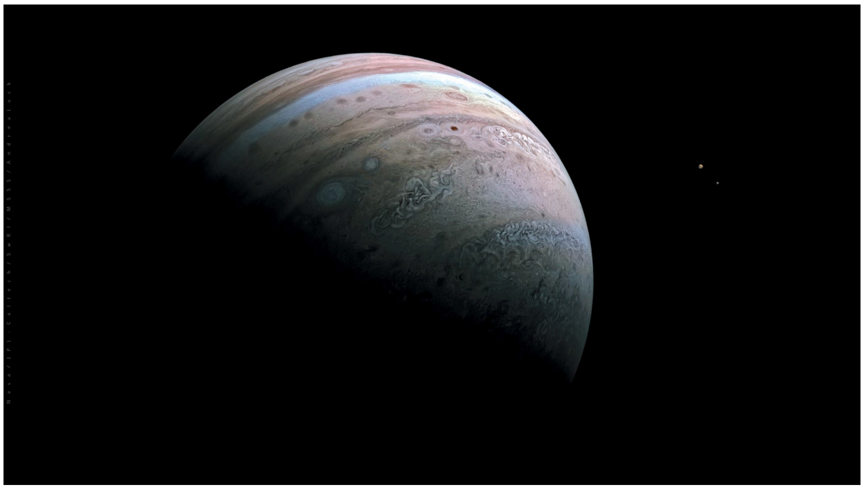
With its nine onboard instruments, Clipper will also study Europa's otherworldly chemistry, make detailed maps of the moon's icy, chaotic surface, search for enigmatic plumes of water vapor wafting into space and use ice-penetrating radar to look for lakes within the frozen rind. That is, if its hardened electronics—shown in a late-breaking curveball to be more vulnerable than expected to Jupiter's spacecraft-frying radiation—can survive the onslaught that awaits.

"Missions like Clipper are building on what has come before," says Elizabeth Turtle of Johns Hopkins Applied Physics Laboratory, who leads one of the spacecraft's camera teams. Turtle is also leading the Dragonfly mission to explore Titan, slated to launch in 2028 at the earliest. "We are incredibly lucky to have this diverse array of worlds in the outer solar system, to be able to give us so much information about the different types of evolution that can happen for these kinds of planetary bodies with an ocean."

Extraterrestrial Seashores

In 1609 Europa was but a twinkle in Galileo Galilei's eye when he aimed a homemade telescope at Jupiter and spotted several smaller dots of light. After plotting their motions, Galileo correctly surmised that the quartet were not distant background stars but Jupiter's most noteworthy lunar companions.

Now, four centuries later, Europa, Io, Ganymede and Callisto—known as the Galilean moons—are challenging stale conceptions about where clement, life-friendly conditions can exist. For a time, scientists thought habitability depended mostly on a world's distance from the radiant warmth of its star; they also assumed the outer solar system was a frigid domain that for eons had been bereft of much geological activity.



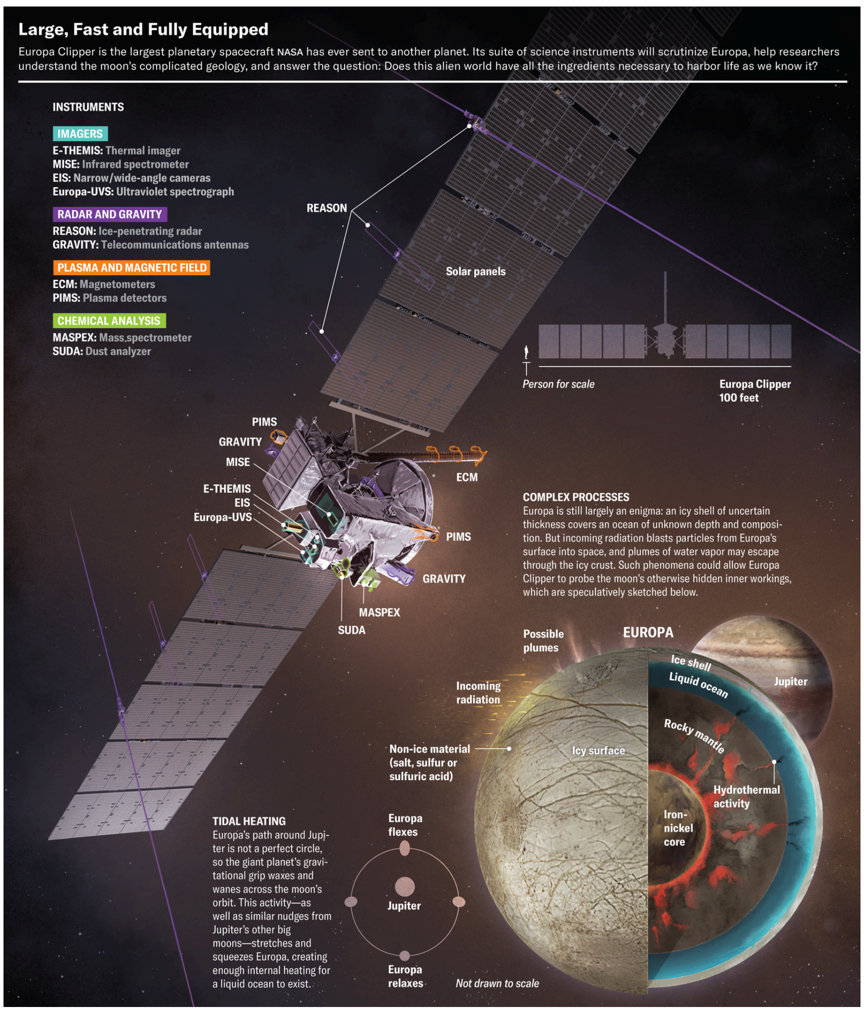
Europa (*rightmost orb, next to neighboring moon Io*) is scarcely noticeable in this Jupiter-dominated image from NASA's Juno spacecraft, but its importance for future exploration of the outer solar system is enormous.

"It wasn't really conceivable for our first trips to the outer solar system to even think about including the search for habitable environments," says Curt Niebur, Clipper's program scientist at NASA headquarters. "It just wasn't in our worldview."

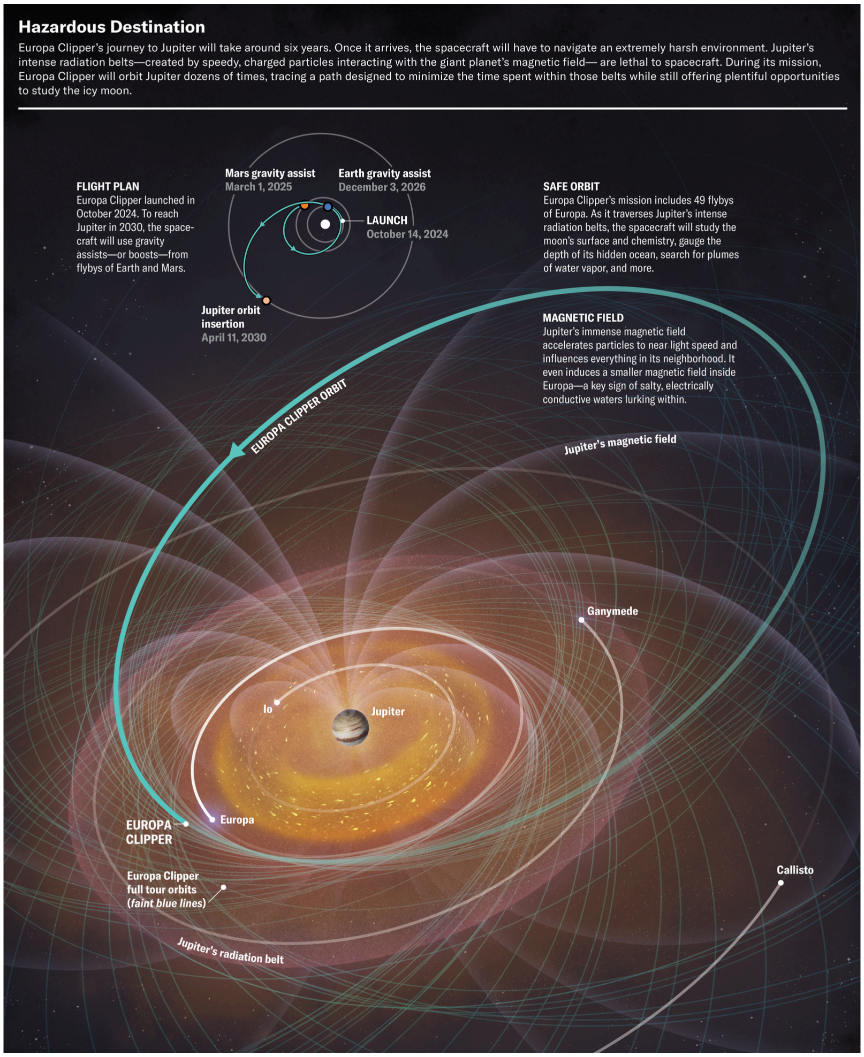
But in 1979 NASA's twin Voyager spacecraft swept by Jupiter and revealed "strange new 'worlds' of fire and ice"—ongoing volcanic eruptions on Io, terrains on Ganymede that turned out to vary in age by billions of years, a curiously youthful icy crust on Europa—and strange clues that, perhaps, something sloshed below.

Then, in 1995, NASA's Galileo spacecraft slipped into orbit around Jupiter to scrutinize the planet and its moons. The probe found that, warmed by gravitational interactions between Jupiter and one another, the Galilean satellites teemed with geological activity. Io was the most volcanic object circling the sun; Europa's sprightly terrain suggested something akin to plate tectonics had resurfaced the moon’s frozen face and shuffled material from the surface to the depths. And the fuzzy hint of a watery interior? That sharpened into almost indisputable evidence for a buried, global, saltwater sea—albeit one of unknown depth—held within a frosty shell of unknown thickness.

Now, based on those observations and studies of Saturn’s oceanic moons, it seems that a world’s biological potential does not depend solely on its distance from its sun—and maybe not even on sunlight at all, if the lessons we’re learning about life around hydrothermal vents and our planet’s other dark nooks are applicable to alien worlds as well.



Matthew Twombly



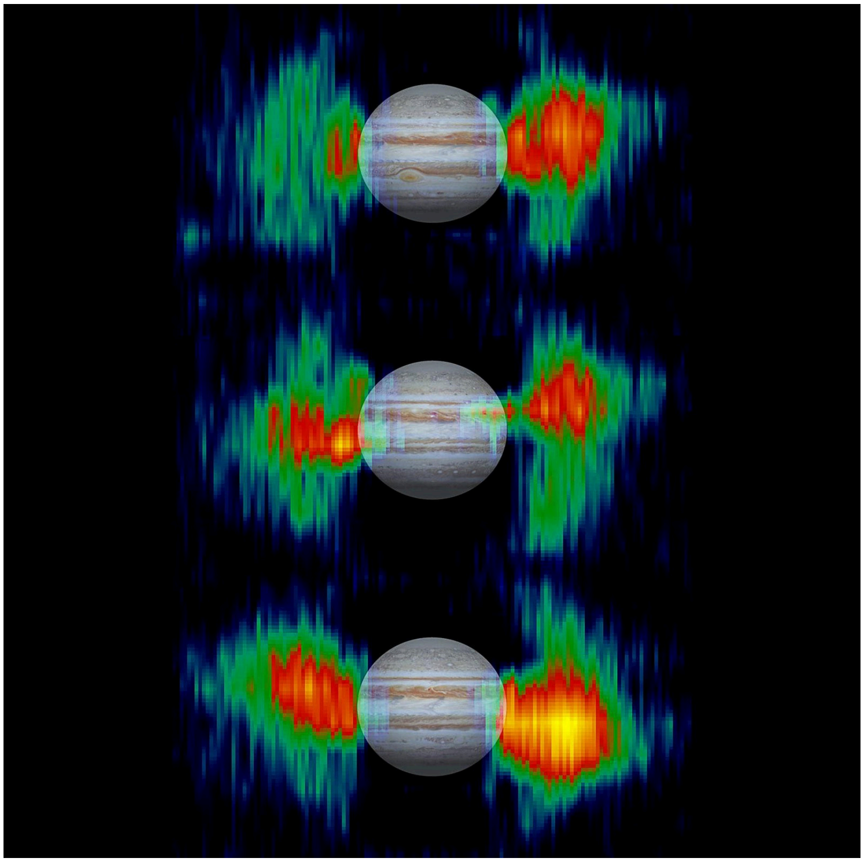
Matthew Twombly

"It hasn't been long that we've known there are oceans out there, and so I think it did take a while to fully appreciate the implications," Turtle says. "And now one of the key areas of scientific interest is habitability—from an astrobiological perspective, how large is the habitable zone around stars?"

Building on years of advocacy from planetary scientists, in 2011 a high-level expert committee that defines NASA's science priorities recommended focusing on a large-scale mission to study Europa and its ocean, labeling the moon as "one of the most important targets in all of planetary science." Until then, the bulk of NASA's astrobiology funding had focused on Mars—a world that is almost certainly sterile today (at least on the surface) but that may have hosted life some three billion to four billion years ago in its warmer, wetter past. Finding room for other worlds within the relentless drumbeat for Mars, a planet right next door, had proved challenging. But the 2011 directive infused momentum into a project that had been quietly coalescing for years: a dedicated Jupiter-Europa mission, conceived by Pappalardo and others.

With the help of planetary science advocacy groups and a crucial assist from former Congressman John Culberson of Texas—himself a Europa aficionado, well versed in the scientific literature and passionate about finding alien life—the mission that eventually became Europa Clipper got the green light from NASA in 2015. Then the team began designing the spacecraft, plotting its trajectory and building the instruments. “The search for life beyond Earth has been a lifelong passion of mine for the sake of truly the entire world’s understanding of who we are in the universe,” Culberson says. “And I knew it in my heart, knew that every successful space mission needs a champion—someone to champion funding and ensure that NASA completed the mission as the science community intended. So that was my mission.”

Culberson was there when Clipper launched on October 14, alongside NASA leadership on a balcony at Kennedy Space Center. He used large image-stabilizing binoculars to watch the spacecraft’s ascent. “It was an immensely gratifying, overwhelming moment that is the result of a huge team effort,” he recalls. “I was very privileged to be one of the spark plugs that helped make it happen.”



Three views of Jupiter's sprawling and deadly inner radiation belts, based on data from NASA's Cassini spacecraft. Each view comes from a different point in the giant planet's 10-hour rotation, revealing how the seething, spacecraft-frying emissions change over time.
NASA/JPL

The final mission that launched isn't much like early concepts. But Europa Clipper is the largest spacecraft yet built for interplanetary exploration: a 7,145-pound probe that, with its giant solar panels unfurled, has a wingspan exceeding 100 feet. It carries world-class cameras, a magnetometer, a surface dust analyzer, and the most capable mass spectrometer—which ingests molecules to determine their composition and origin—ever flown.

"The one thing that we never doubted was that this was going to be worth it," Niebur says. "This is an epic mission. It's a chance for us to explore not a world that might have been habitable billions of years ago but a world that might be habitable today, right now." It's also a mission that, despite many fateful escapes from near-death experiences during its long incubation, almost succumbed to a potentially fatal last-minute plot twist.

A Lethal Challenge

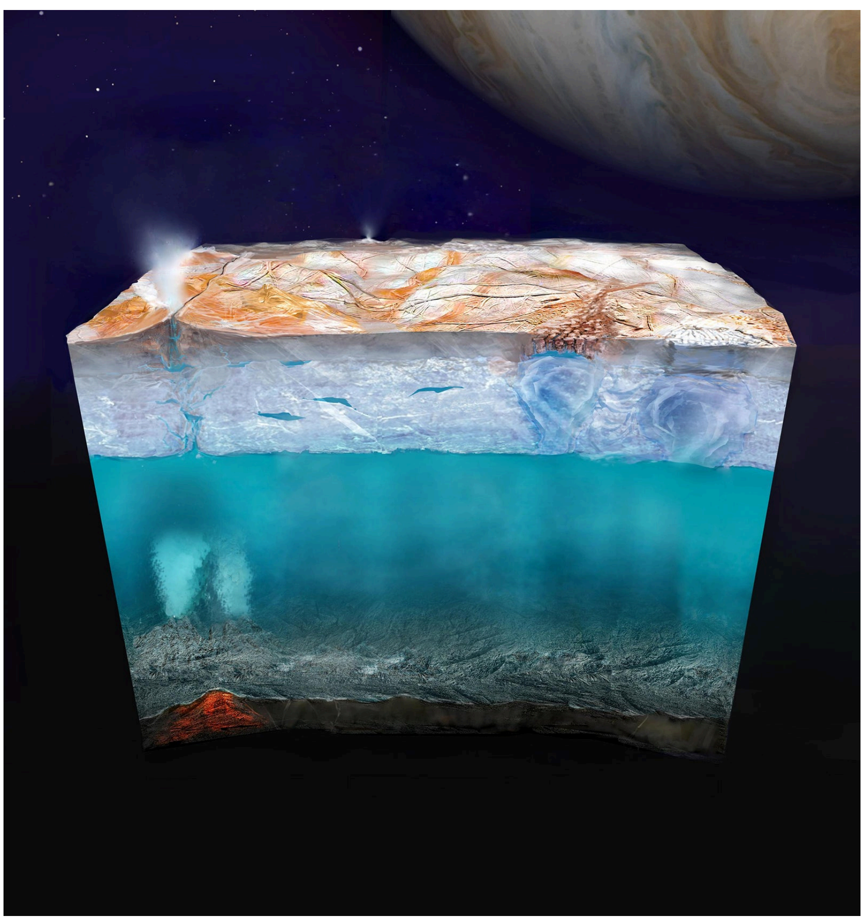
In 1959, two years before he came up with his eponymous framework for estimating the prevalence of life in the cosmos, astronomer Frank Drake aimed a radio telescope at Jupiter and detected the unmistakable signature of high-speed electrons tracing twisted pathways along magnetic field lines. Called synchrotron radiation, the signature exists because Jupiter's magnetic field is strong enough to accelerate charged particles to near light speed. The implication of Drake's observation was undeniable: massive, intense radiation belts swaddled the planet, effectively forming a kill zone for unshielded spacecraft. "Jupiter's magnetic field is 20,000 times more powerful than Earth's. It's basically a giant particle accelerator," says Jordan Evans of JPL, Clipper's project manager.

Every spacecraft destined to explore the Jupiter system is specially designed to endure (at least for a time) those lethal belts. Europa Clipper was no different, as its lunar destination boasts an intense radiation environment. But at a meeting in May 2024, shortly before Clipper was scheduled to ship to Florida, NASA engineers learned that some of the radiation-hardened circuits onboard the spacecraft were unexpectedly vulnerable. The information came from another government agency that had purchased the same parts from the same German supplier. Called metal oxide semiconductor field-effect transistors, or MOSFETs, the weakened parts are transistors that basically act as toggle switches. And this batch of MOSFETs degraded under lower radiation doses than promised—doses so low, in fact, that it was questionable whether Clipper could survive long enough to deliver the observations the team had dreamed of for decades.

"I was devastated," Evans says, recalling that day in May. "It was hard to imagine a path forward. But then you take a step back, and you start to methodically think through things."

Within a day of learning about the problem, a team got to work on it. Soon they had identified more than 1,000 faulty MOSFETs onboard Clipper. The transistors were distributed across the spacecraft and integrated into each instrument system; they were also in the now sealed electronics vault, a specially shielded compartment that is like the nerve center of the entire operation. The mission was in peril. And there was no time to delay: if the spacecraft stayed in California at JPL so the team could replace the faulty parts, it would miss its launch window and might never leave Earth. “I was having nightmares every night. I really was,” Pappalardo says. “It was like our spacecraft was sick, and we didn’t know if we would make it. It was awful.”

Betting on success, JPL sent Clipper to the Kennedy Space Center anyway. And over the summer, worried scientists and engineers worked days, nights and weekends to devise a solution to a vexing problem they hadn’t even created. By the end of August they had a fix.



What lies beneath Europa's frosty exterior? This not-to-scale artist's concept shows one possibility: a deep, global saltwater ocean, surmounted by a sizable crust of ice and with an underlying rocky core. Energy and nutrients may well up from below via hydrothermal vents on the seafloor or could trickle down from above via convective processes within the crust. Plumes of material may vent from the surface into space, sourced either directly from the ocean or from liquid-water reservoirs trapped within the crust.
NASA/JPL-Caltech

Rather than replacing each faulty part or modifying the observation plans, the spacecraft would fly as planned. It would follow its charted sequence of 21-day orbits around Jupiter, circling the giant planet 80 times. At most, it would spend one day during each orbit within the radiation belts. For the rest of the time, when Clipper was outside the harshest radiation, the team could turn on some of the spacecraft's heaters and warm the weakened circuits, in hopes of repairing some of the radiation damage through a process called annealing—essentially a thermally induced salve that redistributes charged particles to preserve the switch's integrity.

It seemed like a miracle solution and almost too good to be true, given its forecasted minimal impacts on Clipper's science. "I started off devastated, and then by the time all was said and done," Evans says, "I was humbled. I was humbled by what the team was able to accomplish."

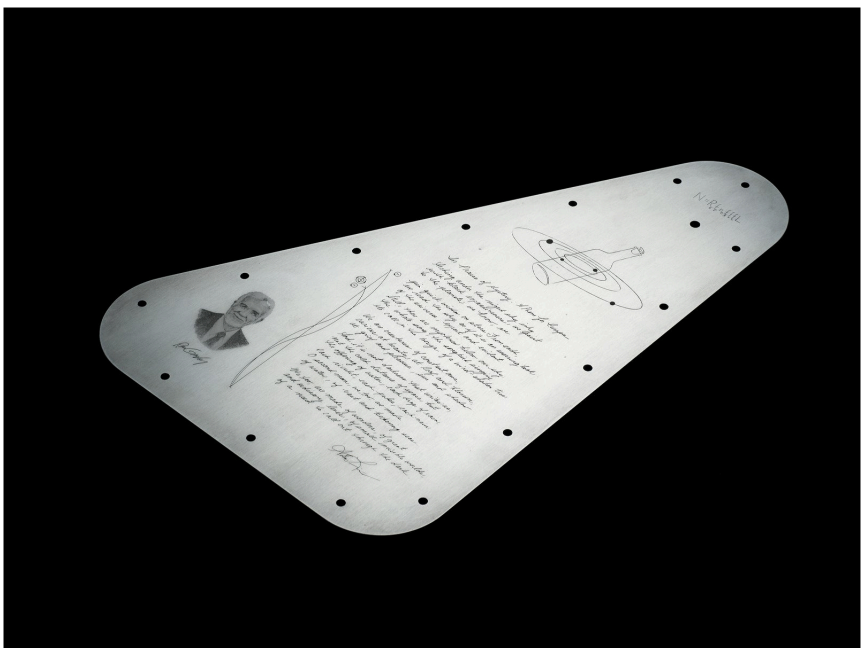
Understanding an Ocean World

As Clipper swoops by Europa, its nine science instruments will be trained on the moon, seeking to understand how it all works. They'll make detailed maps of the surface. They'll gauge the ice shell's thickness and learn whether it contains lenses of seawater, much like Earth's Antarctic ice cap. They'll remotely study the ocean underneath, which could be in contact with a rocky, mineral-rich seafloor. And they'll study the composition of the moon's surface, which could reveal more about the concealed ocean and the chemistry that might power alien ecosystems.

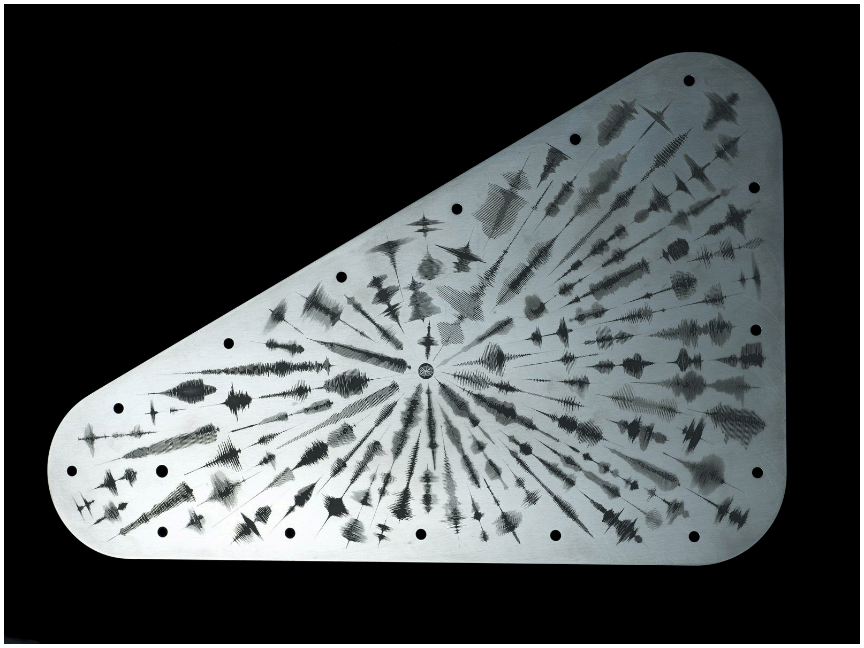
An interactive 3D view of Europa Clipper’s vault plate. Spin the digital model to see the plate’s compendium of Earth languages, a poem for Europa, a version of the iconic Drake equation and more. NASA/JPL-Caltech

“If we go there and we find water and energy and chemistry, that opens up a whole realm of questions,” Nicola Fox, NASA’s chief of science, said during a prelaunch briefing. “If we go there and we find no water, no energy and no chemistry, that also opens up a whole wealth of questions—why did we think this? And why is it not there?”

In other words, if the clarion call of Europa is nothing but a siren song, how could scientists have been led so horribly astray? (No one expects that will be the case, although as all good, cautious scientists do, they’ll wait to see the evidence.)



NASA/JPL-Caltech



Back (*top*) and front (*bottom*) views are shown of Europa Clipper's vault plate, which is engraved with poetry, illustrations, and other messages from Earth.
NASA/JPL-Caltech

As the spacecraft flies, it will also look for any signs of Europa's plumes—tentative puffs of water vapor first described in 2013 that would be smaller, more subtle versions of the energetic geysers erupting from Saturn's moon Enceladus. According to the mission's lore, those plumes are part of the glue that sealed the deal on Clipper; if the spacecraft got lucky, it could fly through a plume and directly sample the stuff of Europa. And although NASA is not billing Clipper as a life-detection mission, flying through a plume could prove otherwise—but sniffing out signs of life hinges on several unlikely events.

"There are a lot of ifs, right?" Pappalardo says. "If there are plumes, if plumes are connected to an ocean, if that ocean is rich enough in life—and therefore the mass spectrometer could get enough of a sample—then it could look at the pattern of organics, and we could try to infer whether that signature might point to biotic processes. It's not impossible, but it's a very low-probability event."

Messages in a Bottle

Clipper will, if nothing else, provide some ground truthing for the idea that when it comes to the rules of life, a world's distance from its star is far from the only thing that matters. And understanding the fundamentals of habitability is crucial for filling in the values of the Drake equation—a framework, devised by the same astronomer who inferred the presence of Jupiter's radiation belts, that has guided the search for life beyond Earth since the early 1960s.

These questions, Pappalardo says, "really bring me back to [Drake's] class"—an undergraduate astronomy course at Cornell University that Pappalardo took in the spring of 1984—and "all these things that we were on the doorstep of being able to know. I think about how far we've come in the direction that he was pointing. And it wasn't a finely tuned direction; it was a broad direction to go out and explore and search," he says. "And we're doing it. It just takes time."

In the grandest sense, Drake's fingerprints—and his willingness to unabashedly ask big questions about alien life—are all over Clipper's mission. He relished the chance to observe Jupiter and its moons until he was in his 90s, often gazing at the planet as it rose above the beloved redwood trees that ringed his home in the hills outside Santa Cruz, Calif. But Drake (better known to me as Dad) didn't live to see Europa Clipper launch. He died in 2022. In the 60 years since Dad wrote the formula we now use to confront our apparent cosmic solitude, the field of astrobiology has emerged and matured. Clipper's lead scientists, many of whom started their careers in the 1970s or 1980s as graduate students or postdocs on Voyager or Galileo, are now at the helm. And the next generation of leading planetary scientists, many of whom weren't even born when we lobbed our first probes toward the outer solar system, are now working on Clipper.

"It's always been part of the arc, if you will," Turtle says. "One of the things on Europa Clipper and on Dragonfly"—NASA's upcoming mission to Titan—"that we take very seriously is this opportunity and responsibility to bridge the generations."

An artist's concept of NASA's Europa Clipper spacecraft swooping over Jupiter's icy ocean-bearing moon Europa, a hot spot in humanity's epochal search for alien life.
NASA/JPL-Caltech

Time, it seems, is the resource that exploring the outer solar system most requires. Every Clipper team member knows this mission could be their fleeting, once-in-a-lifetime chance to get a close look at Europa. Because when it comes to the outer solar system, as a scientist, "it really is an acceptance that you are a piece of something greater than yourself," Niebur says. "You have to be willing to contribute and commit to something that is bigger than you, something that is going to go on longer than you." And so, the Clipper team decided to commemorate this first voyage from one ocean world to another.

Sealing the spacecraft's vault—its nerve center—is a plate forged from tantalum metal. On the front of it, facing the stars, is a visual representation of "water" spoken in 103 languages. On the inside, facing the spacecraft's beating heart, are more personal reflections. One is a poem by former U.S. poet laureate Ada Limón that describes the watery ties binding humanity, Europa and Earth. Another is a portrait of Ron Greeley, a planetary scientist whose leadership helped to make Clipper what it is.

And at the very top of the plate is the Drake equation, rendered in Dad’s handwriting.

Unlike other messages we’ve sent into the stars, Clipper’s tidings will go only as far as the Jupiter system. When the spacecraft bearing our dreams and inscriptions ends its mission, it will crash into Ganymede, where any hitchhiking Earthly microbes are unlikely to contaminate that moon’s lifeless surface. There the vault plate and its records of humanity will end with the mission—in a kind of bittersweet finale that will keep Europa, with its promise of extraterrestrial life, safe for future generations to explore.

Nadia Drake is a freelance science journalist who specializes in covering space science and space exploration. She is a former contributing writer with *National Geographic* and was the interim physics editor at *Quanta* magazine. Her work has appeared in, among other publications, the *New York Times*, the *Atlantic* and *Scientific American*, for which she covered NASA’s Artemis I mission.

---

https://www.scientificamerican.com/article/nasas-europa-clipper-spacecraft-aims-for-jupiters-most-intriguing-moon

| Section menu | Main menu |

Animals

- ## Comb Jelly with Two Butts Is Actually Two Individuals Fused Together
  Two injured sea creatures merged to form a “Franken-jelly”
- ## These Hornets Can Thrive on Just Alcohol without Getting Buzzed
  Social wasps can hold their liquor

Comb Jelly with Two Butts Is Actually Two Individuals Fused Together

Two injured sea creatures merged to form a “Franken-jelly”

By Elizabeth Anne Brown edited by Sarah Lewin Frasier

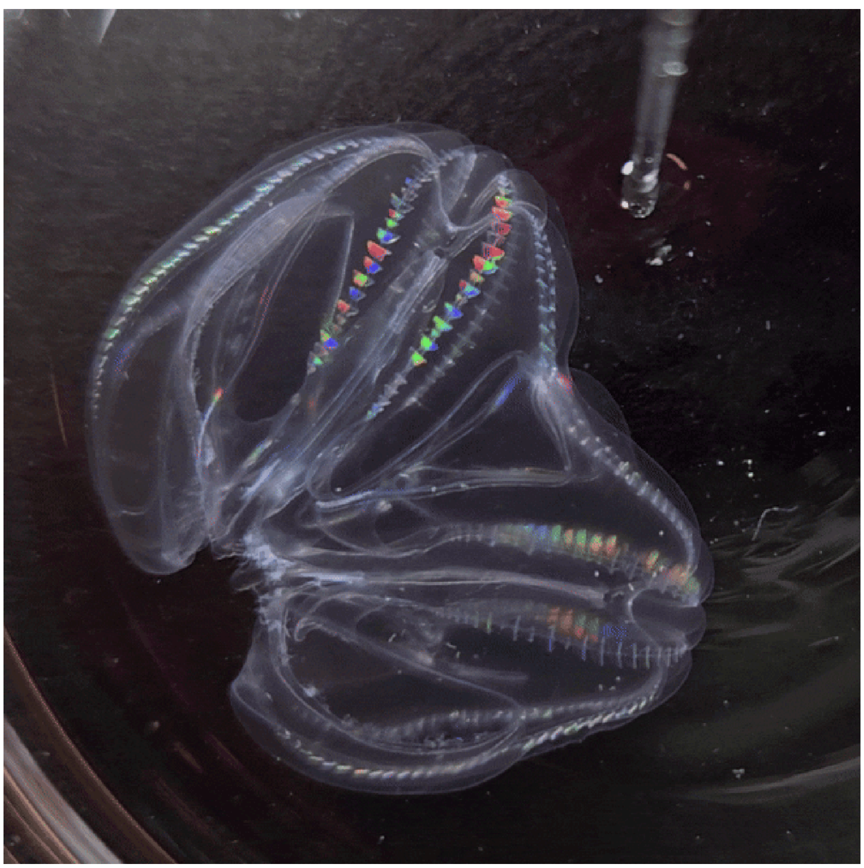
Two comb jellies become one living creature.
Mariana Rodriguez-Santiago (CC BY-SA)

Researchers knew something strange was afoot at the Marine Biological Laboratory in Woods Hole, Mass., when they spied a ctenophore, or comb jelly—a gelatinous sea creature that resembles a jellyfish—with two butts.

Closer examination revealed that the jelly with the double derriere had recently been two separate “sea walnut” comb jellies (*Mnemiopsis leidyi*). After sustaining injuries while being collected the previous day, the comb jellies had fused overnight in the researchers' tank to become one creature joined at the midbody.

The union was extensive, write Kei Jokura, a biologist at the University of Exeter in England and at Japan's National Institutes of Natural Sciences, and his colleagues in a paper published in *Current Biology*. When the scientists poked one side, both bodies flinched, suggesting that the two nervous systems had joined.

This team wasn't the first to discover comb jellies' spooky fusion trick. In the 1930s, at the very same research station, marine biologist B. R. Coonfield performed experiments on comb jellies that would make *Frankenstein* author Mary Shelley shudder. Perhaps the most impressive of Coonfield's cteno-monsters comprised the bodies of four individuals with the mouth, sensory organs and anus of a fifth.



Two comb jellies merge to form one creature whose formerly separate nervous systems react in sync to stimuli.

Mariana Rodriguez-Santiago ()

With 21st-century tools, Jokura and his team were able to rigorously test the process. By taking high-resolution images every second after grafting additional jellies together, the researchers found that the fusing comb jellies synchronized their respective nervous systems in just two hours. “The extent and the rapidity of that integration is pretty shocking,” says Steven Haddock, a marine biologist who studies ctenophores at the Monterey Bay Aquarium Research Institute and wasn’t involved in the study.

The researchers also determined that in the grafted jellies, food eaten by one mouth was shared between both digestive tracts. There was only one holdout of each animal’s individuality: Sea walnuts have a “transient anus,” meaning the opening appears only during defecation. Each body formed an anus and pooped, but they did not do so simultaneously.

The scientists say it’s unlikely that these animals’ fusion happens frequently in the wild because adults of the species aren’t often together. Still, the chance finding suggests that comb jellies lack allorecognition—the ability to distinguish between self and nonself within the same species.

“They’re completely okay with incorporating another animal’s tissue into their bodies,” says study co-author Tommi Anttonen, a sensory physiologist at the University of Southern Denmark.

The researchers hope comb jellies’ fusion could one day inform transplant techniques in humans. Allorecognition triggers the immune response that can lead to transplant rejections, and learning how the ctenophores’ immune system fares without it might help scientists make it easier for human bodies to accept a stranger’s organs. “Simple organisms [hold] clues to understanding our own complexity,” Jokura says, “as well as treasures that can benefit our lives.”

Elizabeth Anne Brown is a freelance science journalist based in Copenhagen, Denmark. Her work has appeared in *National Geographic*, the *New York Times*, the *Washington Post*, and many other outlets. Read more at elizabeth-anne-brown.com, and follow her on X @eabrown18

---

https://www.scientificamerican.com/article/comb-jelly-with-two-butts-is-actually-two-individuals-fused-together

| Section menu | Main menu |

These Hornets Can Thrive on Just Alcohol without Getting Buzzed

Social wasps can hold their liquor

By Rachel Berkowitz edited by Sarah Lewin Frasier

Alcohol works as effective fuel for this hornet species.
JossK/Getty Images

An alcohol-only diet would throw most species for a loop, but new research suggests certain hornets can live apparently unimpaired—with an 80 percent ethanol sugar solution as their sole food source.

Fruit flies, tree shrews, and many other animals naturally consume alcohol in fruits that ferment—a process that happens when yeast or certain bacteria are around to break down sugars in ripe fruit, creating small amounts of ethanol. Most animal species show signs of impairment or toxicity after consuming this substance at concentrations above 4 percent. But animal researcher Sofia Bouchebti, now at Ben-Gurion University of the Negev in Israel, suspected that hornets and wasps might tolerate alcohol better or even use it as a food source. After all, the guts of these insects are known to host yeast that converts fruit sugar to alcohol. When hornets or wasps pollinate and feed, some of this yeast is passed onto plants and their fruits—playing a key role in the fermentation process.

Bouchebti turned her attention to the hornet *Vespa orientalis*, a type of social wasp. For a study in the *Proceedings of the National Academy of Sciences USA*, she and her colleagues at Tel Aviv University fed both hornets and honeybees sugar solutions containing 0 to 80 percent ethanol that incorporated a trackable carbon isotope. The researchers found that hornets' exhaled breath contained up to 300 percent more labeled carbon than the honeybees', suggesting the hornets' bodies broke down the alcohol that much faster.

> Hornets fed with 80 percent ethanol lived out their typical weeks-long lifespan; honeybees died within 24 hours.

"There's lots of energy in ethanol, and it's a great metabolic fuel," says study co-author and zoologist Eran Levin. The problem for humans and many other animals, of course, is that there are behavior and health consequences as the substance interacts with the brain and organs. But when provided with nest-building materials, the ethanol-fed hornets in the study completed construction tasks as efficiently as sugar-fed ones. When faced with an intruder, they did not delay sending the usual "back off" signals. Moreover, hornets fed with 80 percent ethanol lived out their typical weeks-long lifespan; their honeybee counterparts died within 24 hours. Still, hornets showed no preference between sugar and ethanol when given a choice. "If ethanol is more nutritious and without bad effects, shouldn't they want more? Maybe they can't taste it," Bouchebti suggests.

To distill the secret behind this metabolic mastery, study co-author and zoologist Dorothée Huchon led a hunt for genetic clues. She found that hornets possess multiple copies of the gene responsible for the enzyme that breaks down alcohol—an adaptation perhaps fueled by their relationship with yeast.

Three hornets feed on a ripe fig, which could provide naturally occurring ethanol.
Eran Levin

University of Rochester biologist James Fry says the hornets' ethanol metabolism tells an "interesting evolutionary story." But he cautions that the research methods are too different from those of other studies to directly compare ethanol resistance between species.

Robert Dudley, an insect flight specialist at the University of California, Berkeley, notes that the hornets would never encounter such high ethanol values in nature. Bouchebti says the researchers "aimed to find a maximum limit, and we still didn't find it."

Next up is examining gene expression during ethanol consumption and seeking patterns among animals known to be attracted to alcohol (some beetles and bats, for example). Dudley agrees: "A broader survey of social Hymenoptera and other insects is clearly called for."

Rachel Berkowitz is a freelance science writer and a corresponding editor for *Physics Magazine*. She is based in Vancouver, British Columbia, and Eastsound, Wash.

https://www.scientificamerican.com/article/these-hornets-can-thrive-on-just-alcohol-without-getting-buzzed

| Section menu | Main menu |

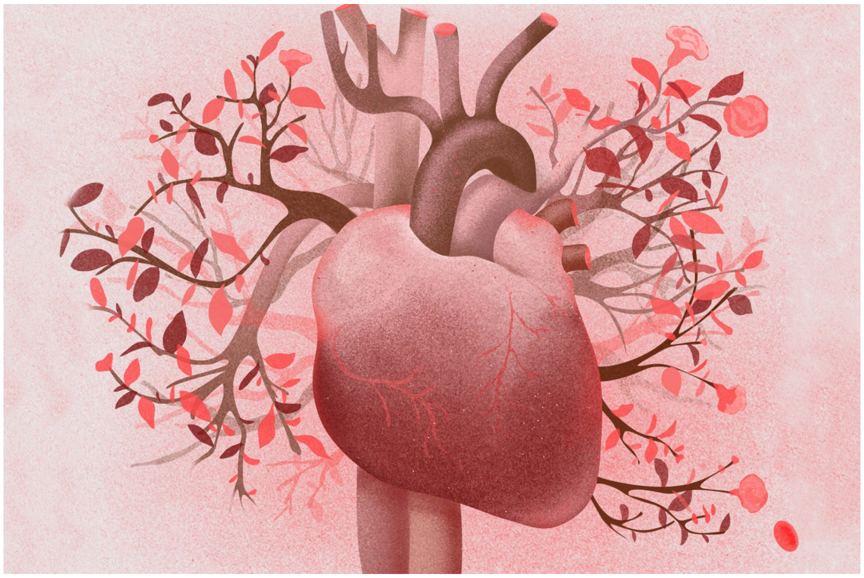
Arts

- **Poem: ‘Cardiac Knotting’**
  Science in meter and verse

Poem: ‘Cardiac Knotting’

Science in meter and verse

By John Liles edited by Clara Moskowitz



Masha Foya

Edited by Dava Sobel

The heart will have no interruption,
begins as a simple tube   (blood flow undivided)
at the middle of embryo
hurried—task of branching sufficient blood
levels into all upcoming situations.   (in-roads throughout the growing body)

The heart, quick, outgrows its own
allotted cavity, and bends a branch right   (every time)
and back—pivots into
the cardiac loop, plotting
pistons, to hang self-knotting,
strung-up. The blood muscle must
raise divisions. The hollow heart

now split, turns intrinsic—walling out
a partition, a pocket, a sinus to house
the pulmonary hinges—a body's
bloodlines soon become confluent   (before bringing back a breath)
to enter the heart.

When later more transitional twisting
has caused a furrow, external,
the interfacing ventricle wall will
thicken—meshwork of muscular
fetters tuck together, reach out,
near-bridge for the atrial pacemaker.
An intra-arterial hollow so self-established.   (lock and chamber)

Meanwhile, against the narrower walls
and paired opposite, loose masses
of migratory tissue   (from the mesoderm)
driven. Could linger on,
the non-particular life of a stem cell.

But here soft commotion reaching out,
endocardial cushions obstruct
the blood rush into opposite corners.
Predestined axes of embryo, peristalsis
in a pre-valved hollow—the body's
first organ to engine
an animal's ontogeny,

the heart
as it begins to beat.

John Liles is a poet, science writer and head naturalist at the Pacific Environmental Education Center in northern California. His forthcoming collection, *Bees, and After*, won the 2024 Yale Younger Poets Prize.

Astronomy

- **Fastest Known Planetary System Might Have Been Pushed by Our Galaxy’s Supermassive Black Hole**
  This blazingly fast star is shooting through the Milky Way with a planet in tow
- **Why Does the Moon Look Bigger Near the Horizon?**
  The rising moon looks huge on the horizon, but it’s all in your head

Fastest Known Planetary System Might Have Been Pushed by Our Galaxy’s Supermassive Black Hole

This blazingly fast star is shooting through the Milky Way with a planet in tow

By Jonathan O'Callaghan edited by Sarah Lewin Frasier

The Milky Way’s galactic bulge is dense with stars.
NASA, ESA, Tom M. Brown

Our solar system orbits the Milky Way galaxy’s center once about every 210 million years, cruising along at around 240 kilometers per second—a staggering rate that we don’t feel because the entire system moves at the same constant velocity. But a new study suggests we’re a cosmic slowpoke compared with one system in our galaxy that was somehow flung to a velocity of 541 kilometers a second, making it the fastest known planetary system.

“This velocity was extremely high and kind of shocking,” says University of Maryland astrophysicist Sean Terry, lead author of the study, which has been posted on the preprint server arXiv.org and submitted to the *Astrophysical Journal*. It introduces “a regime of questions about the survivability of these types of systems.”

This galactic speed demon appears to center on a red dwarf star smaller and dimmer than our sun. It’s about 24,500 light-years from Earth and some 1,500 light-years away from our galaxy’s center. Astronomers discovered the star and a suspected accompanying planet after a 2011 “microlensing” event called MOA-2011-BLG-262, when the system passed in front of a background star and warped the latter’s light.

Terry and his colleagues observed the system again in 2021 from the W. M. Keck Observatory in Hawaii. They found that its known planet most likely is a gas giant with about 29 times Earth’s mass that orbits its star at a distance between those at which Venus and Earth orbit the sun. (The system may have unseen planets as well.) The researchers also mapped the system’s position in the 2021 data relative to where it was about a decade prior, revealing how fast it traveled.

This speed suggests that it might be a hypervelocity star system, an example of a rare class of stellar objects that have been sped up by past encounters with other stars’ gravity—or even by a gravitational slingshot from the supermassive black hole at the center of our galaxy. These objects travel faster than 500 kilometers a second, and the fastest known one hurtles at more than 2,000 kilometers per second. “It’s this really exotic subset of stars,” Terry says, estimating that the system in this study more than doubled its speed after its own dramatic encounter. No previous hypervelocity stars have been found with planets, he notes.

Jessie Christiansen of the NASA Exoplanet Science Institute says the system offers clues about what worlds exist in the dense region of stars at our galaxy’s center. We don’t know if being in that galactic bulge “impacts the types of planetary systems that are formed,” she says.

The speedy system’s known planet orbits far from the zone around a red dwarf where liquid water (and therefore life as we know it) could persist on the surface. But its existence suggests planets can survive the “somewhat chaotic interaction” that occurs when stars are accelerated to immense speeds, Terry says. “This might open up a new study of the origin and evolution of planets around very high-velocity stars,” he adds.

Jonathan O'Callaghan is an award-winning freelance journalist covering astronomy, astrophysics, commercial spaceflight and space exploration. Follow him on X @Astro_Jonny

---

https://www.scientificamerican.com/article/fastest-known-planetary-system-may-have-been-pushed-by-our-galaxys

| Section menu | Main menu |

Why Does the Moon Look Bigger Near the Horizon?

The rising moon looks huge on the horizon, but it's all in your head

By Phil Plait edited by Lee Billings & Clara Moskowitz

Why does the moon seem to loom so large when it's near the horizon? The answer will almost certainly surprise you.
Grant Faint/Getty Images

I remember watching the full moon rise one early evening a while back. I first noticed a glow to the east lighting up the flat horizon in the darkening sky, and within moments the moon was cresting above it. It looked huge! It also seemed so close that I could reach out and touch it. I gawped at it for a moment and then smiled. I knew what I was actually seeing: the moon illusion.

Anyone who has seen the moon (or the sun) near the horizon has experienced this effect. The moon looks enormous there, far larger than it does when it's overhead. I'm an astronomer, and I know the moon is no bigger on the horizon than at its zenith, yet I can't *not* see it that way. It's an overwhelming effect. But it's not real.

Simple measurements of the moon show it's essentially the same size on the horizon as when it's overhead. This really is an illusion.

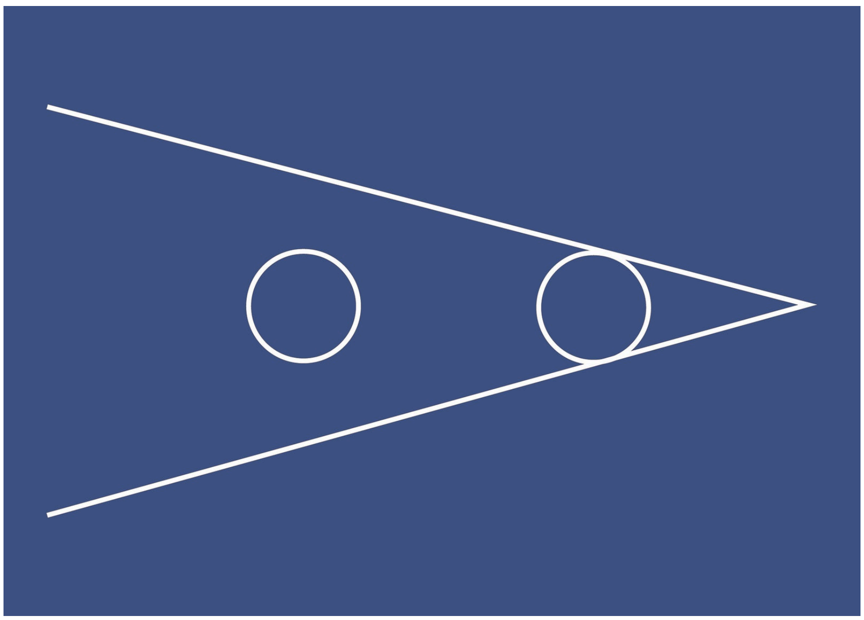
It's been around a while, too: the illusion is shown in cuneiform on a clay tablet from the Assyrian city Nineveh that has been dated to the seventh century B.C.E. Attempts to explain it are as old as the illusion itself, and most come up short. Aristotle wrote about it, for example, attributing it to the effects of mist.

This isn't correct; the illusion manifests even in perfectly clear weather. A related idea, still common today, is that Earth's air acts like a lens, refracting (bending) the light from the moon and magnifying it. But we know that's not right, because the moon is measurably the same size no matter where it is in the sky. Examining the physics of that explanation shows that it falls short as well. In fact, although the air near the horizon does indeed act like a lens, its actual effect is to make the sun and moon look squished, like flat ovals, not to simply magnify them. So that can't be the cause, either.

Another common but mistaken explanation is that when the moon is on the horizon, you subconsciously compare it with nearby objects such as trees and buildings, which make it look bigger. But that can't be right, because the illusion still occurs when the horizon is empty, such as at sea or on the plains. Also, if you're in a city and see the moon high in the sky between buildings, it appears to be its normal size, so this can't be the explanation.

Yet the moon *does* look bigger on the horizon. Experiments in the 1950s and 1960s by cognitive psychologists Irvin Rock and the late Lloyd Kaufman showed that people perceive the moon as much larger on the horizon—sometimes as much as three times bigger than when it's overhead. If the visual cues to the position of the moon go away, however, the illusion vanishes. Looking at it through a paper towel tube, for example, makes it look the same size no matter where in the sky it is.

So what's the cause? Like with so many things in science, two effects are at play. One is the Ponzo illusion (not to be confused with a Ponzi scheme, an investment illusion). It's a very simple yet overwhelming illusion. In its simplest forms, two parallel horizontal lines of equal length (like an equal sign) are placed between two lines that are nearly vertical but converge slightly near the top. When you look at the horizontal lines, the top one appears longer even though they're the same length. It's almost impossible not to see them as unequal.



An illustration demonstrating a variation of the Ponzo illusion.
Science History Images/Alamy Stock Photo

Variations abound, but all rely on tricking the brain by using perspective. We interpret the two nearly vertical lines not as leaning toward each other but as parallel yet converging in the distance, like railroad tracks. This effect, in which lines in two-dimensional space appear to meet at a point called the vanishing point, is often used in art to portray relative distances.

The key is that the two horizontal lines are the same length. Our brain sees that, but it also perceives the top line as farther away. If it's farther away and the same apparent size, according to our brain's messed-up logic, it must be physically larger than the lower line, so it appears bigger. This is very similar to the wonderful

Ames room illusion, in which distorted walls and angles make two people of equal height appear to have wildly different sizes depending on where in the room they stand.

The Ponzo illusion is the heart of the moon illusion, but there's more to it. If I were to ask you what shape the sky over your head appears to be, you'd probably say it's a hemisphere—a half of a sphere. But we don't actually perceive it that way. If we did, you'd see the zenith, the point directly over your head, as the same distance from you as any point on the horizon. Yet experiment after experiment shows that's not the case: we see the horizon as farther away and the sky as more like a flat-bottomed bowl overhead, with the zenith closer to us.

That's not too surprising, actually. If you're outside on a cloudy day, the clouds over your head really *are* closer to you; they might be five kilometers above you, but the ones near the horizon can be more than 100 kilometers distant. So we've evolved to think of the sky as flattened that way.

Now put the two together: When the moon is on the horizon, we think it's farther away. But the moon's size in the sky isn't actually changing, so our brain interprets this as the moon looking huge. When it gets higher in the sky, we perceive it as being closer, so it winds up looking smaller.

Amazingly, this explanation, at least in part, was determined around 1,000 years ago. The brilliant medieval philosopher Ibn al-Haytham studied vision and optics and made major contributions to both. He examined the moon illusion and correctly noted that an object of fixed size will look smaller if it's perceived as closer and will look bigger if it's farther away. He thought intervening objects such as trees or buildings made the moon appear closer and therefore bigger, which we now know isn't correct. But he had the basic idea down, and he came closer than many who lived much later.

Misconceptions about the moon illusion still abound, and like so many myths, they probably won’t go away no matter how much people like me write about them. But in this case, we do know the right explanation, and it’s one of the paradoxes of science: we know why this illusion occurs, but it stubbornly persists.

Phil Plait is a professional astronomer and science communicator in Virginia. His column for *Scientific American*, The Universe, covers all things space. He writes the *Bad Astronomy Newsletter*. Follow him online.

---

https://www.scientificamerican.com/article/why-does-the-moon-look-bigger-near-the-horizon

| Section menu | Main menu |

Book Reviews

- ## Book Review: This Relationship Shaped Rachel Carson’s Environmental Ethos
  The connection between queer love and the power to imagine a more sustainable future
- ## Book Review: The Surprising Comeback of Our Least Appreciated Sense
  The nose knows more than we thought
- ## Book Review: In a Drowning New York City, Can All of Natural History Be Saved?
  In the often-gloomy genre of climate fiction, a new novel hits a high-water mark for its empathy

---

| Next section | Main menu | Previous section |

Book Review: This Relationship Shaped Rachel Carson's Environmental Ethos

The connection between queer love and the power to imagine a more sustainable future

By Brooke Borel edited by Jen Schwartz

Xinyue Chen

NONFICTION

Rachel Carson and the Power of Queer Love

by Lida Maxwell.
Stanford University Press, 2025 ($25)

On a summer night in the mid-1950s, two women lay side by side on Dogfish Head, a spit of land on Maine's jagged coast where a river meets the ocean. They took in the dazzling stars, the smudged filaments of the Milky Way, the occasional flash of a meteor. One woman was Rachel Carson, who would become well known for her book *Silent Spring* and its galvanization of the modern environmental movement; the other, Dorothy Freeman, was Carson's married neighbor. The two had been drawn together from the moment they met in 1953 on Southport Island, Maine, and remained close until 1964, when Carson died of cancer. It was Freeman who scattered Carson's ashes.

The scene on Dogfish Head may sound romantic, and Lida Maxwell's new book, *Rachel Carson and the Power of Queer Love*, argues that it indeed was. Maxwell, a professor of political science and of women, gender and sexuality studies at Boston University, explores the intimate bond between Carson and Freeman by drawing, in part, from a trove of personal letters. The book's message is that the relationship holds a lesson for our modern climate crisis, especially for those of us willing to find meaning outside our culture's dominant narratives.

The correspondence is telling. Carson professes strong feelings after just a few letters ("Because I love you! Now I could go on and tell you some of the reasons why I do, but that would take quite a while, and I think the simple fact covers everything …"). The two call each other "darling" and "sweetheart." During the stretches they spend physically apart, they express what can easily be read as queer yearning, as when Freeman writes: "How I would love to curl up beside you on a sofa in the study with a fire to gaze into and just talk on and on."

There is also reference to the hundreds of letters we'll never read because the two women burned them, perhaps in that same fireplace. As Martha Freeman, Dorothy's granddaughter, told Maxwell, "Rachel and Dorothy were initially cautious about the romantic tone and terminology of their correspondence."

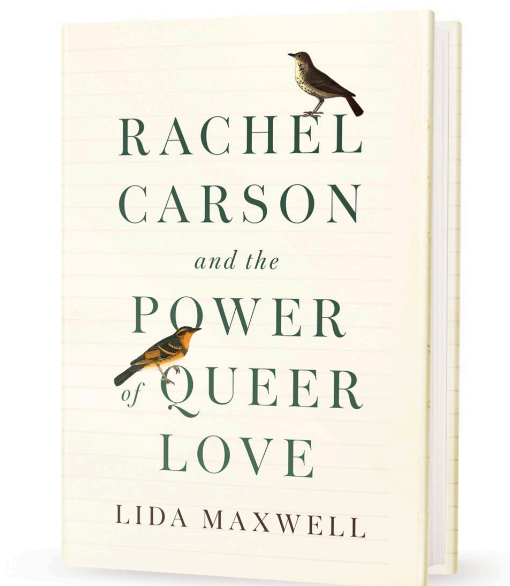
Was Carson a lesbian? The answer has long been the source of speculation. It's impossible to know; she's not known to have publicly identified as such. To Maxwell, though, this question is beside the point: "Whether or not their love was 'homosexual,' to use the language of the time, it was certainly queer. It drew them out of conventional forms of marriage and family and allowed them to find happiness where their society told them they weren't supposed to: in loving each other and the world of nonhuman nature."

Queer love is a rejection of what Maxwell calls "the ideology of straight love," or the pursuit of "the good life" through marriage, buying and decorating a house, having and raising children, and participating in the treadmill of consumer culture to keep it all running. Because Carson and Freeman's love was queer, Maxwell argues, they had no template with which to explore it. Instead they created a new language, expressed through a shared love of nature: the song of the veery, the Maine tide pools, the woods between their houses. This avenue for connection and meaning making, Maxwell argues, is what made Carson's *Silent Spring* possible—it changed her from a writer who captured the wonder of nature to one advocating to save it.

How does this apply to the climate crisis? "As perhaps is obvious," Maxwell writes, "the tight connection of the ideology of straight love with consumption is also bad for our climate because it ties our intimate happiness to unsustainable ways of living." To truly achieve meaningful climate policy, she continues, we'll need to expand our "visceral imaginary of what a good life could be." The queer version embraces a "vibrant multispecies world" where we seek "desire and pleasure outside of the ideologies of capitalism and straight love." These specific points, made throughout the book, are at times repetitive and can feel didactic.

Some readers, particularly straight readers, may bristle at all this. After all, plenty of people who don't identify as queer opt out of consumerism and fight climate change. Straight people can reject the heteronormative story; queer people are not immune to it. But the point of the book isn't that we should take individual action—it's about broader structures and narratives. As a queer woman who spent a decade in a heteronormative marriage, I know how seductive the call of that particular "good life" can be; I also know the liberation of building something new. Max well's book holds lessons for all readers about acknowledging, and then escaping, the structures that ensnare us.

Carson and Freeman found the way through their decidedly queer, deeply romantic, long-lasting love. Even when they were apart, they imagined themselves together. As Freeman writes during one of these spells: "You and I have been walking on the Head in the moonlight. Do you remember the night we lay there in that lovely light? I told you you looked like alabaster. You did. How happy we were then."



Brooke Borel is an award-winning journalist and a features editor at *Undark*.

---

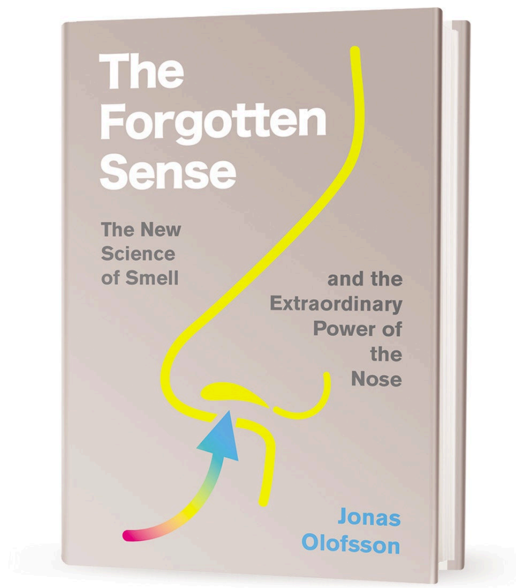
https://www.scientificamerican.com/article/book-review-this-relationship-shaped-rachel-carsons-environmental-ethos

| Section menu | Main menu |

Book Review: The Surprising Comeback of Our Least Appreciated Sense

The nose knows more than we thought

By Dana Dunham edited by Jen Schwartz



The Forgotten Sense: The New Science of Smell and the Extraordinary Power of the Nose
by Jonas Olofsson.
Mariner, 2025 ($28)

As COVID spread across the world in early 2020, people began to report losing their sense of smell. Public health organizations were focused on tracking the spread of the virus based on more traditional symptoms of respiratory illness such as cough and fever, and the loss of smell was initially treated more like a curious anecdote than an important signal. But olfaction researcher Jonas Olofsson knew better: “I like to think I helped protect the public when I repeated to journalists in an almost parrot-like manner that readers and listeners who suddenly lose their sense of smell should isolate themselves immediately," he writes in his new book on olfaction's central role in our lives.

Olofsson is accustomed to defending the significance of smell, which many people seem to take for granted. For evidence, he refers to surveys that asked Americans to choose whether their sense of smell or their pinky toe was more valuable. Half chose the toe. In a 2021 follow-up survey, only 15 percent of responders were on team toe, but Olofsson contends that we still don't adequately understand or appreciate the "special intelligence of the nose."

Smell hasn't always been the underdog of the senses. In previous centuries, odors were integral to everything from spirituality to morality to medicine: burnt offerings reached the gods by wafting to the heavens, medieval devils were thought to reek of flatulence, and doctors used scents to both diagnose and cure. In our current, screen-saturated society that depends on vision and hearing, smell might seem like an evolutionary relic. But although our sense of smell may be primal, it is not primitive.

Olofsson argues that instead of passively reacting to odor molecules in isolation, our olfactory brain works with other brain regions to interpret smells. "The sense of smell does not act on its own," he says, "but is smarter than that—it takes in all the cues in the environment and assesses them using all our accumulated knowledge."

Using this "cognitive perspective" on olfaction to guide readers through the current landscape of smell, Olofsson addresses the complex pheromone debate, the "swamp" of research on aromatherapy, e-noses and other digital smell technologies, and his own successes with smell-based brain training. His work reveals how this ancient and unassuming ability holds profound untapped potential to enrich our lives.

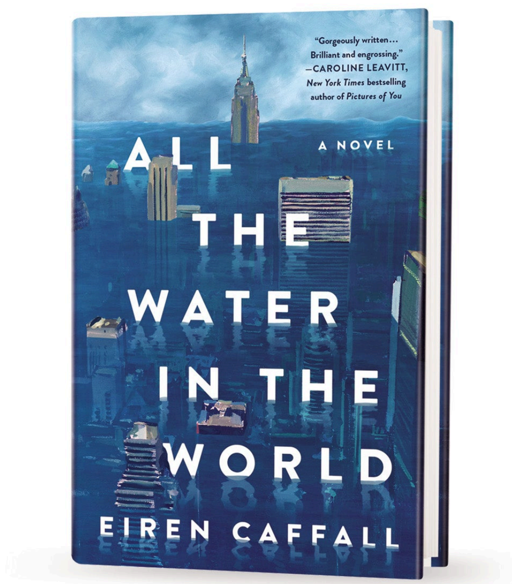
Dana Dunham is a writer and editor based in Chicago.

https://www.scientificamerican.com/article/book-review-the-surprising-comeback-of-our-least-appreciated-sense

Book Review: In a Drowning New York City, Can All of Natural History Be Saved?

In the often-gloomy genre of climate fiction, a new novel hits a high-water mark for its empathy

By Alan Scherstuhl edited by Jen Schwartz



All the Water in the World: A Novel
by Eiren Caffall. St. Martin's
Press, 2025 ($29)

Eiren Caffall's lyric yet gripping first novel centers, as its title suggests, on life after a great flood, with a young woman known as Nonie canoeing over a drowned New York City and up the Hudson River toward the high ground of the Berkshires. Fittingly for the genre of postapocalyptic American fiction, Caffall offers grand visions of the world made strange—Nonie sits in the bow of a canoe, watching the water for "snags" such as the tops of streetlamps or the trees of Central Park—and stirs suspense in encounters with the various settlements and wildlife along the route.

Like the cultural ephemera of Emily St. John Mandel's *Station Eleven*, the seeds in Alison Stine's Road Out of Winter or the child in the womb in Louise Erdrich's *Future Home of the Living God*, a symbol of hope has been carried from the book's fallen civilization to take root in whatever comes next. This time that symbol is natural history itself, as set down in a journal by former scientists at New York's American Museum of Natural History. At the novel's start, in a city that's not yet fully flooded, those scientists and their families have formed a makeshift society on the museum's roof. To protect physical exhibits that may not survive, they've taken pains to preserve the knowledge those exhibits represent in a logbook that, when the waters rise, will be carried in Nonie's pack.

Like her scientists and survivors, Caffall relishes the museum and its treasures. Her vision of the institution stripped bare by desperate caretakers unsettles and moves. The novel is often dark, steeped in grief and uncertainty, concerned with practicalities such as infections and finding antibiotics. Caffall favors a briskly ruminative approach with short, reflective chapters about what life after the end feels like. (Violence, including threats of sexual assault, occurs mostly off page.) But that's not to suggest that *All the Water in the World* neglects the beauty and wonder of Nonie's adventure. The scene of her family floating away from the museum in an Indigenous canoe from an old exhibit is tense, delightful and rich with resonance.

Alan Scherstuhl is a reviewer and editor who covers books for a variety of publications and jazz for the *New York Times*.

---

https://www.scientificamerican.com/article/book-review-in-a-drowning-new-york-city-can-all-of-natural-history-be-saved

Culture

Ape Jokes, Vagus Nerve Hopes and a Mystery Planet

The searches for Planet Nine, bat viruses, life on Jupiter’s moon Europa and lucid dreams

By Laura Helmuth

Scientific American, January 2025

One of the things I enjoy most about *Scientific American* is learning about how scientists do their work—the inspirations, the questions, the insights, the collaborations, the “hmm, that’s strange” moments. Anthropologist Erica Cartmill recounts how she came to study the evolutionary origins of joking. We humans are all just great apes, no matter how fancy we dress up, and she finds that young orangutans and chimps play the same kinds of tricks and peekaboo games that we do.

Another thing I appreciate about *Scientific American* is how our writers distinguish between hope and hype. As social media becomes increasingly fractured and fast and full of misinformation, it’s more important than ever to have trustworthy publications that share the best evidence for health claims. Research on the vagus nerve is at an interesting point right now. It’s the most meandering nerve in the human body, connecting the brain with most of our internal organs. A full-spread graphic by Mesa Schumacher shows just how elaborate its influence is. Charlatans with gadgets to sell will claim that stimulating the nerve can cure whatever ails you. That’s not true ... but a growing body of evidence suggests the vagus nerve is a good candidate for treating a range of health conditions. Author Jena Pincott outlines what we know, what we don’t and what it all means.

We should know soon whether a hypothetical distant planet is orbiting at the edge of our solar system. Planet Nine (also called Planet X), if it’s really there, is five to 10 times the mass of Earth and has been distorting the paths of smaller objects. Volcanologist and science writer Robin George Andrews tracks the evidence and the growing enthusiasm among some astronomers that we’ll soon have a ninth planet to replace poor Pluto. (One of these astronomers is the person who knocked Pluto out of the planetary pantheon and is hoping for atonement.)

People can learn to control their dreams and even communicate while dreaming. Sleep researcher Michelle Carr details the dream adventures of people who have participated in research studies in her laboratory, along with tips about how to practice “lucid dreaming,” which may help some people manage nightmares and improve sleep.

Bats carry a lot of nasty viruses that don’t bother them but do endanger other species, including humans. New research explains how their odd immune systems are tied to their evolution of flight. Science writer Jane Qiu warns that deforestation and climate change make us more vulnerable to spillover pandemics. Photojournalist Doug Gimesy’s images of gigantic bats called flying foxes are gorgeous and surprisingly endearing. Read more about Gimesy in our Contributors column.

NASA's Europa Clipper mission launched on October 14, 2024, toward one of Jupiter's most intriguing moons, with a briny ocean that is one of our best chances for finding life elsewhere in the solar system. The space probe is scheduled to arrive in 2030. Science writer Nadia Drake was there for the launch, and she shares the excitement of the mission and the rich history of the search for life, which is guided in part by the work of her father, astronomer Frank Drake.

Enjoy the two new columns in this issue: a crossword by Aimee Lucido that features clues related to articles in the issue and The Science of Parenting. Please let us know at feedback@sciam.com if you have a question related to parenting that you'd like our experts to answer.

Laura Helmuth was formerly editor in chief of *Scientific American*. She previously worked as an editor for the *Washington Post*, *National Geographic*, *Slate*, *Smithsonian* and *Science*. She is a former president of the National Association of Science Writers. She is currently a member of the National Academies of Sciences, Engineering, and Medicine's standing committee on advancing science communication and an advisory board member for SciLine and The Transmitter. She has a Ph.D. in cognitive neuroscience from the University of California, Berkeley. She recently won a Friend of Darwin Award from the National Center for Science Education. Follow her on Bluesky @laurahelmuth.bsky.social

---

https://www.scientificamerican.com/article/ape-jokes-vagus-nerve-hopes-and-a-mystery-planet

Contributors to *Scientific American*'s January 2025 Issue

Writers, artists, photographers and researchers share the stories behind the stories

By Allison Parshall edited by Jen Schwartz

Doug Gimesy.
Heather Kiley

Doug Gimesy

The Next Viral Plague

Photojournalist Doug Gimesy (*above*) is a font of knowledge about flying foxes. He first photographed a colony of these fuzzy bats eight years ago in Melbourne, Australia, and soon became a rescuer who campaigned for local bans on certain types of netting and barbed wire that can trap and maim these animals. All this work was taking place within a few miles of his home. "It became an urban wildlife story," says Gimesy, whose photography focuses on conservation issues in Australia.

For this issue's story on bats and viruses, Gimesy traveled to Queensland to photograph flying foxes. He didn't have to venture far from population centers to find his subjects; the story's opening image was captured in a public park. After spotting bats in a tree, he would lie below them to await the perfect shot. "I could be there for half an hour just waiting for them to look down," he says. Flying foxes are "magnificent" but vilified mammals. "For me, to show them in their best light is important so I can hopefully get people to fall in love with them," Gimesy says.

Nadia Drake
Mission to Europa

The visceral experience of a rocket launch does not translate to TV. "It shakes the ground, it shakes buildings, it shakes you," says science journalist Nadia Drake, who witnessed the launch of the Europa Clipper mission from the Kennedy Space Center in Florida last October. She attended both as a reporter and to honor the legacy of her late father, astronomer Frank Drake, whose work influenced the Clipper expedition's search for life on Jupiter's icy moon Europa. Her father's eponymous equation is etched on the spacecraft's vault plate in his handwriting, alongside other writings such as a poem by former U.S. poet laureate Ada Limón. When project scientist Robert Pappalardo told Nadia about this commemoration of her father, she was struck by the "beautiful, poignant tribute." The vault plate, she says, "is just a work of art."

Nadia has known Pappalardo for more than a decade; in 2011 she reported on the project that would become Clipper for her first magazine cover story. She initially planned to write about life sciences when she became a journalist—her Ph.D. is in genetics—but ultimately developed a specialty in astronomy and the search for life beyond our planet. "We learn so much about life here on

Earth" in pursuit of those answers, she says, by doing things such as exploring deep-sea hydrothermal vents to learn how organisms can survive without sunlight.

The messages we humans send into the unknown can reveal something about us, too. "Clipper is staying in the solar system. It's going to end its mission on [Jupiter's moon] Ganymede, probably," Nadia says. "So those messages are not intended for anybody except us."

Jane Qiu
The Next Viral Plague

Since the start of the COVID-19 pandemic, Beijing-based journalist Jane Qiu has been keenly focused on bats. In March 2020 she was the first journalist to profile bat virologist Shi Zhengli of the Wuhan Institute of Virology for Western media, in an article for *Scientific American*, and she has been reporting on infectious diseases ever since. Through it all, she's been driven by a question: Why have so many emerging diseases in the past 20 years come from bats? What makes these animals special? "I've been on this kind of journey—a quest, really—to answer those questions," she says. For her feature article, Qiu tells the story of a bat-borne virus in Australia and what it taught us about the flying mammals' immunity and evolution.

Before becoming a journalist, Qiu spent a decade working as a molecular biologist. It seemed like a logical career path at the time—her mother was a medical doctor, and her father is a philosopher of science. Then she decided to follow her intense curiosity and love of learning to the field of science journalism.

She began covering ecology, climate change and development in China—all of which, she has learned, are factors in the spread of infectious diseases because they leave bats increasingly displaced from their habitats and short on resources. This stress can impact their immune systems, just as it would ours, Qiu says. “I started my project asking what’s special about bats, and I think what I found fascinating is that they’re actually not that different from us.”

Michelle Carr
Engineering Our Dreams

While working at a sleep laboratory in college, Michelle Carr began having lucid dreams. It happened spontaneously—she had been “sleeping very poorly because it was college,” and one night she became aware that she was dreaming. “The first one was really eye-opening, and I just started reading everything I could about the subject,” Carr says. Sleep science is a major field, but few labs at the time studied dreams and nightmares specifically; Carr joined one for her Ph.D. “How dismissed dreams are is pretty surprising,” she says. “These are real experiences.”

Dreams, scientists are learning, are more under our control than we have realized. In her feature article, Carr shares how she and other researchers are helping people engineer their dreams to treat nightmares and PTSD. It’s “incredible” how the mind can instantly produce a “completely vivid and detailed simulation,” she says. “It reveals something really impressive about the mind.”

Allison Parshall is an associate editor at *Scientific American* covering mind and brain. She writes the magazine's Contributors column and weekly online Science Quizzes. As a multimedia journalist, she contributes to *Scientific American*'s podcast *Science Quickly*. Parshall's work has also appeared in *Quanta Magazine* and Inverse. She graduated from New York University's Arthur L. Carter Journalism Institute with a master's degree in science, health and environmental reporting. She has a bachelor's degree in psychology from Georgetown University. Follow Parshall on X (formerly Twitter) @parshallison

---

https://www.scientificamerican.com/article/contributors-to-scientific-americans-january-2025-issue

Readers Respond to the September 2024 Issue

Letters to the editors for the September 2024 issue of Scientific American

By Aaron Shattuck

Scientific American, September 2024

QUANTUM COLLAPSE

"The Quantum Observer," by Anil Ananthaswamy [July/August], notes that outcomes in quantum mechanics depend on observations and asks whether the observer must be a human being.

It seems very anthropocentric to assume that only humans can observe a superposition. Quantum entanglement and superposition probably occur everywhere all the time. Do particles stay entangled or in superposition indefinitely until they are observed or measured by "people"—or maybe just by physicists?

PAUL BACINA *VIA E-MAIL*

ANANTHASWAMY REPLIES: *This is exactly the argument made by those who oppose observer-dependent interpretations of quantum mechanics. In a 1990 paper, physicist John Bell quipped elegantly, "What exactly qualifies some physical systems to play the role of 'measurer'? Was the wavefunction of the world waiting to jump for thousands of millions of years until a single-celled living creature appeared? Or did it have to wait a little longer, for some better qualified system ... with a Ph.D.?"*

So, for example, there are so-called collapse theories, which propose that states of quantum superposition can randomly collapse to one of the possible classical states, and the observer merely discovers the final state after measurement.

But both observer-dependent and observer-independent interpretations lead to paradoxical situations in thought experiments: neither gives theorists a free pass. We are missing something in the foundations of quantum theory.

CIRCADIAN RHYTHMICITY

In "The End of the Lab Rat?," Rachel Nuwer writes that "90 percent of novel drugs that work in animal models fail in human clinical trials," implying that only a small percentage of the data obtained from such animal research turn out to be applicable to human biology.

But the story didn't mention chronobiology, the science that investigates the dimension of time in biology and medicine. Typical physiological events in nearly every living thing are characterized by statistically significant circadian rhythmicity—a rise and then fall of function.

The common practice of using single-time-point sampling leads to much nonreproducibility, and it is no wonder that nonapplicability occurs when data from mice or rats are expected to transfer directly to human biology. When high-frequency sampling is done, however, there is remarkable reproducibility. And only an intact organism, such as a human or animal, contains a circadian body-clock-timing system. In 2017 the Nobel Prize in Physiology or Medicine was awarded for discoveries on how the circadian mechanism works in living things.

E. ROBERT BURNS *PROFESSOR EMERITUS, UNIVERSITY OF ARKANSAS FOR MEDICAL SCIENCES*

ENGINEERING VS. MATH

In his article “Cracked” [July/August], Manil Suri implies that mathematics is the only tool that can safely mitigate the dangers of structural failure. Yet facts dictate why aerospace structures are designed by engineers, not mathematicians.

The advances mathematicians are bringing to the finite element method (FEM) used to solve engineering problems are welcome. What is unwelcome is the misguided smugness toward “rank-and-file” engineers who “learn about FEs [finite elements] in a couple of courses at best.” We engineers do typically take one or two courses—at best—in our core studies. Yet within the rigors of real-world engineering is where we learn of the pitfalls inherent in FEM and gain a solidified understanding of necessary principles in structural mechanics.

Significant dangers lurk when basic engineering principles are not applied or are applied incorrectly. No FEM software is safe in the hands of an unwitting user. The paramount way to achieve structural safety is through the training and development of engineering minds. As I’ve told younger engineers, the most powerful CPU you have is between your ears.

MARK BAXTER *VIA E-MAIL*

SURI REPLIES: *Baxter passionately defends the role of engineering judgment, but he risks undervaluing the symbiotic relation between mathematics and engineering. The point of my article was that progress in structural safety is a collective effort in which mathematical insights enhance and support rather than replace engineering expertise. The "CPU between our ears" must process both empirical experience and mathematical theory to achieve safety and innovation.*

END-OF-LIFE CARE

As a retired hospice nurse, I fully endorse the idea of "Starting Palliative Care Sooner," as Lydia Denworth argues in the June Science of Health column. Death continues to be a subject that is anathema to most people, but preparation of the patient and the family for upcoming death is incredibly helpful.

Symptoms can be controlled, and the patient can have a quiet, peaceful death. Palliative care is not giving up; it is preparation for a known life-altering event for everyone involved. It can improve the quality of the death tremendously—for the patient and their family alike. It can take pressure off family members and allow the death to be what it should be—a natural end to a life well lived.

This is what I want for myself, and my family is well aware. I believe it should be the norm for health care in the U.S.

MICHAEL ORLIN *VIA E-MAIL*

ADVANCED MEDITATION

In "Beyond Mindfulness" [July/August], Matthew D. Sacchet and Judson A. Brewer present their cutting-edge studies of advanced meditation, with many concepts that could be the future of clinical practices. There may still be issues regarding advanced meditation as a generalized practice, however.

When one thinks of meditation in general, the immediate thought is often of religion, mainly Hinduism and Buddhism. Many people may thus feel uncomfortable because of their personal beliefs. Also, given that religious background and the rigorous requirements of any medical practice, should the use of advanced meditation by patients require informed consent, with clinicians giving detailed instructions about the benefits and risks? I strongly agree with the authors' optimistic vision, but I prefer to keep the champagne on ice until everything is wrapped up.

WANBO WANG *CLEMMONS, N.C.*

SLEEP INTRUSIONS

In "Beyond the Veil" [June], Rachel Nuwer's article on near-death experiences, a box says neuroscientist Charlotte Martial and her colleagues "suggest thinking about consciousness as a space with three main dimensions: wakefulness, internal awareness and connectedness with the outside world." It also notes that "an intrusion of wakefulness into REM [rapid eye movement] sleep ... cannot be represented in this scheme."

If REM intrusions into wakefulness can't be represented, another dimension may be needed. I've experienced them on occasion, apparently because of sleep deprivation. Adding a fourth dimension, ranging from being fully rested to being completely exhausted, might be helpful.

BRUCE A. KNIGHT *VIA E-MAIL*

Aaron Shattuck is a senior copy editor at *Scientific American*.

---

https://www.scientificamerican.com/article/readers-respond-to-the-september-2024-issue

Ecology

- ## Revealed: Elephants and Gorillas Hang Out in Hidden Playgrounds

  In a dense Republic of Congo rainforest, scientists have mapped a network of strangely open clearings where wild beasts go to eat and hang out

Hidden Playgrounds of Elephants and Gorillas Revealed in Republic of Congo Rainforest

In a dense Republic of Congo rainforest, scientists have mapped a network of strangely open clearings where wild beasts go to eat and hang out

By Zhengyang Wang edited by Mark Fischetti & Sarah Lewin Frasier

Elephants trek through an expansive rainforest *bai*.
Irene Galera/African Parks

Elephants and gorillas that live in the Republic of the Congo's rainforests spend a lot of time hiding in the shadows—or so we thought. Using drone surveys and artificial-intelligence processing, scientists have discovered an extensive network of mysteriously open grass and sedge clearings among the trees. Elephants, gorillas, and other iconic animals visit these muddy concourses, called *bais* in the languages of the Indigenous Ba'Aka, to forage for vital nutrition and maintain their intricate social networks. The numerous playgrounds are visible in satellite images, and AI analysis is helping researchers find them more effectively.

Recognizing the surprising extent of the bai network began on the ground. In May 2021 Sylvain Ngouma, a local botanist at Odzala-

Kokoua National Park in the north of the Republic of the Congo, led a small team of researchers through the rainforest's verdant arrowroots. Evan Hockridge, then a second-year Harvard University graduate student, was with Ngouma in search of a thesis idea. As they walked, the forest's 150-foot canopy of kapok and red ironwood trees abruptly ended at an unobstructed meadow the size of Times Square. Ngouma pointed to a trail of wet, pot-sized footprints leading through the woods to the open rotary and murmured, "*Les éléphants*."

> "You can't understand animal interactions without first understanding *bais*." —Evan Hockridge *Harvard University*

Hockridge was planning to study forest animal behavior and had thought *bais* were anomalies in his data collection. "I had it backward," he says. "It kind of hit me when I was there: these freaking enormous *bais*, with buffalo at the front and elephants right in the middle ... you can't understand animal interactions without first understanding *bais*."

For the next three summers Hockridge and his colleagues investigated the clearings. They first sifted through more than two million camera trap images placed around 13 known *bais*, confirming what many local people had told them—that these natural clearings are crucial gathering grounds for some of the world's most endangered mammals. Among the regulars: Forest elephants congregate to consume nutrient-rich soil. Western lowland gorillas feed on salt-rich roots of *bai* plants. Forest buffalo, blue duikers, sitatungas and even bongos—nocturnal, forest-dwelling antelopes with large spiraled horns—graze around *bais*. The ungulates in turn attract predators such as spotted hyenas and lions. The *bais*, the researchers realized, are big melting pots, big playgrounds, for a menagerie of forest dwellers.


Elephants and others congregate at a *bai* playground in the Republic of Congo.
Irene Galera/African Parks

“There is something quite magical in watching a family of elephants, gorillas or giant forest hogs emerge from the forest edge and bask in sunlight and social opportunities before slipping back into the cool shade of the forest interior,” says Vicki Fishlock, deputy director of research at the Amboseli Trust for Elephants, who is not involved in Hockridge and Ngouma’s work. *Bais* are like Viennese cafés: social arenas where animals hang out. Elephant families meet, and the young get introduced. In open space, they can see one another clearly. The calves play in the mud or, according to Odzala park managers, spend a lot of time chasing birds. Female gorillas get a better look at solitary males and decide whether to join them. Herbivores graze with their calves, perhaps because clearings allow them to more easily spot predators.

During the initial surveys, the team often followed elephant trails—so-called elephant boulevards—to move through the rainforest from *bai* to *bai*. This process led Hockridge to wonder about a network. Although previous studies documented animal behavior in selected *bais*, no one had counted them or had the means to map their distribution.

Doing so required taking to the sky. Partnering with African Parks, a nonprofit organization that manages Odzala, the team flew drones equipped with high-resolution lidar over some of the 220 *bais* that park rangers already knew about, gathering structural and spectral signatures. The researchers used this information to train a machine-learning algorithm that picked out *bais* from satellite images. For a study in *Ecology*, Hockridge and Ngouma mapped all the *bais* in a national park the size of Connecticut and found 2,176 of them—10 times more than the park management had previously known of. (Disclosure: The writer of this *Scientific American* article was formerly affiliated with the senior study author's laboratory at Harvard but was not involved in the work.)

A *bai* in Odzala-Kokoua National Park in the Republic of the Congo.
Gwili Gibbon/African Parks

Bais are always located near rivers or streams. Most are smaller than a city block, but a few, at more than 100 acres, are larger than some college campuses. "Especially in the West, we often view rainforest as a continuous sea [of trees], but we need to consider where the forests cease to be," Hockridge says. "*Bais* are ultimately islands of resources, and animals produce these networks of trails to essentially navigate to and from a nodal network of *bais*."

The researchers' map of *bais*, the first of its kind, is also a map of conservation priorities. "We find that a huge portion of the animal community is dependent on this unique ecosystem. These species don't have alternative habitats other than *bais*," Hockridge says.

“We name a lot of the animals as the *forest* elephants, the *forest* buffalo, but if you look at their movement patterns and the amount of time they spend in the *bais*, they are almost like *clearing* specialists.”

Observers have been able to clearly see the network only recently as satellite resolution and computation capacity have improved, says senior study author Andrew Davies, an ecologist in Harvard’s department of organismic and evolutionary biology. Davies hopes to apply the same algorithm to chart *bais* across the entire Congo basin—the second-largest rainforest in the world.

The study is also a step toward solving the ultimate mystery: How did *bais* form? Many ecologists have argued that a combination of hydrology and animal landscaping, especially by forest elephants, is at play. But definitive proof has been elusive; no one has ever documented their formation or recession. Now, with a map in hand and camera traps still in place, the research team is tracking long-term changes, which have implications for the maintenance of these crucial animal habitats. For example, would rampant ivory poaching affect elephant population and thus *bais*? Would changing climate cause the *bais* to shrink or expand?

“We have hypotheses,” Davies confides, “but the short answer is: we don’t know.”

A version of this article entitled “Rainforest Playgrounds” was adapted for inclusion in the January 2025 issue of Scientific American. *This text reflects that version, with the addition of some material that was abridged for print.*

Zhengyang Wang is a writer and conservation biologist at Sichuan University in China. He uses molecular ecology and remote sensing to track animals across landscapes.

---

https://www.scientificamerican.com/article/revealed-elephants-and-gorillas-hang-out-in-hidden-playgrounds

Electronics

- **This Sponge Pulls Gold from Electronic Waste**
  A self-building sponge that efficiently collects gold could eliminate some harsh methods used to process e-waste

This Sponge Captures the Teeny Bits of Gold in Electronic Waste

A self-building sponge that efficiently collects gold could eliminate some harsh methods used to process e-waste

By Ben Guarino edited by Sarah Lewin Frasier

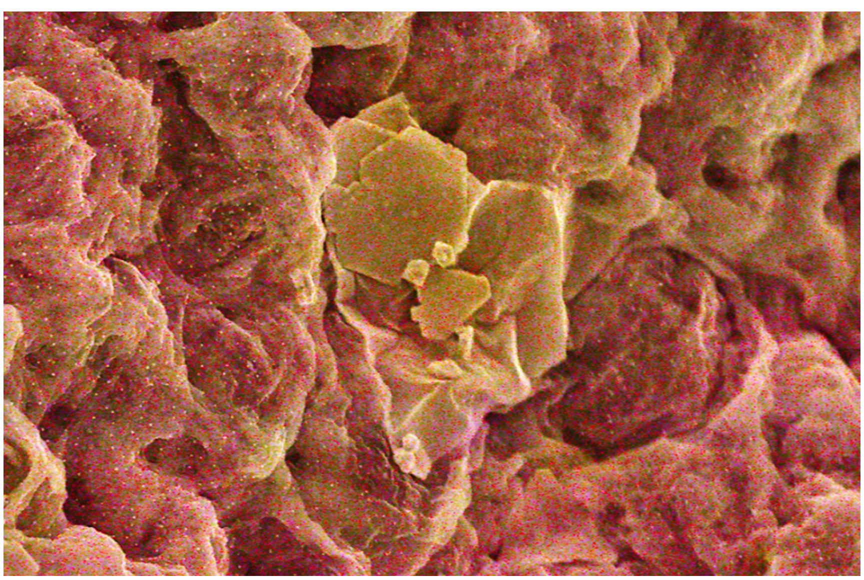
Thomas Fuchs

If all 62 million metric tons of electronic waste the world produces in a year were loaded into garbage trucks, they'd encircle the planet bumper to bumper, according to a recent United Nations report. And hidden in that monstrous traffic jam would be startling amounts of precious metals, including gold—crucial in electronics because it conducts electricity, stretches into wires and won't easily corrode. Modern iPhones have gold in their cameras, circuit boards and USB-C connectors. Pound for pound, there is more of the substance in cell phones than in ore from a typical gold mine.

But wringing precious metals from trashed electronics is a harsh business. Using energy-intensive smelters, recycling facilities process e-waste with punishing heat. Or caustic agents are used to break down bulk electronics into liquids full of metal ions. This approach then requires complex electrochemical processes and toxic treatments to extract valuable elements in their metallic forms. The search for environmentally friendlier methods that skip those additional steps has led materials scientists down some unusual alleyways. For instance, an aerogel made from whey protein—a cheese by-product—can capture gold ions from computer motherboards bathed in acid.

An experimental sponge, described in the *Proceedings of the National Academy of Sciences USA*, combines graphene oxide (a thin sheet of carbon and oxygen molecules) with chitosan, a sugar derived from shrimp shells, to strain out gold. Because chitosan spontaneously attaches to the carbon sheet, the sponge essentially builds itself.

In their initial experiments, the study authors used the sponge to filter water that contained gold ions. The pale yellow liquid became clear as gold particles piled up in the material's molecular mesh. Once there, the ions reacted with the chitosan, which, as a natural reducing agent, helped to transform the gold back into its metallic form.



Gold (*yellow*) nestles in a graphene-chitosan sponge.
Kou Yang

The researchers also tested the sponge on partially processed e-waste; when they increased the acidity of the liquid to a pH of 3, the sponge's chitosan captured the remaining gold while ignoring other metals. Although it requires an acidic environment to work, the sponge could eliminate the need for further processing, which can rely on poisonous substances such as cyanide to obtain metallic gold from liquids. "Our method allows for efficient recovery of gold directly from the waste mixture," say study co-authors Daria Andreeva-Baeumler and Konstantin Novoselov, materials scientists at the National University of Singapore.

The new material is one of the most potent gold adsorbers ever created. ("Adsorption" is similar to the more familiar "absorption," but adsorbed things accumulate on surfaces, whereas absorbed things are internalized. It's the difference between a mustard glob on your chin and the hot dog you just ate.) The sponge collected up to 99.5 percent of the gold by weight from liquids with gold concentrations as low as three parts per million.

"To the best of my knowledge, this is a record-high value," says ETH Zürich physicist Raffaele Mezzenga, an author of the whey protein aerogel study, who wasn't involved with the graphene-chitosan research. He notes that as efficient as the sponge is, the components needed to make it aren't cheap, and he questions whether it would be a workable option "under real operating conditions." Adapting the technique for industrial-scale use, Novoselov and Andreeva-Baeumler say, "is indeed the next step in our research."

Ben Guarino was formerly an associate technology editor at *Scientific American*. He writes and edits stories about artificial intelligence, robotics and our relationship with our tools. Previously, he worked as a science editor at *Popular Science* and a staff writer at the *Washington Post*, where he covered the COVID pandemic, science policy and misinformation (and also dinosaur bones and water bears). He has a degree in bioengineering from the University of Pennsylvania and a master's degree from New York University's Science, Health and Environmental Reporting Program.

---

https://www.scientificamerican.com/article/this-sponge-pulls-gold-from-electronic-waste

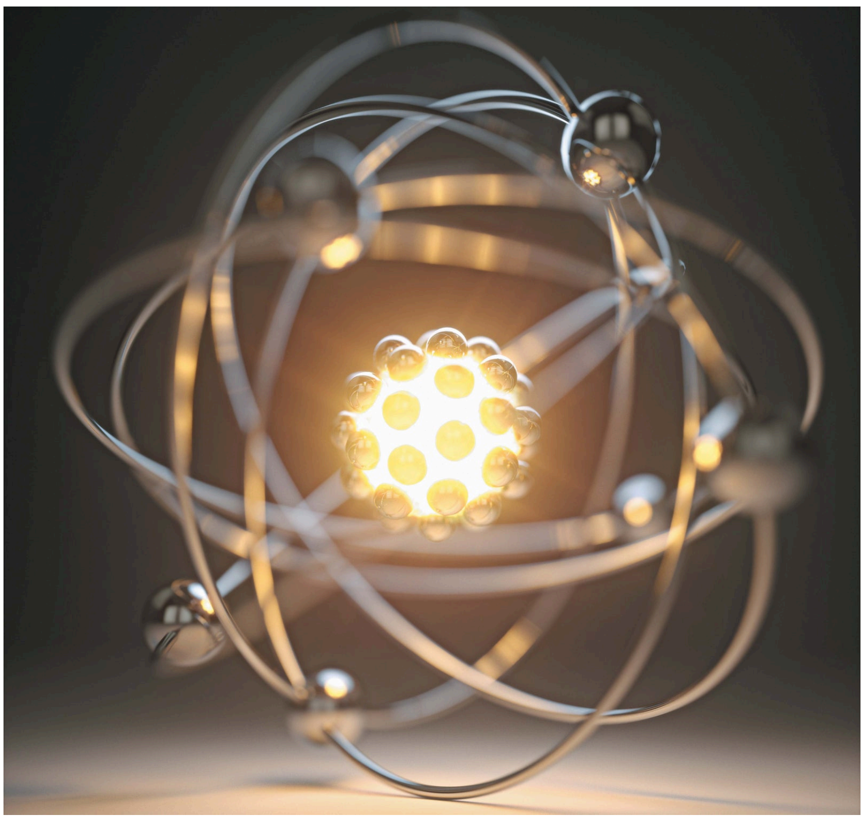
Engineering

- **The World’s First Nuclear Clock Could Unlock the Universe’s Dark Secrets**
  After decades of work, physicists have finally broken into the atom to build the first nuclear clock

The World’s First Nuclear Clock Is Finally Ticking

After decades of work, physicists have finally broken into the atom to build the first nuclear clock

By Allison Parshall edited by Lee Billings



KTSDESIGN/SCIENCE PHOTO LIBRARY/Getty Images

To measure time, you need a constant rhythm. For eons, the regular movements of the sun and moon have set the pace for all of life on Earth. But over millennia, humans have sought and found more controllable and precise methods, such as the swing of a pendulum or the rates at which water flows and incense burns. Today most electric clocks or watches measure the steady vibrations of quartz crystals.

But even the best pacemakers drift; in one form or another, creeping chaos eventually corrupts the order of any timekeeping system. A month's worth of varying temperatures and movements, for example, can be enough to knock a quartz watch off its mark by 15 seconds. Questing for a truly constant "tick," scientists have focused on the atomic world, where the minuscule scales and unchanging physical properties of atoms allow time to be sliced into smaller, more stable increments. The resulting atomic clocks that set official international times today are astonishingly robust, losing only about one second every 100 million years.

Physicists have been trying for decades to escape clock-contaminating noise by zooming in even further, past an atom's outer electron shells and into the far smaller, more tightly wound atomic nucleus at its core. Now they have finally succeeded. The world's first nuclear clock, created in Boulder, Colo., by an international team of scientists, was detailed in a paper published in *Nature.* Although this particular timekeeper is not yet more accurate than its best atomic partner, the technology could soon shatter precision timekeeping records and vastly improve GPS and deep-space navigation.

And making such sharp measurements within an atom's nucleus might just give physicists access to vast, unexplored realms of the physical world. This "will really open a new window into looking at the fundamental laws of nature," says José R. Crespo López-Urrutia, a physicist at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany, who was not involved in the new research but co-authored a companion article that was published in the same issue of *Nature*.

At their core, atomic clocks and nuclear clocks work using the same principle. Atoms can become "excited" when they're hit by photons packing just the right punch—that is, waves of light at a very specific energy level, or frequency. Which tiny range of frequencies will do the trick depends on the type of targeted atom, but it remains the same for all atoms of a particular element. “An atom of cesium or an atom of sodium is the same everywhere [in the universe], or at least that’s what we believe,” Crespo López-Urrutia says.

In the 1940s scientists realized this cosmic constancy could be used to measure time without the chaotic noise associated with other physical clocks. Photons travel as waves, and their frequency is simply a measure of how many wave cycles pass a given point per second. So you can turn a laser beam with a known, fixed frequency into a clock by counting its waves to determine time’s passage. The best way scientists have found to do this is to excite an atom by hitting it with an ultraprecise laser using the exact frequency of the beam as a constant measurement of time.

Since the first atomic clock was built in 1949, this process has only gotten more sophisticated. The most precise and accurate atomic clock in the world, the ultracold strontium clock at JILA in Boulder, is like a stopwatch that can count the billionths of a nanosecond, or 18 digits past the decimal point. It loses only one second every 40 billion years.

But physicists have long dreamed of something even better. What if they could excite not entire atoms but the nuclei deep inside? Nuclei contain 99.99 percent of an atom’s mass but are truly minuscule; if an atom were the size of an American football stadium, its nucleus would be only as big as a marble. Exciting something so tiny and heavy requires thousands or millions of electron volts of energy, usually in the form of photons that are precisely tuned to incredibly specific frequencies. This difficulty is exactly why a nuclear clock could drift less and “tick” more times per second than an atomic clock. Unfortunately, no tabletop laser can generate enough energy to excite a nucleus in the vast majority of elements.

There is one exception, however: the rare radioactive isotope thorium-229. This isotope requires only about eight electron volts of energy to jump to an excited state, and physicists have no idea why. “Its [transition energy] is so low that nuclear physicists actually don’t know what to do with it,” says co-author Thorsten Schumm, a physicist at the Vienna University of Technology.

This exception provided a golden opportunity for nuclear clock builders. But while thorium-229’s transition energy was technically within reach, they had to find it first. Only a minuscule range of energies could excite the nucleus, and narrowing down that range required building brand-new laser systems and many years of clever trial and error by physicists around the globe.

“It’s this ‘needle in a haystack’ problem—although finding a needle in a haystack is much easier than what we did, in terms of orders of magnitude,” Schumm says.

The researchers also had to find a way to hold the thorium-229 atoms still. While many atomic clocks suspend single atoms in a vacuum using electromagnetic fields, physicists building a nuclear clock knew they’d have a better shot at success if they could hit many nuclei at once. Schumm’s team embedded tens of thousands of thorium-229 nuclei in transparent crystals, allowing more nuclei to be hit by the lasers at one time and increasing the probability that some would transition to their excited state.

In just the past year all of these necessary discoveries finally began converging. In May Schumm’s team shipped the thorium crystals to physicist Jun Ye’s lab in Boulder, which runs the ultracold strontium clock. Researchers there had developed an advanced laser system that could narrow the range of remaining possible frequencies down to a precise answer. This laser system could also sync up the nuclear “ticks” with the atomic clock, allowing the atomic clock to stay on track with nuclear time.

The Boulder team shot its special laser system at the crystal, sweeping through different frequencies. A faint, telltale ultraviolet glow from the excited thorium would be the only sign of a successful nuclear transition. For weeks, however, the researchers saw nothing.

“It was close to midnight when we saw the first indication of the signal,” says Chuankun Zhang, a Ph.D. student studying laser physics at Ye’s lab at the University of Colorado Boulder. “Nobody could sleep after the experiment.” Instead the team spent those sunless early-morning hours verifying its results. By around 4 A.M., the conclusion was crystal clear: Zhang and his team had successfully excited the thorium-229 nuclei and synced their frequency measurements with JILA’s atomic timekeeper, creating the world’s first nuclear clock. Currently it falls short of the world record for precision because it only reads out 12 digits of a frequency measurement compared with the strontium clock’s 18.

“This first realization is not about ‘Oh, they got only 12 digits.’ The first realization is ‘Oh, they got this thing to *run,’*”Crespo López-Urrutia says. While technical challenges remain, mostly involving the laser system, “people are confident that they can be overcome in a few years,” and then the nuclear clock will overtake the atomic clock in preciseness and accuracy. Measurements reaching to 20 or even 21 digits may be possible, he says.

“It’s beautiful work,” says physicist Eric Hudson, whose team at the University of California, Los Angeles, has also been working to narrow down the transition frequency and grow thorium crystals. Hudson is most excited about the team’s creation of a crystal-based, or “solid-state,” clock, which trapped the nuclei in place rather than levitating them with electromagnetic fields. “This could lead to a much more portable and robust clock that could come out of the lab into the real world,” he says.

Such portable nuclear clocks could find their way onto GPS satellites or spacecraft navigation systems. GPS satellites triangulate a device's location by measuring tiny differences in a signal's transmission time. The technology is currently accurate down to a few meters for nonmilitary applications. That's too inaccurate for autonomous cars, Schumm says, or for positioning technology that could help people who are blind or have low vision navigate. "There's an urgent need to get positioning to centimeter- or millimeter-level because then there's a qualitative change."

And on a more fundamental level, nuclear clocks provide an entirely new way to study the unseen forces and particles that surround us. The frequencies measured by atomic clocks arise from the jostling of electrons, meaning they are governed by the well-understood electromagnetic force. But the ticking of a nuclear clock comes from a comparative terra incognita, the mysterious domain of the strong force that binds nuclei together. Physicists generally assume that these two forces remain constant over time, but they haven't been able to rigorously test whether that is true, Zhang says. However, by comparing the outputs of an atomic and a nuclear clock, they can, in principle, track whether these two forces are truly unchanging.

It's also possible that this nuclear probe could reveal something about dark matter, which remains elusive despite being 85 percent of the matter in the universe. "Our difficulty with dark matter is that it doesn't interact with what we know, so we don't have [successful] detectors yet," Schumm says. But if dark matter interacts with the nucleus differently than it does the atom as a whole, those differences might show up in comparisons between nuclear and atomic clocks.

"All those forces which are yet not well explained, or for which the origin is unknown, could appear in the comparison of frequencies of clocks," Crespo López-Urrutia says. If their pace changes relative to one another, scientists in search of a steady timekeeper might instead have discovered that there's no such thing after all.

A version of this article entitled "Nuclear Time" was adapted for inclusion in the January 2025 issue of Scientific American. *This text reflects that version, with the addition of some material that was abridged for print*

Allison Parshall is an associate editor at *Scientific American* covering mind and brain. She writes the magazine's Contributors column and weekly online Science Quizzes. As a multimedia journalist, she contributes to *Scientific American*'s podcast *Science Quickly*. Parshall's work has also appeared in *Quanta Magazine* and Inverse. She graduated from New York University's Arthur L. Carter Journalism Institute with a master's degree in science, health and environmental reporting. She has a bachelor's degree in psychology from Georgetown University. Follow Parshall on X (formerly Twitter) @parshallison

---

https://www.scientificamerican.com/article/the-worlds-first-nuclear-clock-could-unlock-the-universes-dark-secrets

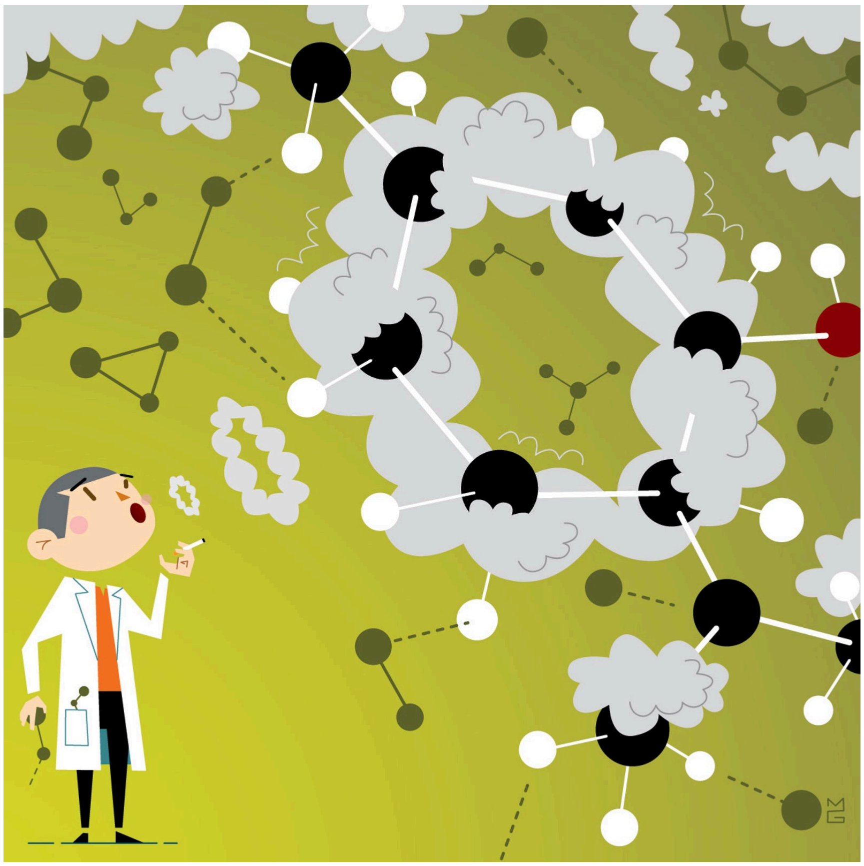
Health

- **How Tobacco Companies Use Chemistry to Get around Menthol Bans**
  Regulating chemicals one-by-one has allowed the tobacco industry to skirt menthol bans by creating new additives with similar effects but unclear safety profiles

How Tobacco Companies Use Chemistry to Get around Menthol Bans

Regulating chemicals one-by-one has allowed the tobacco industry to skirt menthol bans by creating new additives with similar effects but unclear safety profiles

By Julie B. Zimmerman, Hanno C. Erythropel, Tobias D. Muellers, Predrag V. Petrovic, Stephanie S. O'Malley, Suchitra Krishnan-Sarin, Sairam V. Jabba, Sven E. Jordt & Paul T. Anastas



Martin Gee

In 2020 lawmakers in California and Massachusetts banned menthol, a chemical that causes a cooling sensation, as an additive in cigarettes. The idea was partly to help curb youth smoking; menthol makes cigarettes more palatable. Regulators called the chemical unsafe for its role in promoting nicotine addiction.

Soon after, we learned in detail how the tobacco industry circumvented these laws by substituting menthol with other cooling chemicals in their new “nonmenthol” cigarettes. This is the oldest trick in the book for dealing with chemicals deemed hazardous or otherwise problematic: stop using the original molecule and either find or make a substitute with the same function but with scant or nonexistent safety data. This approach allows a company to continue to produce chemicals of concern while U.S. agencies such as the Food and Drug Administration or the Environmental Protection Agency grind away to catch up to these new alternatives.

Although these new products may be legal, the original concerns remain. In this case, R.J. Reynolds simply switched out menthol for an odorless, structurally similar synthetic agent known as WS-3. Like menthol, it reduces the harshness of cigarette smoke by producing a cooling effect.

That the tobacco industry can readily make this kind of shift speaks to a fatal flaw in how we regulate chemicals in this country. We do so not according to the concern about or the intended effect of a compound or based on what we know about related compounds. Instead we assess chemical by chemical, final product by final product. The status quo means regulators are constantly chasing tiny tweaks and clever substitutions instead of regulating classes or, better, the properties that make molecules problematic.

This game of whack-a-mole plays out with all kinds of products, not just cigarettes. Take, for example, bisphenol A (BPA), a plastics precursor and endocrine disrupter that interferes with the normal production and work of the body’s hormones. As BPA became increasingly regulated by countries around the world, it was replaced with bisphenol S (BPS), which has a molecular structure only slightly modified from that of BPA. BPS helped manufacturers achieve the goal of removing BPA from commercial products, but it causes the same endocrine problems. By banning BPA, we removed the chemical but not the concern.

Why has this obvious flaw been allowed to persist? First, it isn't recognized as a flaw. There is a prevailing perspective in the U.S. that chemicals have rights, so to speak. When we move to regulate a chemical, we are putting that compound "on trial." The evidence against its use generally needs to meet a certain standard of peer review, and the process needs to include public review and comment. Sadly, in the U.S., the chemical regulatory system moves more slowly than the judicial system. Regulatory action has taken many years even for substances that are well known to be hazardous, such as dichloromethane, chloroform and trichloroethylene.

But the pace of the legally required review of the science and costs is not the most significant impediment to more responsive regulation. The biggest problem is that we focus on the chemical and not the concerns people have about it, such as its toxicity or addictive properties. For regulators, a substance's ability to cause harm should be based on the combination of its inherent physical and chemical properties. Its real-world potential to make people sick or change the atmosphere has nothing to do with the name humans have given it, and yet that is how we regulate—one discrete chemical at a time.

Regulation of chemicals does not have to be this slow, laborious, costly and ineffective. Changing this regulatory framework could benefit the chemical industry by incentivizing sustainable innovation while more effectively protecting public health and the environment. Using our understanding of how physical and chemical properties relate to different concerns gives us a new way to protect human health—by regulating the concern and not the chemical. We could define groups of chemicals as safe or troublesome based on similar physical and chemical properties, which would allow us to focus on what might create a risk or affect the function of the chemical rather than looking at its structure alone.

This approach is based on intrinsic molecular properties that contribute to both hazards and functions of different substances. Regulators could use this insight when a new chemical was proposed for commercial use. Innovative companies could benefit by using this knowledge to design molecules or invent substances that are more likely to be safe. This approach would also create greater regulatory certainty, reducing a company's risk in bringing a chemical to market or putting one in its product that might eventually be banned.

For cigarette coolants, this would mean banning any chemical, regardless of structure, that activates the body's receptor for menthol, named TRPM8. This receptor is located on sensory neurons that enable us to feel cool temperatures and is also activated by coolants such as WS-3 found in the new nonmenthol cigarettes. Menthol cigarettes have already been banned in the European Union, Canada, and other countries. Some nations, such as Germany and Belgium, have also banned diverse TRPM8 activators. Interestingly, the Belgian approach specifically restricts any additives to tobacco products that "facilitate nicotine inhalation or intake," including "all components and mixtures with cooling and/or analgesic effects." This is essentially a property-based approach. California has recently done something similar.

A property-based approach can be used to help define safer chemical properties and provide regulatory confidence, as well as to outline hazardous-chemical spaces in which chemicals with certain properties known to be associated with hazards would come under greater scrutiny. Fortunately, leading companies across many industrial sectors—from cosmetics to electronics—are beginning to think and design in this way.

If we want a chemical world that is truly safe and sustainable by design, we should match our regulatory framework to our intentions. That is, rather than banning individual molecules, which forces us to chase each new molecule of concern for decades with new regulation, we should aim to ban the central concern defined by a set of physical chemical properties. This change would lead to chemicals that are safe for people and the planet based on their intrinsic properties. Had we taken this approach from the outset, we could have protected vulnerable people from additives that make cigarettes more appealing and pleasant rather than seeing those hopes go up in smoke.

This is an opinion and analysis article, and the views expressed by the author or authors are not necessarily those of Scientific American.

Julie B. Zimmerman is a professor of green engineering and the vice provost for planetary solutions at Yale University.

Hanno C. Erythropel is a lecturer and research scientist in the Center for Green Chemistry and Green Engineering at Yale University.

Tobias D. Muellers is a doctoral student at the Yale School of the Environment.

Predrag V. Petrovic is an associate research scientist in the Center for Green Chemistry and Green Engineering at Yale University.

Stephanie S. O'Malley is a professor and deputy chair for clinical research in the department of psychiatry at Yale University School of Medicine. She co-leads the Yale Tobacco Center for Regulatory Science.

Suchitra Krishnan-Sarin is a professor of psychiatry and chair of the Human Investigations Committee at Yale University School of Medicine. She co-leads the Yale Tobacco Center for Regulatory Science.

Sairam V. Jabba is a senior research scientist in the department of anesthesiology at Duke University School of Medicine.

Sven E. Jordt is an associate professor in anesthesiology and pharmacology and cancer biology at Duke University School of Medicine.

Paul T. Anastas is the Teresa and H. John Heinz III Professor at the Yale School of the Environment and the Yale School of Public Health. He is the director of Center for Green Chemistry and Green Engineering at Yale University and is widely regarded as the "father of green chemistry."

---

https://www.scientificamerican.com/article/how-tobacco-companies-use-chemistry-to-get-around-menthol-bans

History

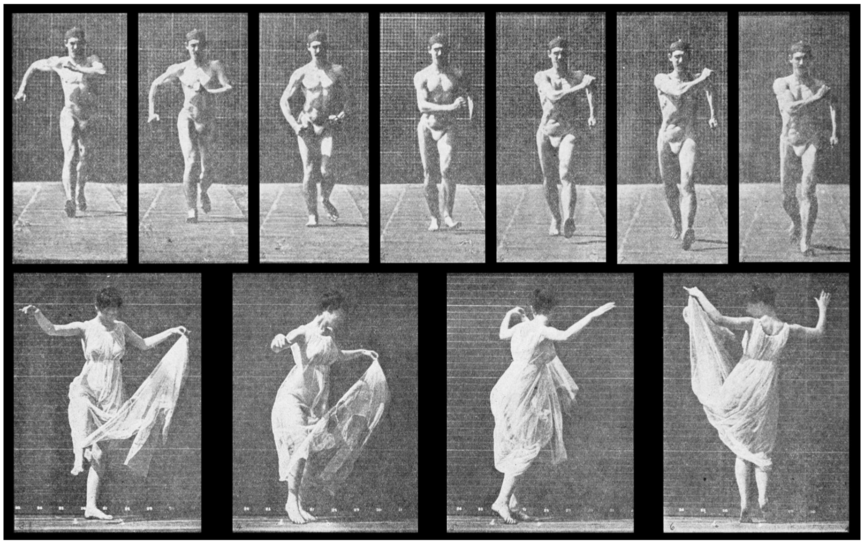
- **January 2025: Science History from 50, 100 and 150 Years Ago**
  The J particle; a nitroglycerin engine

| Next section | Main menu | Previous section |

January 2025: Science History from 50, 100 and 150 Years Ago

The J particle; a nitroglycerin engine

By Mark Fischetti



1925, Exercise in Motion: "Years before the motion picture was invented, Mr. Eadweard Muybridge, at the University of Pennsylvania, used electrically timed cameras to study the exact movements of human muscles during exercise. The cross lines in the background were used to measure each movement exactly. The image is from plates copyrighted in 1887 by Eadweard Muybridge."
Scientific American, Vol. 132, No. 1; January 1925

1975

Thunder Crack or Thunder Rumble

"A lightning flash lasts only a few tenths of a second. Why does the resulting sound persist for half a minute or even longer? A typical lightning discharge consists of three strokes through a channel extending some 10 kilometers. The light from all parts of the channel reaches the observer almost instantaneously. The sound from the various parts, however, reaches the observer at different times. If the lightning channel is generally at right angles to the line of sight, the sound will reach the observer at almost the same time: an abrupt, loud crack. If the channel is generally parallel to the line of sight, the sound from the farthest part will reach the observer many seconds later than the sound from the nearest part: a long rumble."

J Particle May Be Charmed Quark

"The most puzzling aspect of the recent discovery of a new kind of subnuclear particle at two high-energy-physics laboratories is the particle's extraordinarily long lifetime of 10^{-20} second. This unexpectedly 'slow' decay sets the comparatively massive new particle apart from hundreds of other unstable sub–nuclear species that have been created with particle accelerators. Most of the latter particles have lifetimes on the order of 10^{-23} second. The new particle is called the J particle by one group of experimenters and the psi particle by the other. Another possibility being discussed is that the particle represents a 'bound state' consisting of a 'charmed' quark and its cor responding antiquark."

1925

Does Lactic Acid Cause Muscle Fatigue?

"What happens when we get out of breath or become exhausted? Dr. A. V. Hill, professor of physiology at University College London, recently discovered that there was a very close relation between the fatigue caused by exercise and the production of a certain chemical called lactic acid in the muscles that are being used. Dr. Hill discovered that fatigue was accompanied by an increase in the amount of lactic acid in the muscles, whereas recovery from fatigue was always marked by a decrease in lactic acid."

Scientists discredited the lactic acid idea more than two decades ago, but it persists today. They suspect that inorganic phosphate *contributes to skeletal muscle fatigue.*

1875

Chromosphere Cloaks the Sun

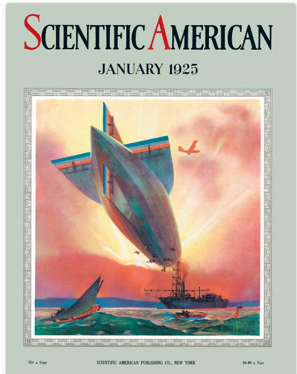
“The edge of the sun’s visible disk is surmounted to an elevation of between 8,000 and 10,000 miles by an envelope of rose-colored gases, to which Mr. Norman Lockyer has given the name of chromosphere. The scarlet flame clothes the whole surface of the sun, and here and there rises in cloudlike forms that ascend to enormous heights. The spectroscope has shown that uprising jets are nothing but heated clouds of gas, largely hydrogen. Their spectrum exhibits conspicuously the bright lines of that element, yet another very prominent line as well. To this hypothetical element the name of helium has been assigned by Lockyer and Edward Frankland, though with rather doubtful propriety.”

Wanted: A Nitroglycerin Engine

“M. Champion, a French chemist, states that the heat developed by a given quantity of nitroglycerin when exploded is capable of exerting, when converted into motion, a maxi· mum energy five times that produced by the explosion of the same amount of gunpowder, and 3,000 times more than that of combustion of an equal quantity of coal. A quart of nitroglycerin, it is asserted, has the potential energy of 5,500 horsepower working during 10 hours. It remains to invent a machine in which the gigantic force can be harnessed and controlled.”

Monorail, with Leather Brakes

“The Turkish government has recently commenced the construction of a railway, termed the Steam Caravan, between Alexandretta and Aleppo, Syria, a distance of 94.2 miles. A single rail is employed, raised on a wall 28 inches high and 17.5 inches broad. The vehicles straddle both rail and wall. The locomotives are provided with horizontal, leather-covered wheels, which rest against the sides of the masonry and serve as brakes, and the last vehicle of each train has similar arrangements. Each side of each carriage contains two persons, and the complete train is calculated to accommodate 96.”



Mark Fischetti has been a senior editor at *Scientific American* for 17 years and has covered sustainability issues, including climate, weather, environment, energy, food, water, biodiversity, population, and more. He assigns and edits feature articles, commentaries and news by journalists and scientists and also writes in those formats. He edits History, the magazine's department looking at science advances throughout time. He was founding managing editor of two spinoff magazines: *Scientific American Mind* and *Scientific American Earth 3.0*. His 2001 freelance article for the magazine, "Drowning New Orleans," predicted the widespread disaster that a storm like Hurricane Katrina would impose on the city. His video *What Happens to Your Body after You Die?*, has more than 12 million views on YouTube. Fischetti has written freelance articles for the *New York Times, Sports Illustrated, Smithsonian, Technology Review, Fast Company,* and many others. He co-authored the book *Weaving the Web* with Tim Berners-Lee, inventor of the World Wide Web, which tells the real story of how the Web was created. He also co-authored *The New Killer Diseases* with microbiologist Elinor Levy. Fischetti is a former managing editor of *IEEE Spectrum Magazine* and of *Family Business Magazine*. He has a physics degree and has twice served as the Attaway Fellow in Civic Culture at Centenary College of Louisiana, which awarded him an honorary doctorate. In 2021 he received the American Geophysical Union's Robert C. Cowen Award for Sustained Achievement in Science Journalism, which celebrates a career of outstanding reporting on the Earth and space sciences. He has appeared on NBC's Meet the Press, CNN, the History Channel, NPR News and many news radio stations. Follow Fischetti on X (formerly Twitter) @markfischetti

---

https://www.scientificamerican.com/article/january-2025-science-history-from-50-100-and-150-years-ago

Language

- **Science Crossword: Out of Sight**
  Play this crossword inspired by the January 2025 issue of Scientific American

Science Crossword: Out of Sight

By Aimee Lucido

This crossword is inspired by the January 2025 issue of Scientific American. *Read it here.*

We'd love to hear from you! E-mail us at games@sciam.com to share your experience.

Aimee Lucido makes crosswords part-time for several outlets and writes trivia full-time for Bloomberg's news quiz, Pointed. She is also the author of several books for kids, including *Emmy in the Key of Code*, *Recipe for Disaster*, and *Pasta Pasta Lotsa Pasta*. Lucido lives with her husband, daughter and dog in New York.

https://www.scientificamerican.com/article/science-crossword-out-of-sight

Mathematics

- ## Math Puzzle: Move the Tower
  Transport the disks in this math puzzle
- ## This Elegant Math Problem Could Help You Make the Best Choice in House Hunting and Even Love
  Math’s “best-choice problem” could help humans become better decision-makers at everything from choosing the best job candidate to finding a romantic partner

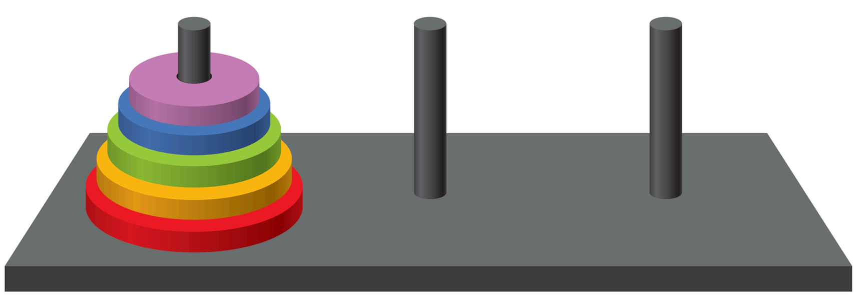
Math Puzzle: Move the Tower

By Heinrich Hemme

French mathematician Édouard Lucas was born in Amiens in 1842 and died in Paris 49 years later. He wrote the four-volume work *Recréations Mathématiques*, which became a classic of recreational mathematics. In 1883, under the pseudonym “N. Claus de Siam” (an anagram of “Lucas d’Amiens”), he marketed a solitaire game that he called the Tower of Hanoi.

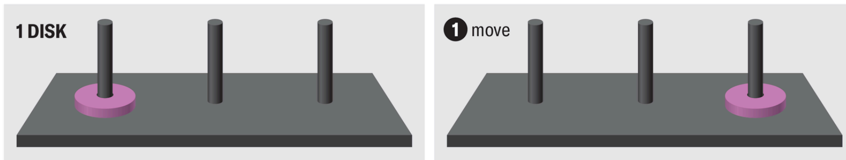
He claimed that the game was a simplified version of the so-called Tower of Brahma. In this supposed legend, monks had to move a tower made of 64 golden disks in a great temple. Before they could complete this task, however, the temple would crumble to dust, and the end of the world would arrive.

The Tower of Hanoi consists of a small board on which three identical cylindrical rods are mounted. On the left rod there are five disks of different sizes with a hole in the middle. They are ordered by size, with the largest disk at the bottom. The goal of the game is to move all the disks from the left rod to the right rod in as few moves as possible. In each move, only one disk can be taken from one rod and placed on another rod, and a larger disk can never be placed on a smaller disk. How many and which moves are necessary to transport the disks?



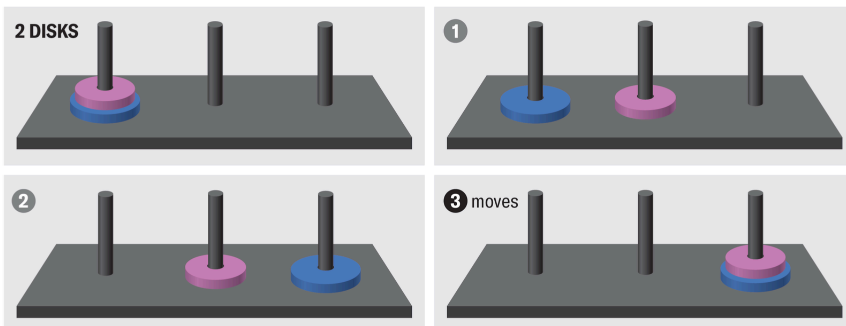
Amanda Montañez

We replace the disks with numbers according to size. Now we build the solution systematically, starting with a tower with only one disk. The solution is trivial. With one move you transport the single disk from left to right.



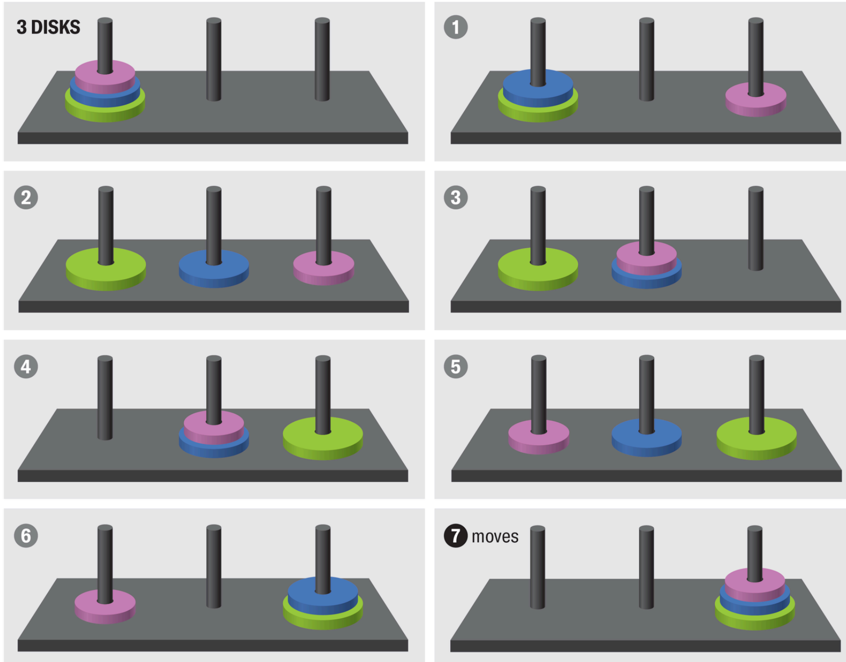
Amanda Montañez

For a tower with two disks you first move disk 1 from left to middle, then disk 2 from left to right and finally disk 1 from middle to right. So you need $3 = 2^2 – 1$ moves.



Amanda Montanez

For a tower with three disks we first mentally leave disk 3 out. This reduces the problem to the task with only two disks, which we now transport from left to middle with three moves. With a fourth move we then transport disk 3 three from left to right. Now we mentally leave disk 3 out again and again transport the two disks from middle to right with three moves. In total this consists of $3 + 1 + 3 = 7 = 2^3 – 1$ moves.



Amanda Montañez

The problem of the tower with four disks can be reduced in a very analogous way to that of the tower with three disks. Therefore, you need $7 + 1 + 7 = 15 = 2^4 – 1$ moves. Finally, for the tower with five disks, you need $15 + 1 + 15 = 31 = 2^5 – 1$ moves. In general, you need $2^n – 1$ moves for a tower with n disks. The original game by Édouard Lucas had eight disks.

We'd love to hear from you! E-mail us at games@sciam.com to share your experience.

This puzzle originally appeared in Spektrum der Wissenschaft *and was reproduced with permission.*

Heinrich Hemme is a physicist and a former university lecturer at FH Aachen–University of Applied Sciences in Germany.

---

https://www.scientificamerican.com/article/math-puzzle-move-the-tower

This Elegant Math Problem Helps You Find the Best Choice for Hiring, House Hunting and Even Love

Math's "best-choice problem" could help humans become better decision-makers at everything from choosing the best job candidate to finding a romantic partner

By Jack Murtagh edited by Jeanna Bryner

Jonathan Kitchen/Getty Images

Imagine you're cruising down the highway and notice that you are running low on fuel. Your GPS shows 10 gas stations ahead on your route. Naturally, you want the cheapest option. You pass the first few and observe their prices before approaching one with a seemingly good deal. Do you stop, not knowing how sweet the bargains could be up the road? Or do you continue exploring and risk regret for rejecting the bird in hand? You won't double back, so you face a now-or-never choice. What strategy maximizes your chances of picking the cheapest station?

Researchers have studied this "best-choice problem" and its many variants extensively, attracted by its real-world appeal and surprisingly elegant solution. Empirical studies suggest that humans tend to fall short of the optimal strategy, so learning the secret might just make you a better decision-maker.

The scenario goes by several names: two examples are "the secretary problem," which involves ranking job applicants by their qualifications (instead of gas stations or the like by prices), and "the marriage problem," in which you rank suitors by eligibility. All incarnations share the same underlying mathematical structure, in which a known number of rankable opportunities present themselves one at a time. You must commit yourself to accepting or rejecting each of them on the spot with no take-backs (if you decline all, you'll be stuck with the last choice). And the opportunities can arrive in any order.

Let's test your intuition. If the highway were lined with 1,000 gas stations and you had to evaluate them sequentially and choose when to stop, what are the chances that you would pick the absolute best option? If you chose at random, you would find the best only 0.1 percent of the time. Even if you tried a strategy cleverer than random guessing, you could get unlucky if the best option happened to show up quite early, when you lacked the comparative information to detect it, or quite late, by when you might have already settled for fear of dwindling opportunities.

Amazingly, the optimal strategy results in the number-one pick being selected almost 37 percent of the time, and its success rate doesn't depend on the number of candidates. Even with a billion options and a refusal to settle for second best, you could find your needle in a haystack more than a third of the time. The winning strategy is simple: Reject the first approximately 37 percent of the choices no matter what. Then pick the first option that is better than all the others you've encountered so far. (If you never find such an option, take the final one.)

Adding to the fun, mathematicians' favorite little constant, *e* = 2.7182..., rears its head in the solution. Also known as Euler's number, *e* holds fame for cropping up all across the mathematical landscape in seemingly unrelated settings—including in the best-choice problem. Under the hood, those references to 37 percent in the optimal strategy and corresponding probability of success are actually 1/*e*, or about 0.368. The magic number comes from the tension between wanting to see enough samples to feel informed about the distribution of options and not wanting to wait too long lest the best pass you by. The proof argues that 1/*e* balances these forces.

The first known reference to the best-choice problem in writing appeared in Martin Gardner's beloved Mathematical Games column in *Scientific American*. The problem had spread by word of mouth in the mathematical community in the 1950s, and Gardner outlined it in the February 1960 issue by describing a puzzle game called Googol, following up with a solution the next month.

Today the problem generates thousands of hits on Google Scholar as mathematicians continue to study its many variants: What if you're allowed to pick more than one option, and you win if any of your choices are the best? What if an adversary chose the ordering of the options to trick you? What if you don't require the absolute best choice and would feel satisfied with second or third? Researchers study such when-to-stop scenarios in a branch of math called optimal stopping theory.

Looking for a house—or a spouse? David Wees, who designs math curricula, applied the best-choice strategy to his personal life. While apartment hunting, Wees recognized that to compete in a seller's market, he would have to commit to an apartment on the spot at the viewing before another buyer snatched it. With his pace of viewings and six-month deadline, he extrapolated that he had time to visit 26 units. And 37 percent of 26 rounds up to 10, so Wees rejected the first 10 places and signed the first subsequent apartment that he preferred to all the previous ones. Without inspecting the remaining batch, he couldn't know whether he had in fact secured the best, but he could at least rest easy knowing he had maximized his chances.

When in his 20s, Michael Trick, now dean of Carnegie Mellon University in Qatar, applied similar reasoning to his love life. He figured that people begin dating at 18, and he assumed that he would no longer date after 40 and would meet potential partners at a consistent rate. Taking 37 percent of this time span would put him at age 26, at which point he vowed to propose to the first woman he met whom he liked more than all his previous dates. He met Ms. Right, got down on one knee and was promptly rejected. The best-choice problem doesn't cover cases where opportunities may turn you down. Perhaps it's best we leave math out of romance.

Empirical research finds that people tend to stop their search too early. So applying the 37 percent rule could improve your decision-making, but be sure to double-check that your situation meets all the conditions: a known number of rankable options is being presented one at a time in any order, you want the best, and you can't double back. Nearly every conceivable variant of the problem has been analyzed, and tweaking the conditions can change the optimal strategy in ways large and small. For example, Wees and Trick didn't really know their total number of potential candidates, so they substituted in reasonable estimates instead.

If decisions don't need to be made on the spot, that nullifies the need for a strategy entirely: simply evaluate every candidate and pick your favorite. If you can settle for a broadly good outcome instead of the absolute best option, then a similar strategy still works, but a different threshold, typically lower than 37 percent, becomes optimal. Whatever dilemma you face, there's probably a best-choice strategy that will help you quit while you're ahead.

Jack Murtagh is a freelance math writer and puzzle creator. He writes a column on mathematical curiosities for *Scientific American* and creates daily puzzles for the Morning Brew newsletter. He

holds a Ph.D. in theoretical computer science from Harvard University. Follow Jack on X @JackPMurtagh

---

https://www.scientificamerican.com/article/this-elegant-math-problem-could-help-you-make-the-best-choice-in-house

Medicine

- ## The First Person to Receive an Eye and Face Transplant Is Recovering Well
  A man who received a partial face and eye transplant after a serious accident does not have any vision in the transplanted eye, but the eye itself is still alive

The First Person to Receive an Eye and Face Transplant Is Recovering Well

A man who received a partial face and eye transplant after a serious accident does not have any vision in the transplanted eye, but the eye itself is still alive

By Tanya Lewis edited by Dean Visser

Aaron James received a whole-eye and partial-face transplant in 2023.
Haley Ricciardi/NYU Langone Health

In June of 2021 Aaron James, then 44 years old, experienced a terrible accident while working as an electrical lineman. The military veteran and Arkansas resident lost much of the left side of his face—including his left eye—to severely disfiguring electrical burns that also destroyed his left arm.

Two years later James received the first-ever partial-face and whole-eye transplant, performed by surgeons at NYU Langone Health in New York City. More than a year after that James had made a strong recovery with no evidence of tissue rejection, as reported by his medical team in a paper published last September in *JAMA*. He still lacks any vision in the transplanted eye, but the eye itself has maintained its shape and blood flow—and there is evidence of electrical activity in the retina in response to light.

Other researchers say the findings represent a step toward successful whole-eye transplants while illustrating the challenge of regenerating the optic nerve after a major injury. “It’s a delightful surprise that the surgery has worked so well, that the patient is so happy, that the aesthetic or cosmetic outcome has worked so well. The eyeball itself has stayed alive and is able to stay in that space and can continue to contribute to the overall success of hemifacial transplant,” says Jeffrey Goldberg, a professor and chair of ophthalmology at the Byers Eye Institute at Stanford University, who was not involved in the study but wrote a commentary on it that was published in the same issue of *JAMA*.

The lack of restored vision was not unexpected, Goldberg says, because preclinical studies in animals have shown the difficulty of regrowing an optic nerve. He notes that the surgical team’s technique of injecting the tissue surrounding the optic nerve with stem cells from James’s bone marrow has not been validated in animals and could pose a safety risk if the cells grew into a tumor. Fortunately, there is no evidence of this happening to date.

Another risk was that if the donor eye’s optic nerve had regrown, it could have compromised the vision in James’s other eye because of the way input from the two eyes can interact in the brain. There is no sign of this complication, either. This exciting first case helps to lay the groundwork to push whole-eye transplant into a vision-restoring reality, Goldberg says.

Whole-eye transplants have long been a dream among doctors and scientists seeking to treat people with serious eye injuries or blindness. The first corneal transplant took place in 1905. But efforts to transplant an entire eye have been thwarted by the devilish difficulty of regrowing the optic nerve, which carries signals from the eye’s light sensitive retina to the brain’s visual centers, where they are perceived as sight. There had been limited success in previous efforts to regenerate the optic nerve in some animals, but no one had succeeded in transplanting a whole eye into a human until now.

Aaron James (*left*) with Eduardo Rodriguez, director of the face transplant program and chair of the department of plastic surgery at NYU Langone Health.
Haley Ricciardi/NYU Langone Health

“Aaron has had amazing functional improvement, and the aesthetic result is remarkable,” says Eduardo Rodriguez, one of the many physicians involved in James’s care. “My ultimate goal was to preserve [the eye] alive,” says Rodriguez, who is director of the face transplant program and chair of the department of plastic surgery at NYU Langone Health. “The fact we achieved that is remarkable. What would happen afterward, no one could say because it had never been done.”

Even though James’s transplanted eye lacks vision, the fact that it has maintained its shape and blood supply for more than a year is remarkable, says Vaidehi Dedania, an associate professor in the department of ophthalmology at the NYU Grossman School of Medicine, who has been monitoring the eye’s health. The retinal cells’ response to light was also surprising, she says, adding that “an eye has not been transplanted from one human to another before and continued to survive and sustain itself within that body for so long."

James and his wife, Meagan James, were in New York City in August 2024 to meet with his medical team as part of his postoperative monitoring. *Scientific American* sat down with them to discuss Aaron's recovery and what this surgery has meant for his life.

An edited transcript of the interview follows.

It's been a little under a year and a half since your transplant surgery. How are you doing?

AARON JAMES: Everything's going good. It's been, as you said, a little over a year, and the face is still kind of moving. There's still work to be done. I'm still going to speech therapy. And just because we had the surgery, that doesn't mean it's finished. We've still got a lot of maintenance to do. But, I mean, I feel good. All my blood work and stuff has come back good. And so, yeah, we're just kind of holding where we're at right now, you know?

Your face looks like it's healed really well.

AARON JAMES: It's amazing how well the body can regenerate. It's great. There are a lot of people who don't even know that I've had a face transplant.

I know you don't have any vision in the transplanted eye, but do you have any pain or discomfort?

AARON JAMES: No. I mean, it feels just like my own. There's no pain. The doctors were kind of concerned in the beginning that there might be a lot of pain, but it's really just exceeded expectations—I mean, just the fact that it's still alive after almost a year and a half. Right after the surgery, they said, "Okay, the eye's survived the surgery. Now let's do 90 days." And we made it past

90 days. And it just keeps going and going. So we're kind of in uncharted waters right now. We're just kind of seeing what happens next.

Meagan and Aaron James.
Haley Ricciardi/NYU Langone Health

How does it feel to be the first person to have had this surgery?

AARON JAMES: It feels good. To be a part of this, it's kind of overwhelming, I guess, because we're just a simple family from Arkansas. If I can be a part of something that gets it started, that makes me feel good. It makes me feel like I've helped out possibly millions of people in the future.

Ever since my accident, it's made me think about things I normally wouldn't give a second thought to. Now I think of people with visual problems. There are so many people who have visual impairments, and once I thought about it I can't believe something hadn't been done before, because there are so many people with eye issues. So it's about time.

What has your life been like in the past year? Have you been able to get back to doing things you did before the accident?

AARON JAMES: In the beginning, once we got home, I'd have to kind of watch what I was doing because of my white blood cell count. It was kind of fluctuating. But, knock on wood, I think we finally got that figured out. There's still things I have to kind of watch out for, you know, being out in the sun too long [because the immunosuppressive drugs increase the risk of skin cancer]. But that's really not that big of a deal.

Have you had any immune rejection of the face or eye or other complications?

AARON JAMES: No.

Did your vision in your right, nontransplanted eye change after the accident?

AARON JAMES: Yeah, it formed a cataract first, and they had to remove that. I wear a contact and reading glasses if I need to see something up close.

What are some of the emotional challenges you've both experienced?

AARON JAMES: We live about two and a half hours from the rest of our family. My mom is in a nursing home because she had a stroke. So that's kind of hard because they've always got COVID cases and other illnesses in this nursing home, so I can't really go up there like I want to, because I can't be around that stuff.

MEAGAN JAMES: Just the number of things that it entails, from the beginning of the accident. Aaron mentioned his mom had a stroke. And a few months after that, I actually lost my mom. And then, a few months ago, I lost a sister to breast cancer she had battled for five years. So it's a lot of extra mental toll on top of the amount of mental toll that it is. We've definitely become closer through all of this.

AARON JAMES: Yeah, definitely. And now we've got our daughter fixing to start college. So now we can kind of focus on real life—regular stuff. It's finally getting back on track.

Aaron James with Meagan (*left*). Aaron James and family (*right*).
Meagan James

Have you found any helpful ways to cope with the recovery?

AARON JAMES: One way we deal with it is having a sense of humor—joke about it, you know?

MEAGAN JAMES: If you listened to our daily conversations, you probably wouldn't believe any of this. We're just mean to each other, but it's just our way of coping, I guess. We have fun; we joke and laugh.

Meagan, is there anything you'd like to say about your experience taking care of Aaron?

MEAGAN JAMES: I always said I was going to be famous one day. But I never expected it would be anything like this that I would be a part of. And it's pretty amazing to know that I had a small role. They just sent me home with the first transplanted eye and said, like, "Take care of it." And I'm like, "Who am I to take care of this?"

Aaron, how has this face and eye transplant changed you?

AARON JAMES: It’s definitely something that I still think about every day. I’ll think about everything that’s happened in the past. And now, to be honest, when I look at an older picture of me, it kind of looks weird to me. I recognize it. I know who it is; I know it’s me. But I don’t know—it’s hard to explain that.

Tanya Lewis is a senior editor covering health and medicine at *Scientific American*. She writes and edits stories for the website and print magazine on topics ranging from COVID to organ transplants. She also appears on *Scientific American*'s podcast *Science, Quickly* and writes *Scientific American*'s weekly Health & Biology newsletter. She has held a number of positions over her eight years at *Scientific American*, including health editor, assistant news editor and associate editor at *Scientific American Mind*. Previously, she has written for outlets that include *Insider*, *Wired*, *Science News*, and others. She has a degree in biomedical engineering from Brown University and one in science communication from the University of California, Santa Cruz. Follow her on Bluesky @tanyalewis.bsky.social

---

https://www.scientificamerican.com/article/the-first-person-to-receive-an-eye-and-face-transplant-is-recovering-well

| Section menu | Main menu |

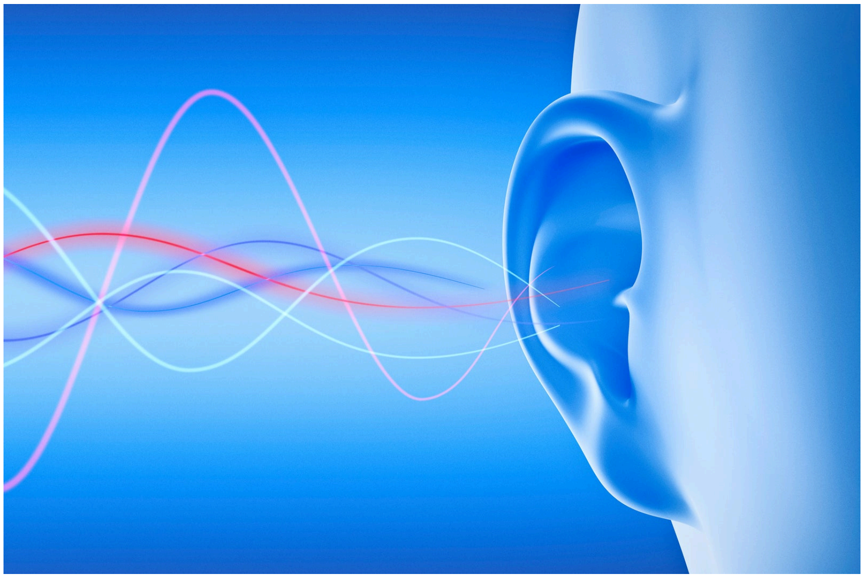
Neuroscience

| Next section | Main menu | Previous section |

How Your Brain Tells Speech and Music Apart

Simple cues help people to distinguish song from the spoken word

By Andrew Chang edited by Daisy Yuhas



Peterschreiber.media/Getty Images

People generally don't confuse the sounds of singing and talking. That may seem obvious, but it's actually quite impressive—particularly because we can usually differentiate between the two even when we encounter a language or musical genre we've never heard before. How exactly does the human brain so effortlessly and instantaneously make such judgments?

Scientists have a relatively rich understanding of how the sounds of speech are transformed into sentences and how musical sounds move us emotionally. When sound waves hit our ear, they activate the auditory nerve within a part of the inner ear called the cochlea. That, in turn, transmits signals to the brain. These signals travel the so-called auditory pathway, first to the subregion for processing all kinds of sounds and then to dedicated music or language subregions. Depending on where the signal ends up, a person comprehends the sound as a particular type of meaningful information—and can distinguish an aria from a spoken sentence.

That’s the broad-strokes story of sound processing. But it remains surprisingly unclear how exactly our perceptual system differentiates these sounds within the auditory pathway. Certainly there are clues: music and speech waveforms have distinct pitches (tones sounding high or low), timbres (qualities of sound), phonemes (speech-sound units) and melodies. But the brain’s auditory pathway does not process all those elements at once. Consider the analogy of sending a letter in the mail from, say, New York City to Taipei. The letter’s contents provide a detailed explanation of its purpose, but the envelope still must indicate its destination. Similarly, even though speech and music are packed with information, our brain needs some basic cues to rapidly determine which regions to engage.

The question for neuroscientists is how the brain decides whether to send incoming sound to the language or music regions for detailed processing. My colleagues at New York University, the Chinese University of Hong Kong and the National Autonomous University of Mexico and I decided to investigate this mystery. In a study published last spring, we present evidence that a simple property of sound called amplitude modulation—which describes how rapidly the volume, or “amplitude,” of a series of sounds changes over time—is a key clue in the brain’s rapid acoustic judgments. Our findings hint at the distinct evolutionary roles music and speech have had for the human species.

Past research had shown that the amplitude-modulation rate of speech is highly consistent across languages, measuring four to five hertz, meaning four to five ups and downs in the sound wave per second. Meanwhile the amplitude-modulation rate of music is consistent across genres, at about one to two hertz. Put another way: when we talk, the volume of our voice changes much more rapidly in a given span of time than it does when we sing.

Given the cross-cultural consistency of this pattern, we wondered whether amplitude modulation might reflect a universal biological signature that plays a critical role in how the brain distinguishes speech and music. We created special audio clips of white noise in which we adjusted how rapidly volume and sound changed over time. We also adjusted how regularly such changes occurred—that is, whether the audio had a reliable rhythm. We used these white noise clips rather than realistic audio recordings to better control for the effects of amplitude modulation, as opposed to other aspects of sound, such as pitch or timbre.

Across four experiments with more than 300 participants, we asked people to listen to these audio files and tell us whether they sounded more like speech or music. The results revealed a strikingly simple principle: audio clips with slower amplitude-modulation rates and more regular rhythms were more likely to be judged as music, and the opposite pattern applied for speech. This suggests that our brain associates slower, more regular changes in amplitude with music and faster, irregular changes with speech.

These findings inspire deeper questions about the human mind. First, *why* are speech and music so distinct in their amplitude over time? Evolutionary hypotheses offer some possible answers. Humans use speech for communication. When we talk, we engage muscles in the vocal tract, including the jaw, tongue and lips. A comfortable speed for moving these muscles for talking is around four to five hertz. Interestingly, our auditory perception of sound at this speed is enhanced. This alignment in speed, production and perception is probably not a coincidence. A possible explanation is that humans talk at this neurophysiologically optimized fast speed to ensure efficient information exchange—and this fast talking could explain the higher amplitude-modulation rate in speech versus music.

Separately, one hypothesis about the evolutionary origin of music is that it effectively builds social bonds within a society by coordinating multiple people's activities and movement, such as through parent-infant interactions, group dancing and work songs. Studies have shown that people bond more closely when they move together in synchrony. Therefore, it's possible that for music to serve its evolutionary function, it needs to be at a speed that allows for comfortable human movement, around one to two hertz or lower. Additionally, a predictable beat makes the music more appealing for dancing in a group.

There are still many questions to explore. More studies are needed on whether the brain is able from birth to separate music and speech based on acoustic modulation or whether it relies on learned patterns. Understanding this mechanism could help patients with aphasia, a condition that affects verbal communication, comprehend language via music with carefully tuned speed and regularity. Our evolutionary concepts, too, warrant further investigation. Diverse hypotheses exist around the evolutionary origins of music and speech, which could spur other studies. And more cross-cultural research could ensure that these ideas really hold up across all communities.

As to how the brain distinguishes music from speech in the auditory pathway, we suspect there is more to uncover. Amplitude modulation is most likely just one factor—one line, perhaps, on the addressed envelope—that can help explain our brain's amazing capacity for discernment.

Are you a scientist who specializes in neuroscience, cognitive science or psychology? And have you read a recent peer-reviewed paper that you would like to write about for Mind Matters? Please send suggestions to Scientific American*'s Mind Matters editor Daisy Yuhas at dyuhas@sciam.com.*

Andrew Chang is a postdoctoral fellow at New York University, whose work has been supported by the National Institutes of Health's Ruth L. Kirschstein Postdoctoral Individual National Research Service Award and by the Leon Levy Scholarships in Neuroscience. He studies the neural mechanisms of auditory perception and the ways people use music and speech to interact in the real world.

https://www.scientificamerican.com/article/how-your-brain-tells-speech-and-music-apart

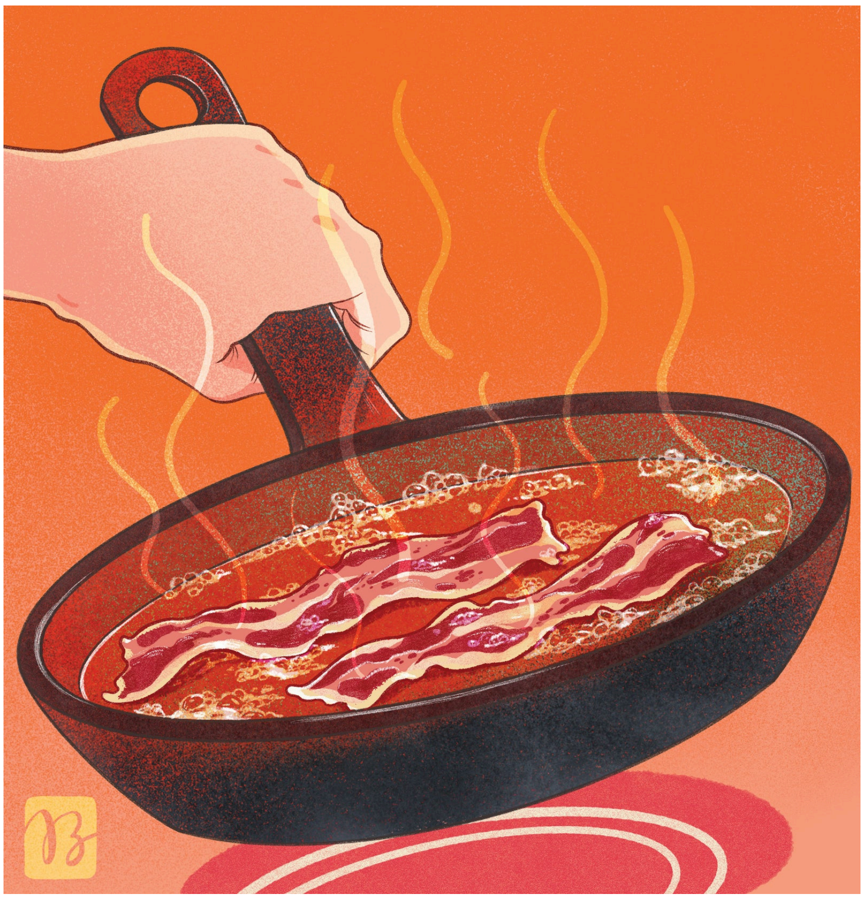
Nutrition

- **Delicious Bacon Highlights Food That Enraptures Our Senses but Endangers Our Health**
  Some foods, no matter how simply prepared, contain many substances linked to disease

Delicious Bacon Highlights Food That Enraptures Our Senses but Endangers Our Health

Some foods, no matter how simply prepared, contain many substances linked to disease

By Lydia Denworth edited by Josh Fischman



Jay Bendt

My love of bacon is legendary in my family. When I was about five, I stood by the stove while my Great Grandma Bess cooked breakfast. “I like bacon!” I told her repeatedly, as I stood on tiptoe, peering over the edge of the pan and watching the sizzling strips brown to perfection. Or so the story goes.

I still like bacon, and I’m not alone. Some vegetarians I know make an exception for the stuff. “Bacon is a sensory triple whammy,” says Dani Reed, chief science officer of the Monell Chemical Senses Center in Philadelphia. First, the smell lures most people in, thanks to the volatile organic compounds created and released during frying. Then there's the taste of salt and sugar, both of which are enormously appealing to humans. Finally, there's the fat, which creates "a lovely texture in the whole mouth," Reed says. Taken together, these three features make bacon "hard for people to resist, even those who have strong prohibitions against pork. It's a tsunami of yummy," she says.

Yet that powerful wave of deliciousness consists of clearly unhealthy elements. The World Health Organization declared bacon a carcinogen in 2015. Bacon is about 40 percent saturated fat, one of the consistent no-no's of nutrition. Nitrates and nitrites added to cure bacon are linked to hypertension and cancer. While it's cooking, bacon releases molecules called heterocyclic amines and polycyclic aromatic hydrocarbons, which are also linked to cancer. And the salt in bacon may contribute to metabolic problems.

In recent years, however, the focus of nutritional research has shifted from the nutritional profiles of various foods the work that tells us whole grains are good for us and the saturated fat in bacon is not—to the issue of how much industrial processing food undergoes, especially a class of foods described as "ultraprocessed."

According to the most common classification system (called NOVA), ultraprocessed foods and drinks have numerous industrially derived additives that can include oils, fats, color enhancers, flavor enhancers, nonsugar sweeteners, and bulking and firming agents. Soda, potato chips and candy are typically ultraprocessed, but so are flavored yogurt and lots of bread you buy at the supermarket. Processed foods, the next class, have fewer added ingredients put in for preservation or to heighten taste. Unprocessed foods, as you might expect, are edible parts of plants and animals; they might be frozen or dried for storage but nothing else.

Bacon is generally considered processed because it has added salt, sometimes sugar, nitrates, and so on. It's called ultraprocessed only when it has extra flavoring and other chemical agents. That has generated concern among some nutrition researchers. They fear the message the public may hear is that it's okay to eat more bacon and other unhealthy foods so long as they are not ultraprocessed. These scientists want consumers to remember that substances in simply processed bacon are also linked to diseases.

There hasn't been a lot of research comparing the illness risks of ultraprocessed versus processed foods. A 2024 meta-analysis found that higher consumption of ultraprocessed foods increased the risks of cardiometabolic disorders, mental health issues and mortality. But much remains unknown. One major issue is that there is not yet a widely agreed-on definition of "ultraprocessed." (The NOVA classification system is only a rough guide.) As a result, scientists working on the 2025–2030 Dietary Guidelines for Americans, a U.S. federal government project, announced in October 2024 that they would not be weighing in on ultraprocessed foods. Instead they will stick closely to recommendations in the current guidelines, which emphasize eating foods that are high in nutrients and low in sugar, sodium and saturated fat.

Nutrition scientist Julie Hess of the U.S. Department of Agriculture has shown how complicated the ultraprocessed question can be. She and her colleagues created a seven-day diet of about 2,000 calories per day that meets U.S. healthy dietary guidelines but consists of mostly ultraprocessed food. One sample breakfast is a breakfast burrito with liquid egg whites, shredded cheese and canned beans. The scientists also created a diet that consists almost entirely of less processed foods yet overall is of low nutrient quality. That version of breakfast is high-fat, high-sugar pancakes and bacon.

It is probably best to consider both nutrient quality and the degree of food processing, says nutritionist and epidemiologist Mingyang Song of the Harvard T. H. Chan School of Public Health. In a 2024 study, he and his colleagues broke foods into subgroups based on processing, then looked at mortality risk and the amount consumed. Sugar-sweetened drinks such as soda and processed meats were both linked to heightened mortality for people who consumed more servings per day, about seven compared with three. But there was no such increased risk for some types of ultraprocessed foods such as breakfast cereals and commercial breads. Overall, Song says, “if people can maintain a pretty healthy diet, consuming some amount of ultraprocessed food doesn’t really [have much effect].”

Nutritional epidemiologist Kathryn Bradbury of the University of Auckland in New Zealand also cautions against losing sight of what we know is unhealthy. “We don’t need to get too caught up in whether a food product is technically ultraprocessed or not,” she says. As we’ve long been told, we should eat more fruits, vegetables and whole grains. And we should avoid foods that are high in calories, saturated fat, salt and added sugar, Bradbury says. In other words, go back to basics—and not back to bacon, which should be consumed only as an occasional treat. Alas.

Lydia Denworth is an award-winning science journalist and contributing editor for *Scientific American*. She is author of *Friendship* (W. W. Norton, 2020).

---

https://www.scientificamerican.com/article/delicious-bacon-highlights-food-that-enraptures-our-senses-but-endangers-our-health

Oceans

- **‘Marine Snow’ Studies Show How the Ocean Eats Carbon**
  The ocean’s digestive system is dictated by picky microbes and precise dynamics of drifting debris

‘Marine Snow’ Studies Show How the Ocean Eats Carbon

The ocean’s digestive system is dictated by picky microbes and precise dynamics of drifting debris

By Susan Cosier edited by Sarah Lewin Frasier

Carbon falls as “marine snow” through ocean layers.
Ippei Naoi/Getty Images

From the sunlit top 200 meters of the sea, plankton carcasses, excrement and molt particles constantly drift toward the depths. As this so-called marine snow sinks, the bits can clump together or break apart, gain speed or sink more slowly, or get eaten up by bacteria. They descend through darker, colder and denser waters, carrying carbon with them and settling on the bottom as biomass.

The oceans absorb billions of tons of carbon every year, a process crucial to account for in climate models. But researchers have long been stumped by how much carbon actually reaches the seafloor—and stays there. To find out, oceanographers are investigating how carbon is eaten, expelled and otherwise influenced as it drifts through what some scientists think of as the ocean's "digestive system."

Measuring the rate of carbon storage means scrutinizing the composition of what sinks, how particles stick together and thus drop faster or slower, the decelerating effects of mucus-producing phytoplankton—and even, for a new study published in *Science*, specific microbes' dietary preferences.

"We currently do not have a very good way to connect the processes at the surface with what's arriving at the seafloor," says Monterey Bay Aquarium Research Institute oceanographer Colleen Durkin. "We know they're linked, but it's been very difficult to observe the mechanisms that drive that connection."

Recent advances in sensor development, imaging and DNA sequencing are now giving researchers a closer look at the particular organisms and processes at work. By isolating and testing bacterial populations in marine snow, the study's co-author Benjamin Van Mooy, a researcher at Woods Hole Oceanographic Institution, and his colleagues found that specific microbe populations prefer to eat phytoplankton that contain specific kinds of fatty acid biomolecules called lipids.

Lipids constitute up to 30 percent of the particulate organic matter at the ocean's surface, so bacterial dietary preferences in a given region could significantly alter how much carbon-containing biomass reaches the seafloor. "If we can start to understand what [microbes] can do, then we can imagine a future where we can start to predict, potentially, the fate of carbon based on the organisms that are present," says Van Mooy, who was awarded a MacArthur Fellowship in 2024 for his work.

Scientists are also working to document what falls through particular locations over various time frames. Sediment traps reveal a snapshot of certain areas' marine snow, and Durkin and others are deploying sensors with autonomous cameras to observe sinking particles over a longer period. Seeing the complexity of marine snow distribution, says Rutgers University microbial oceanographer Kay Bidle, “reveals how we can’t necessarily model and understand carbon flux by the very simple constructs and equations and laws that we had before.”

Susan Cosier is a freelance journalist focused on science and the environment. She is based in Chicago. Follow Cosier on Twitter @susancosier

---

https://www.scientificamerican.com/article/marine-snow-studies-show-how-the-ocean-eats-carbon

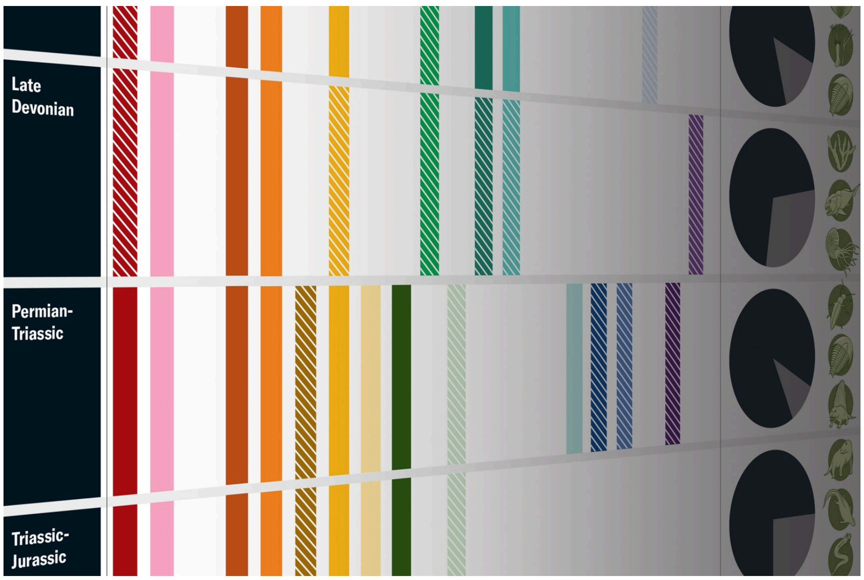
| Section menu | Main menu |

Paleontology

How Earth’s Biggest Mass Extinctions Stack Up

Earth’s deadliest mass extinctions have important commonalities—and significant differences

By Clara Moskowitz & Rick Simonson edited by Clara Moskowitz & Jen Christiansen



Rick Simonson

Life on our planet has experienced many mass extinctions over its 4.5 billion years. Scientists see evidence for at least five major episodes that eradicated creatures great and small. And many experts argue that the Anthropocene age, the current period of human activity altering Earth, is causing a sixth.

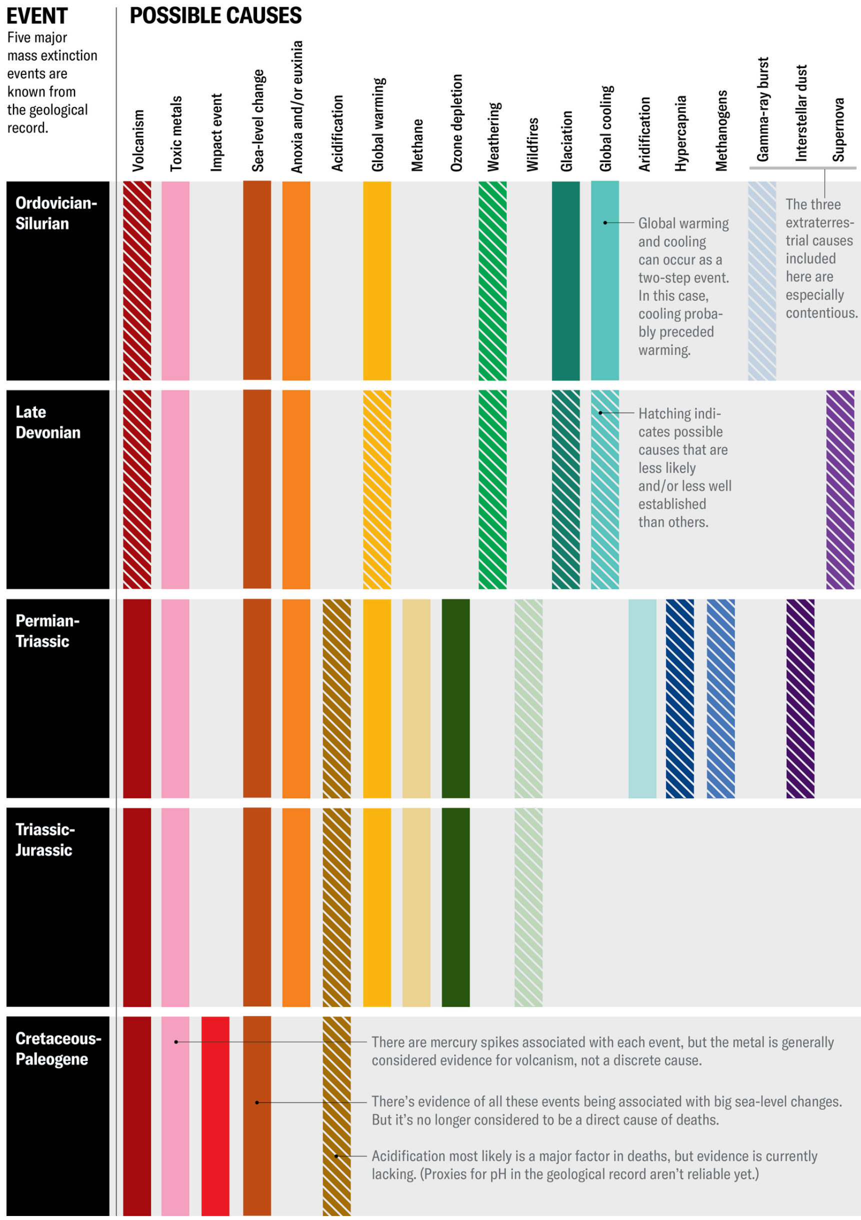
Paleontologists track mass extinctions by studying rock samples from different eras. When they reach a point where large numbers of species that had been abundant in the earlier fossil record become scarce, they’ve found an extinction event. The big five extinctions all wiped out more than 70 percent of Earth life at the time—and the most -lethal of them, the Permian-Triassic extinction around 252 million years ago, most likely took down more than 90 percent.

The origins of these extinctions are still being debated, but scientists think that most involved large spates of volcanism—giant rifts opening in Earth's surface and spewing lava over periods of thousands or even millions of years. The volcanism probably triggered many other changes that led directly to extinctions, including anoxia, or a lack of oxygen, in the oceans as a consequence of ocean warming; ozone depletion, which resulted from volatiles released by volcanism; and wildfires caused by a heated climate.

Studying our geological past can also teach us about the present, says David Bond, a mass extinction expert at the University of Hull in England. "We need to learn lessons from these events and use them to try to understand our potential impending diversity crisis."

Triggers vs. kill mechanisms

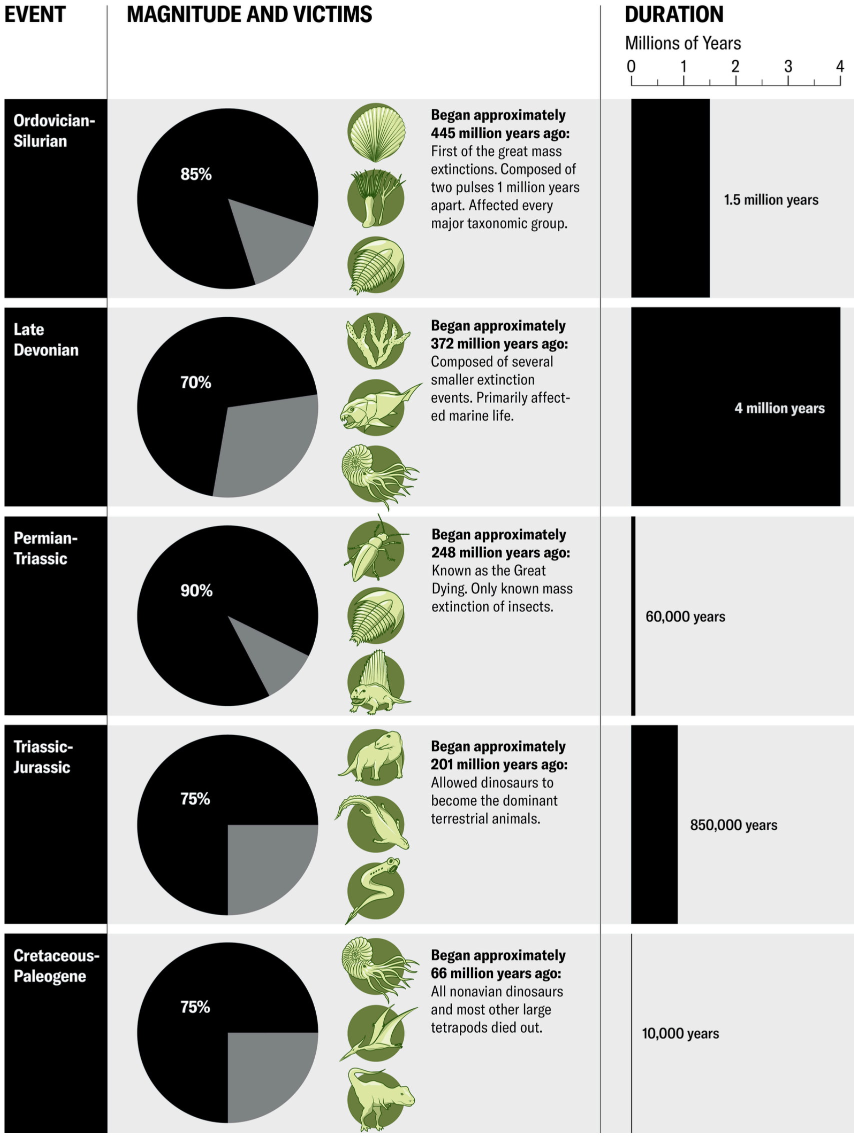
Several of the causes listed here—including volcanism and sea-level change—aren't necessarily major kill mechanisms in and of themselves. For example, an asteroid is not the actual cause of death beyond individuals that are hit directly by it. Rather it triggers widespread deadly conditions, such as anoxia and acidification.



Rick Simonson; David Bond/University of Hull (*scientific reviewer*)

Magnitude and Victims

Each of the five mass extinction events is characterized by the extinction of 70 percent or more of the species living at the time. Some groups completely died out while others experienced significant declines.



Rick Simonson; David Bond/University of Hull (*scientific reviewer*)

Clara Moskowitz is a senior editor at *Scientific American*, where she covers astronomy, space, physics and mathematics. She has been at *Scientific American* for a decade; previously she worked at Space.com. Moskowitz has reported live from rocket launches, space shuttle liftoffs and landings, suborbital spaceflight training, mountaintop observatories, and more. She has a bachelor's degree in astronomy and physics from Wesleyan University and a graduate degree in science communication from the University of California, Santa Cruz.

Rick Simonson is a visual science communicator at Science Lab Studios, Inc. His work can be found at www.scilabstudios.com

---

https://www.scientificamerican.com/article/how-earths-biggest-mass-extinctions-stack-up

| Section menu | Main menu |

Parenting

- ## Why You Should Listen When Your Child Cries, ‘Not Fair!’

  Children need patient adults and lots of practice to understand fairness, justice and equality

Why You Should Listen When Your Child Cries, 'Not Fair!'

Children need patient adults and lots of practice to understand fairness, justice and equality

By Kendra Thomas edited by Megha Satyanarayana

Malte Müller

This piece is part of Scientific American*'s column The Science of Parenting. For more, go here.*

"That's not fair!" I live with two young children and hear this cry often. They say it's unfair that adults get to stay up later, that they didn't get dessert and that they don't have a pool.

I study children's perceptions of justice, so I knew this moment was coming. Even so, I have been surprised at how their cries of injustice over seemingly trivial things irritate me. I sometimes take it personally. How dare they question my benevolent leadership!

I could just shut down the conversation with the classic "life is not fair." I could defend the justice in my actions or call them out for their bad attitudes. I could listen and address the heated emotions over the who-got-what argument. Or I could distract them because I am too tired to tackle a big life lesson. I have done all of these things.

But for kids to become just, they need to practice talking about justice. They need patient adults to help them sort out what's merely unlikable from what is truly unfair.

My research has solidified my understanding that how I respond to my children in these moments will shape their sensitivity to, and empathy toward, people affected by injustice. If we want our children to fight for justice, we need to "lean in" as they grapple with the discomforts of existence. Justice is central to morality, and grappling with unfairness is part of moral development. Disengaging or dismissing children's early cries for justice fosters cynicism and complacency.

Human awareness and concern around justice start early. Babies gaze at kinder puppets longer, preferring them over a puppet that stole a ball and ran away. Toddlers give tasty cookies to good characters and yucky foods to bad ones. Children prefer fairness even when it does not favor them. They would rather take their toy and go home than tolerate an unfair game. With age, children increasingly grasp differences between equality (everyone gets the same) and equity (based on need or merit), as well as individual and structural reasons for inequality. Their understanding of justice deepens.

My research with children in São Paulo, Brazil, shows that by age 12, youths have sophisticated beliefs about justice. Children from wealthier families said their lives were more fair than the world in general. Those in low-income families rated their lives as less just.

We found that by adolescence children at all income levels know justice is not distributed equally.

Families that can afford insurance or call a lawyer friend for free legal advice suffer fewer random injustices. They are less likely to have a devastating house fire or debilitating car accident that plunges them into poverty. Teachers are more likely to give affluent children the benefit of the doubt or ask for their side of the story. Children in poverty are more likely to have negative interactions with the police early in their lives—driving different beliefs about police legitimacy and justice. Systemic issues are undeniable. But social class doesn't fully explain how children develop their views.

> When teachers are fair and policies are transparent, children's lives become more fair. When parents provide explanations and natural consequences, they teach children to expect justice.

Consider families and schools. The children in our research whose parents listened to their side of the story said that their lives were fairer and that they were less likely to become cynical in the coming years—even in poverty. The adolescents most at risk for delinquency were the ones who said their parents and teachers were disrespectful or demeaning.

Children can grow up financially stable and unscathed by systemic prejudice yet still experience sibling favoritism, be dehumanized on social media, or attend a school where administrators are clueless or authoritarian. Zero tolerance school policies typically backfire because they are unfair. A student trying to break up a fight may get the same suspension as the ones who were fighting. Such policies halt conversations about context and intent.

Every experience shapes a kid's worldview. In childhood, injustice comes with a sense of powerlessness; it is both outraging and demoralizing, often fostering cynicism and disengagement. If children are not treated fairly in a group, they assume they do not belong there, which breaks down their social contract. Conversely, when they benefit from injustice (that is, when they are favored or privileged), they may learn to dismiss people's concerns over it, blunting their sensitivity and care for others.

Some schools have disciplinary policies focused on restoring justice. In this model, adults give children ample opportunities to practice constructive conversations. Moreover, they provide students with a way to make things right again. I am part of a team that assessed a school intervention designed to make the classroom more structured and supportive. We asked 1,865 fourth and fifth graders questions throughout the year about fair treatment, rule clarity and the quality of their relationships with teachers. We found that clear school rules and strong relationships within schools predicted youths' expectations of justice and their moral character.

Interestingly, most of these students grew up in low-income families with low social mobility and were exposed to high inequality. Nevertheless, the justice students experienced in the school predicted their bravery, fairness and helping behavior. A child who expects injustice is less likely to speak up to defend a classmate. But youths who experience justice are more likely to model it.

Children need to practice having control over injustice. Injustice is deflating, and every child will experience it. But adults in their lives teach them how to cope with it and act on it. Neuroscience research has revealed that under harsh conditions, the human default is helplessness. Yet even when in pain, we can learn control if we see even minor results. Children need parents, teachers and coaches to buffer injustices and help them feel powerful.

When teachers are fair and policies are transparent, children's lives become more fair. When parents provide explanations and natural consequences, they teach children to expect justice. A child who can tell their side of the story before facing a consequence is receiving due process. A teacher who refrains from disrespecting students when they need to be corrected is offering justice. Parents teach their children about justice when they do not shut down the conversation after a child screams, “That’s not fair!”

When your child says something is unfair, resist the urge to snap back. Consider the unpleasantness they are experiencing, and discern what level of complexity they can handle. Perhaps they are just annoyed and need help differentiating injustice from discomfort. Perhaps they are handling a minor injustice and need a listening ear and some perspective. Or maybe they need space to be told they are not wrong to feel outraged and are part of a larger story of injustice and tragedy.

Let children tell their side of the story; provide predictable consequences; let them make it right. If children grow up believing life is always fair, they will be easily discouraged when life gets hard. Those who believe the world is a just place are the most likely to believe a victim deserved whatever happened and blame that person so they can feel less vulnerable. It is a natural self-protective mechanism, but it erodes empathy and character development. Believing life is always unfair, however, can rob children of a sense of power over their environment and could leave them cynical and demoralized.

Children need to think about justice, grapple with it, act on it. Acknowledging unfairness and striving for justice is the only rational path in a painful world.

A while back my son, age four, lost his cookie-eating privileges for the day because of his bad attitude at breakfast. That afternoon my daughter, age six, surprised me by saying she wasn’t going to eat her cookie, either. Motivated by justice, she chose solidarity with her brother and equality. Yet she has no problem understanding that she can stay up later than her brother because she is older. She comprehends equity; she also knows she can’t flaunt it. These tiny family moments are part of a bigger picture.

When I hear my children say, “That’s not fair,” as much as I want to override their arguments, my better judgment reminds me to slow down and let them practice thinking about it. I want to teach my children to identify real injustices and learn that their behavior matters. I want them to feel strong enough to speak up for a child who gets mocked online and to listen to others’ side of the story. Then, chances are, when faced with both personal and societal injustice, they’ll be sensitive enough yet strong enough to do something about it.

Kendra Thomas is an associate professor of psychology at Hope College in Michigan and a mother of two. She researches youths’ perceptions of justice. The Templeton World Charity Foundation and the John Templeton Foundation fund her work.

---

https://www.scientificamerican.com/article/why-you-should-listen-when-your-child-cries-not-fair

| Section menu | Main menu |

Space Exploration

- **It’s Never Been a Better Time to Look Up**
  Astronomy is a bright spot amid turbulence on Earth

It’s Never Been a Better Time to Look Up

Astronomy is a bright spot amid turbulence on Earth

By The Editors

A JWST photograph shows the NGC 602 star cluster in the Small Magellanic Cloud.
ESA/Webb, NASA and CSA, P. Zeidler, E. Sabbi, A. Nota, M. Zamani (ESA/Webb)

Things have been tumultuous lately on Earth. Donald Trump will soon be sworn in as U.S. president, wars are raging, and ecosystems are at risk of collapsing. Many aspects of life feel unpredictable. But beyond our planet, things are swell. It’s arguably the best time in history to study space.

The colossally powerful James Webb Space Telescope (JWST) has upended textbook basics several times since its launch in 2021. It’s spied galaxies born shortly after the big bang that are far brighter and bigger than scientists thought they had a right to be, seen surprisingly gigantic ancient black holes, and identified life-supporting compounds such as carbon dioxide in the atmospheres of exoplanets for the first time. Its discoveries are coming so fast that scientists sometimes don’t know which of its many findings to focus their research on.

These riches are only growing with several other big-ticket observatories that have recently opened or will soon. In 2023 Europe launched its Euclid telescope into space to focus on the dark universe—the mysterious dark energy and dark matter that seem to dominate the cosmos. This year the Vera C. Rubin Observatory in Chile will begin photographing the full sky every few nights, observing moving objects, brief flares and how the universe changes over time. And in 2027 NASA's Nancy Grace Roman Space Telescope will join JWST in viewing space through infrared light, peering back to the earliest epochs of the universe.

With JWST's price tag at $10 billion (it's the most expensive observatory ever built), Euclid's at $1.5 billion, Nancy Grace Roman's at $4.3 billion and Vera C. Rubin's at $473 million and counting, why spend this kind of money on space when there are so many problems here on Earth?

Making life on Earth better is a worthy goal, but so is astronomy. Even with these high costs, less than 0.5 percent of the U.S. federal budget goes to NASA every year. And our study of space shows that we humans can still work together across nations and rivalries to accomplish great things. It proves that we can dedicate huge resources and effort to goals that offer no financial gain or material advantage. Knowledge for its own sake is valuable, and its pursuit is justified even if it makes no practical difference here on our planet.

But in fact, astronomy does directly affect people's lives. The need to power spacecraft has pushed development of the solar panel technology we use on Earth. Research on the charge-coupled device (CCD) cameras used in telescopes has enabled the cell-phone camera technology in our pockets. Furthermore, viewing Earth from space has helped us understand our changing climate and even drawn humans together in appreciating the fragility of our world.

And what we stand to lose if we divert funding for space research is literally astronomical. The Rubin observatory alone will produce about 20 trillion bytes of raw data per night, and the Roman telescope will add another trillion bytes daily—not to mention the roughly 50 billion bytes coming in from JWST every day. All told, astronomers now have access to a fire hose of celestial information where they once were lucky to get a trickle. Mining these troves will help us understand what happened when the universe was first created. We might figure out how stars and galaxies are born, evolve and die, and we hope we will, possibly, solve some of the biggest mysteries in space: What is dark matter made of? What's the nature of the dark energy pulling apart the cosmos? Is there life beyond us out there somewhere?

The money and work that go toward understanding the universe and our place in it are far from a waste—this project is among the most noble that humanity undertakes. Astronomy serves to remind us that we are part of something much grander than ourselves—that the turmoil of life on Earth, both its wonders and its tragedies, isn't all there is. By peering at the stars, we can see that our lives are a small piece of a great and mysterious working.

Just a few hundred years ago we relied on stories to explain what we saw when we looked into the night sky. Today we are more poised than ever to describe our universe the way it really is. This unfolding tale is turning out to be more fascinating than anything humans can invent, and our knowledge of it is worth every penny we spend.

---

https://www.scientificamerican.com/article/its-never-been-a-better-time-to-look-up

Weather

- **Lightning on Earth Knocks ‘Killer Electrons’ Loose in Orbit**
  High-energy electrons released by storms on Earth can threaten satellites and spacecraft

Lightning on Earth Knocks ‘Killer Electrons’ Loose in Orbit

High-energy electrons released by storms on Earth can threaten satellites and spacecraft

By Kate Graham-Shaw edited by Sarah Lewin Frasier

Lightning releases charged particles in Earth’s orbit.
Samuel Boivin/Getty Images

Lightning strikes in the atmosphere can trigger a rain of high-powered “killer electrons” in low-Earth orbit that form harmful streams of radiation, new research suggests. Scientists had previously thought killer electrons might appear only in our planet’s distant outer radiation belt, but a study in *Nature Communications* finds that lightning nudges them loose in the much closer inner belt, too.

“These high-energy particles are damaging to spacecraft and also to humans in space,” says study co-author Lauren Blum, an astrophysicist at the University of Colorado Boulder. “Knowing when there are very high-energy electrons in the inner radiation belt would be helpful to know when to avoid it.”

Electron precipitation occurs when charged particles, held in place by Earth's magnetic field, are dislodged from stasis in one of the planet's doughnut-shaped radiation belts. Examining data from NASA's SAMPEX mission, which tracked charged particles, the new study's lead author Max Feinland (then an undergraduate student at Boulder) noticed something strange in the readings on "microbursts"—quick surges of high-energy electron precipitation recorded between 1996 and 2006. After designing an algorithm to find these spikes in the data, Feinland was surprised to see readings from the inner radiation belt, which many scientists thought hosted only less energetic, slower electrons. Feinland and Blum, then Feinland's research adviser, immediately began wondering about potential causes. "People knew that there was lightning-induced electron precipitation in the inner belt," Feinland says, but "they hadn't conclusively seen it for electrons that are going this fast."

Comparing their microburst data with National Lightning Detection Network datasets, the researchers found a statistical likelihood that bursts in the inner belt indeed coincide with lightning flashes. Electromagnetic waves unleashed by the latter travel up Earth's magnetic field lines from the atmosphere and into the region of the inner radiation belt, where their energy is enough to knock high-energy electrons out of their magnetic confinement.

The team's findings are compelling because it seems that no one has made such a link before, says space weather scientist Steven Morley of Los Alamos National Laboratory. This area of research has data constraints, he adds, as there have been few measurements since SAMPEX ended two decades ago. But he says that the study "is very exciting, even though it is very data-limited. It really does open up a lot of other questions."

These findings are a "wake-up call" for how weather on Earth and in space are intertwined, Blum says; this connection could potentially have consequences for the ozone layer, atmospheric chemistry and even climate. "We can't just study sun-to-Earth and radiation belt dynamics separately," she says. "We have to understand what's going on below in our own atmosphere and terrestrial weather systems, too."

Kate Graham-Shaw is a journalist based in New York City. She covers international news for Japanese media and also covers health and science topics as a freelancer.

---

https://www.scientificamerican.com/article/lightning-on-earth-knocks-killer-electrons-loose-in-orbit