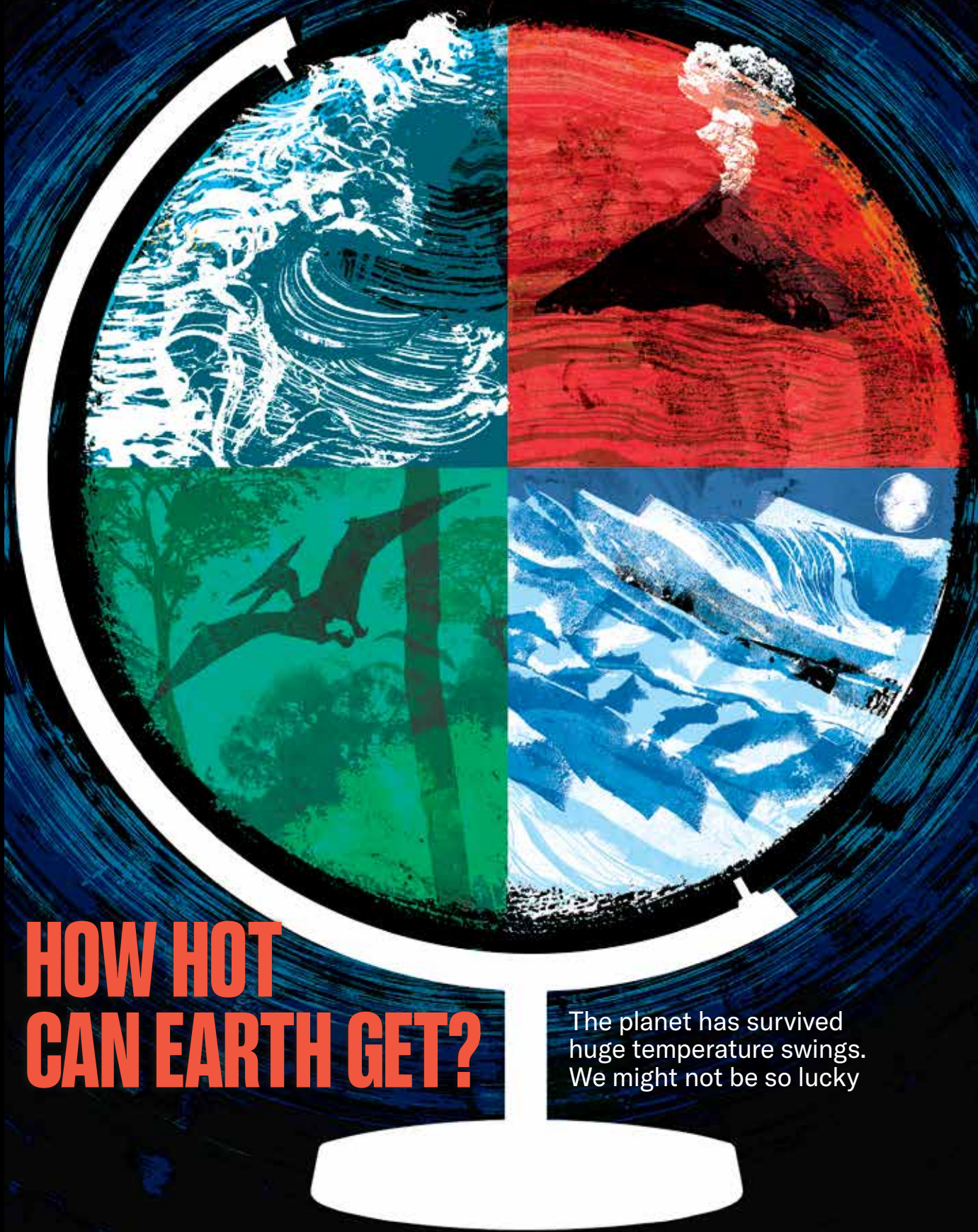
ScienceNews



# HOW HOT CAN EARTH GET?

The planet has survived huge temperature swings. We might not be so lucky

SCIENCENEWS.ORG | VOL. 207 NO. 8 | AUGUST 2025

JOHNS HOPKINS
UNIVERSITY

# WHERE STEM STUDENTS BUILD THE FUTURE

Counselors and educators like you play a major role in helping identify talented students who would thrive in a community like ours—a place with expert mentors, significant research opportunities, and funding to match. That's why we've created resources to support you in your work.

**#1**
in the U.S. for Research Investment

**$156M+**
Awarded in Need-Based Scholarships Last Year

**98%**
Students With at Least One Research or Internship Experience

## Here are some helpful resources for you and your students:

### COLLEGE PLANNING GUIDE

Valuable insights straight from our admissions committee.

→ APPLY.JHU.EDU/PLANNING-GUIDE

### ESSAYS THAT WORKED

Sample application essays and why they stood out.

→ APPLY.JHU.EDU/COLLEGE-ESSAYS

### STUDENT BRAG SHEET

Guidance on writing successful letters of recommendation.

→ APPLY.JHU.EDU/TIPS-AND-BRAG-SHEET

### EVENTS

A range of events, from what we look for in applications to financial aid 101.

→ APPLY.JHU.EDU/COUNSELOR-EVENTS

## Counselor & Educator Newsletter

Sign up to get resources delivered directly to your inbox.

APPLY.JHU.EDU/COUNSELOR-EDUCATOR-NEWSLETTER

VOL. 207 NO. 08 | AUGUST 2025

26



# News




**On the Cover**

Illustration by Andy Lovell

JUAN GAERTNER/SCIENCE PHOTO LIBRARY/GETTY IMAGES

DISCOVER WHY EMBRY-RIDDLE IS

# #1 IN INNOVATION

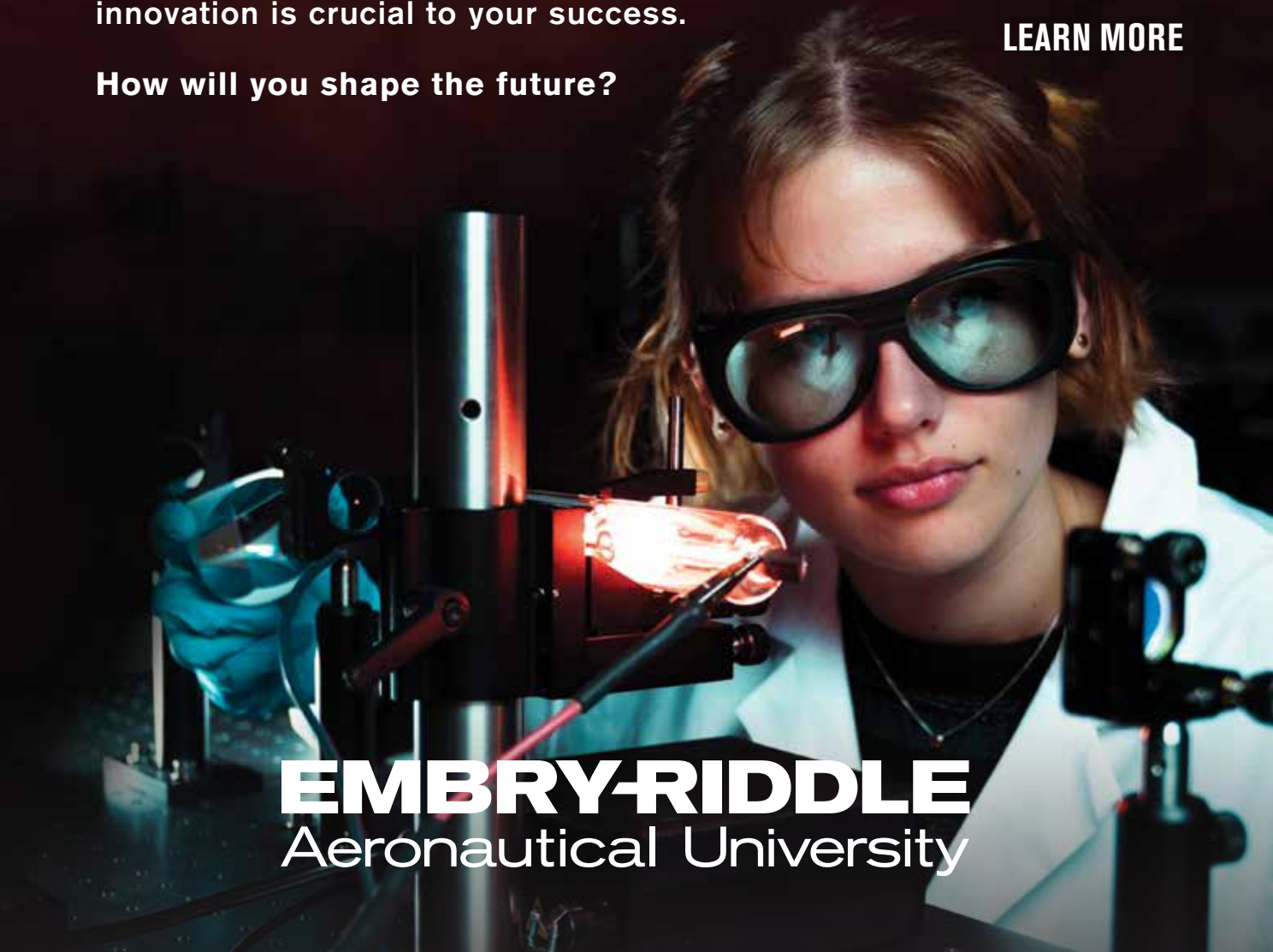
## U.S. NEWS & WORLD REPORT

## EXPLORE 100+ STEM DEGREE PROGRAMS

A degree from Embry-Riddle Aeronautical University helps you stand out from the crowd. Our programs are designed to address the needs of tomorrow — and we know that staying on the cutting-edge of STEM innovation is crucial to your success.

**How will you shape the future?**

LEARN MORE



EMBRY-RIDDLE
Aeronautical University

VOL. 207 NO. 08 | AUGUST 2025

48

## Features



## Curiosities



64

FROM TOP: MAXAL TAMOR/ALAMY; WALTER BIBIKOW/THE IMAGE BANK UNRELEASED/GETTY IMAGES PLUS

# A summer of escalating existential threats

This month marks the 80th anniversary of the first, and so far only, use of atomic weapons in war. The United States dropped an atomic bomb on Hiroshima, Japan, on August 6, 1945. A second bomb was dropped three days later on Nagasaki. The death toll is estimated in the hundreds of thousands. The attacks prompted Japan's surrender and ended World War II. They also kick-started an arms race based on deterrence: If multiple countries have the bomb, they should be less likely to use it, or risk global devastation.

The threat of nuclear war has flared and faded in the decades since, but it became much more salient in June, when the United States bombed Iranian facilities devoted to developing nuclear weapons. Iran has a stockpile of enriched uranium but does not yet have nuclear weapons. But the increased hostilities raise the question of whether the conflict will expand to include countries beyond the United States that do have them — and how the United States could protect itself.

The current U.S. nuclear defense system was designed to fend off a small-scale attack by a country with limited offensive capabilities, such as North Korea. In May, President Donald Trump unveiled plans for his "Golden Dome" concept. It is imagined as a major upgrade, able to block multiple kinds of strikes from a well-armed foe such as China or Russia. Missile defense technology has advanced over the years. But as *Science News*' senior physics writer Emily Conover reports, the laws of physics make a successful interception of even one missile extremely challenging (Page 48).

As if the threat of nuclear warfare wasn't enough to worry about, this summer has also brought more record-smashing heat. Critics of human-caused climate change sometimes note that the planet has gone through cycles when it was much, much hotter than it is now, and thus argue that the current upward trend is not a threat. The planet has indeed endured multiple wild temperature swings.

But while the planet has survived those changes, many of its inhabitants did not. Scientists are closely examining Earth's chaotic history to get a clearer sense of when things will get too hot for humans in the future, freelance writer Elise Cutts reports (Page 32). There's no question that the rising levels of human-generated carbon in the atmosphere are increasing the odds that things will get too toasty much sooner than many of us would like.

**Nancy Shute**
**Editor in Chief**
nshute@sciencenews.org

# For the Man Who Gives Everything and Expects Nothing

If you're anything like my dad, you give your family everything. Your name, your time, your values — the people in your life know they can depend on you for practically anything. In exchange for imparting all of this energy and experience, you expect nothing in return.

The point? You deserve to treat yourself once in a while. You do so much for the people you care about. Now it's time to focus on you for just a few minutes. That's where the Men's Due Volta Watch comes in. This astonishing innovation provides a digital readout that's powered by a precise quartz engine, combining both analog and digital timekeeping.

Outfitted with a stopwatch, alarm, a.m./p.m. settings, and day, date and month complications, this timepiece stands out from the crowd. With its large face and handsome, masculine design, this watch is perfect for the back nine and the happy hour afterwards. Water-resistant up to 3 ATM, this timepiece won't wimp out if you have a run-in with a water hazard.

Other hybrid watches can sell for thousands of dollars, but because we've built more than 1 million watches, we know how to create real value. That's why we can offer this timepiece for just $59! If you're not completely satisfied with this watch, return it for a full refund.

Act quickly! This one-of-a-kind watch has been one of our fastest sellers this year. Of our original run of 2,872, we only have 389 left for this ad! In the last couple of years there's been a watch shortage, but Stauer has got you covered. If you're the kind of man who gives everything and expects nothing in return, it's time to treat yourself.

**Watch Specifications:**

- Complications: stopwatch, alarm, a.m./p.m. settings, and day, date and month
- Precision movement chronograph
- Stainless steel caseback and crown
- Water-resistant to 3 ATM

Men's Due Volta Watch ~~$399~~ $59* + S&P *Save $320*

**Special price only for customers using the offer code.*


*100s of 5 Star Reviews*

★★★★★

*"I like the look and intelligent design of the watch."*

*— Anthony V., Tacoma, WA*

**1-800-333-2045**

**Your Insider Offer Code: DVW284-04**

JOIN MORE THAN 1 MILLION SMART PEOPLE WHO OWN STAUER WATCHES

Stauer, 14091 Southcross Drive W., Dept. DVW284-04, Burnsville, MN 55337 | **www.stauer.com**

Stauer® | AFFORD THE EXTRAORDINARY®

# Science News

Society for Science, publisher of *Science News*, is a nonprofit organization best known for our award-winning journalism, world-class science competitions and STEM outreach programming aimed at increasing opportunities for all young people. For more than a century, *Science News* journalists have provided accurate, editorially independent coverage of science that gives people the information and context they need to evaluate the news and the world around them.




*Science News*
1719 N St. NW
Washington, DC 20036
(202) 785-2255

Alliance for Audited Media

| | |
|---|---|
| **Subscriber services:** | |
| **Email** | subscriptions@sciencenews.org |
| **Phone** | (800) 552-4412 in the U.S. or (937) 610-0240 outside of the U.S. |
| **Web** | www.sciencenews.org/subscribe For renewals, www.sciencenews.org/renew |
| **Mail** | Science News, PO Box 292255, Kettering, OH, 45429-0255 |
| **Editorial and Letters** | feedback@sciencenews.org |
| **Science News Learning** | snlearning@societyforscience.org |
| **Advertising and Sponsor Content** | ads@societyforscience.org |

*Science News* (USPS 484680, ISSN 0036-8423) is published 12 times per year, monthly by the Society for Science & the Public, 1719 N St. NW, Washington, DC 20036.

**Subscribe to *Science News*** Subscriptions include 12 issues of *Science News* and full access to www.sciencenews.org and cost $59 per one year (international rate of $77 includes extra shipping charges).

**Subscribe** www.sciencenews.org/subscription

Single copies are $9.99 plus shipping and handling ($1.01 domestic, $5.01 international). Periodicals Postage Paid at Washington, D.C., and additional mailing offices.

**Postmaster** Send address changes to *Science News*, PO Box 292255, Kettering, OH 45429-0255. Two to six weeks' notice is required. Old and new addresses, including zip codes, must be provided.

VOL. 207 NO. 08 | AUGUST 2025

# ELISE CUTTS

FREELANCE JOURNALIST

● TWO EXTREME, competing attitudes often pop up in discussions of climate change: Either it's harmless to humans because Earth's climate has changed before, or it's the literal end of the world. "Earth's history teaches us that neither is true," says Elise Cutts. For this issue's cover story, she lays out the temperature ups and downs that our planet has experienced over the last 4.5 billion years (Page 32). Thanks to her academic background in earth science, Cutts knew instantly which episodes from the history of our planet to highlight. Her training also allowed her to put the events, which happened over unfathomably long periods of time, into context and convey the nuances of climate change. "The Earth can take a beating, and life will go on with or without us. Climate change isn't *the* end of the world, but if we're reckless, it could well be the end of *our* world," she says.

**Tara Haelle**
It's a journalist's job to evaluate all the evidence when reporting on a controversy. And that's just what freelance journalist Tara Haelle did for her feature about the validity of shaken baby syndrome (Page 40). With lawyers questioning the science in court, "it is important to clarify that the diagnosis is real. It relies on an extensive foundation of peer-reviewed science," she says. "The 'controversy' created by defense experts that has taken hold in media narratives is dangerous."

**Jake Buehler**
The illicit trade of rhino horns continues to be a multimillion-dollar industry despite efforts to halt illegal poaching. Freelance journalist Jake Buehler reports on the success of an out-of-the-box intervention: preemptively chopping off the animals' horns (Page 16). He was surprised to learn that the horns grow back quickly, so they need trimming every 12 to 18 months. "Dehorning appears to straddle a line somewhere between surgery and getting a haircut," Buehler says.

**Celina Zhao**
When Celina Zhao was called for jury duty mere months after moving to Massachusetts, she joked to her friends that the system was rigged. Picking juries is just one example of how random number generators are used. And now, *Science News*' intern reports on the newest iteration of the technology that's cheat-proof (Page 26). "I don't think the random number generator for my jury duty actually got hacked. But this new, supersecure version could improve trust in systems that use it."

**Zach Wissner-Gross**
Remember how hard it was to meet up with a friend before cell phones? Zach Wissner-Gross takes you back to that era with this month's math puzzle (Page 64). In addition to developing STEM curriculum at the company Amplify Education, Wissner-Gross writes Fiddler on the Proof, a weekly math puzzle newsletter. He grew up loving puzzles and math competitions. As an adult, he missed not only the puzzles but also the puzzling community. "With my newsletter, I get to present new puzzles and invite thousands of readers into the community," he says.

CLOCKWISE FROM TOP LEFT: BEN GILLETTE; JOSH MARTIN; NICOLE BERRY; JINGER CHONG; AMPLIFY EDUCATION

VOL. 207 NO. 08 | AUGUST 2025

ASTRONOMY

## A NEW EYE ON THE COSMOS

*By McKenzie Prillaman*

● **This striking image** of the Virgo cluster, captured for the public debut of the Vera C. Rubin Observatory, features two spiral galaxies (lower right), three merging galaxies (upper right), distant galaxy groups and many stars in the Milky Way. Composed of over 4,400 snapshots gathered in just a few days, it showcases the observatory's capabilities: a wide field of view and rapid imaging using a car-sized digital camera — the largest ever built. From a mountaintop in Chile, the observatory will scan the entire southern sky every few nights for the next decade starting later this year. The amount of data gathered in the first year alone will be greater than that compiled by all other optical observatories combined. These observations will help scientists explore everything from nearby stars to distant dark matter.

PHOTO BY NSF-DOE VERA C. RUBIN OBSERVATORY

TRINE
UNIVERSITY

# DON'T JUST MAKE A LIVING, MAKE A DIFFERENCE.

At **Trine University's Brooks College of Health Professions (BCHP)**, our graduate programs prepare you to transform lives—starting with your own. Whether you're pursuing a career as a physician assistant, occupational therapist, or physical therapist, you'll gain the knowledge, skills, and clinical experience to thrive in today's healthcare landscape.

Here's what sets BCHP apart:

- **Train in our cutting-edge facility**, featuring:
  - A fully immersive hospital simulation center
  - Virtual and augmented reality labs
  - Hands-on therapy labs for patients of all ages and abilities
- **Learn from expert faculty** who are personally invested in your success
- **Gain real-world experience** through clinical placements with top healthcare providers
- **Secure your future early** with direct entry from Trine's undergraduate programs on our Angola campus

**Take the next step toward a meaningful career.**

## LEARN MORE AND APPLY

**at trine.edu/bchp**

This rhinoceros mother in South Africa has had her horns removed. Research shows that preemptively removing rhino horns dramatically reduces deaths from poaching (see Page 16).

# News

TIM KUIPER

HEALTH & MEDICINE

# Bespoke gene editing saved a baby but has a long way to go

*By Tina Hesman Saey*

● **When a baby born in Philadelphia** was announced as the first person to get a gene therapy designed just for him, many people hailed the achievement as a starting point to treat virtually any genetic disease.

"I don't think I'm exaggerating when I say that this is the future of medicine," cardiologist Kiran Musunuru, who helped create the therapy, said in a news briefing. "This is a step towards the use of genetic editing therapies to treat a wide variety of rare genetic disorders for which there are currently no definitive medical treatments."

But there is a long road to pave before other people with genetic disorders can get bespoke gene therapies. Regulations, funding and the details of the diseases themselves pose challenges to making these therapies more widely available.

The treated child, KJ Muldoon, has a disorder that prevents his liver from converting ammonia, a normal byproduct of protein metabolism, to urea, which is flushed from the body in urine. When ammonia accumulates, it can cause brain and nerve damage and death.

KJ's form of the disease stems from a mutation in both copies of his *CPS1* gene. That gene contains instructions for building an enzyme called carbamoyl-phosphate synthetase 1, which is important in the conversion of ammonia to urea. About 1 in 1.3 million people lack the enzyme, about half of whom die in early infancy. Low protein diets, medications that help lower ammonia levels and liver transplants are used to treat the condition, though these measures may not entirely cure the disorder.

KJ was born prematurely in August 2024 and was too small for a liver transplant. Medications

↑ Doctors Kiran Musunuru (left) and Rebecca Ahrens-Nicklas (right) helped develop a gene therapy for baby KJ, who was born with a rare genetic disease.

CHOP

and extremely low protein diets helped. But his ammonia levels often spiked, and doctors worried he could be left with permanent brain damage or die.

Musunuru, of the University of Pennsylvania Perelman School of Medicine, and pediatrician and medical geneticist Rebecca Ahrens-Nicklas of Children's Hospital of Philadelphia quickly assembled a coalition of academic and industry scientists to manufacture a gene therapy to fix KJ's mutated gene and make sure it was safe. The researchers described the gene therapy in the *New England Journal of Medicine*.

The team also applied to the U.S. Food and Drug Administration for permission to treat the baby. The FDA recognized that "KJ was very, very sick and there wasn't time for business as usual," Musunuru said. The agency approved the treatment within one week of getting the application.

KJ has gotten three infusions of gene therapy. It's not known whether all the cells in his liver have the corrective edits. But KJ can eat more protein and needs less medication to keep his ammonia levels in check, Ahrens-Nicklas said.

KJ's gene therapy is based on CRISPR, a targeted gene-editing system that's being developed to treat cancers and a wide variety of genetic diseases. KJ got a version called a base editor, which chemically erased a mutation in KJ's broken *CPS1* gene and wrote in the correct DNA letter, or base.

This therapy started with messenger RNA, or mRNA, instructions for making the base editor. Messenger RNA is a copy of DNA instructions for building a protein. The mRNA is read by cellular machinery and used to produce the protein, which then carries out a particular job — in this case, making the base editor that would correct the typo in KJ's gene.

The researchers encased mRNA instructions for making the base editor in a lipid nanoparticle, which is "basically like a soap bubble," says Petros Giannikopoulos, a molecular pathologist at the California-based Innovative Genomics Institute. Giannikopoulos was involved in testing KJ's base editor to make sure it didn't cause unintended changes elsewhere in his DNA.

Researchers tested the base editor in lab-grown cells. They gave doses of the therapy to crab-eating macaques to test for toxicity. The team also genetically engineered mice to carry KJ's mutation, then used the base editor to correct the DNA typo. It took only six months to develop and test the therapy.

KJ got his first intravenous infusion containing the therapy in February. He got a very low dose to start with. Two subsequent doses have been higher. The researchers will continue to monitor KJ, and he was able to leave the hospital where he had lived since birth.

"What was very unique about this was that the therapy was manufactured for an individual patient," Giannikopoulos says. "That was why this was so monumental."

Previous CRISPR and other gene therapies are proactive, he says. "We make and preapprove something, and then wait for the patients to come along" whose mutations match the therapy. KJ's treatment is reactive, targeting a specific mutation after the patient is diagnosed.

That personalized approach could be used for many super-rare diseases — though not all of them. Giannikopoulos estimates that 15 to 20 percent of CONT. ON PAGE 14

ANIMALS

## PENGUIN POOP FERTILIZES CLOUDS IN ANTARCTICA

*By Carolyn Gramling*

● Penguin poop may make Antarctica cloudier — and help mitigate the regional impacts of climate change.

Gases like ammonia emitted from the birds' guano supply key chemical ingredients to form the seeds of clouds — the tiny particles that clouds coalesce around, researchers report in *Communications Earth & Environment*.

Near Argentina's Marambio Station on the Antarctic Peninsula, the snow and soil are frequently blanketed with excrement from a nearby breeding colony of Adélie penguins. Matthew Boyer, an atmospheric scientist at the University of Helsinki, and colleagues measured concentrations of ammonia and other gases from January 10 to March 20, 2023. They observed concentrations of ammonia up to 13.5 parts per billion, 1,000 times as high as the concentration in areas without penguins.

Over a single day, they observed that winds blowing from the direction of the penguin colony brought a sharp spike in aerosol particle concentrations (and a bit of fog). Overall, the penguins' contributions to the atmospheric chemical soup boosted particle formation rates by up to 10,000 times in the region, the team found.

The impact lingered even after the birds had left, heading out on their annual migration. ✖

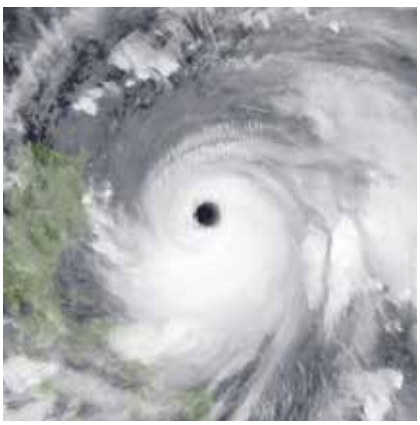
CYRIL GOSSELIN/MOMENT/GETTY IMAGES

CONT. FROM PAGE 13 the 7,000 known genetic diseases might be fixable using current technology. Ones that are caused by single-letter typos in a single gene might be correctable using a base editor. Other CRISPR editors potentially can repair many types of mutations, including small deletions.

Diseases that affect easily accessible organs, like the skin, eye or liver (as in KJ's case), may be the most treatable. Immune system or blood disorders may be fixed by removing stem cells from the bone marrow, editing them in the lab and then returning them to the patient so they proliferate. But diseases that affect multiple organs at once or those that affect hard-to-reach organs, like the kidney, might not be easily treated.

Changes in regulations are probably necessary for personalized gene therapy to become widespread. It may also be a struggle to get insurance companies to pay for expensive one-off therapies. Even when therapies have been proved to work, pharmaceutical companies often don't have the resources to conduct clinical trials to get FDA approval, or to keep the treatments on the market once they have been approved. Drastic cuts in federal research funding may also hinder early gene therapy development in academic laboratories in the United States.

Standardized playbooks for designing and implementing gene therapies are also needed. Many doctors want to treat patients who have genetic diseases but don't know how, Giannikopoulos says. He, Ahrens-Nicklas and Musunuru are in a consortium that's building such playbooks. "That's going to be really how to scale this, [by] teaching everybody how to fish." ✖



CLIMATE

# AI surpasses current weather forecasts

*By Kathryn Hulick*

● **Weather forecasting** is getting more accurate. An AI model named Aurora outperforms current weather prediction systems, researchers report in *Nature*.

Standard forecasting systems model Earth's weather by solving complex math and physics equations to simulate how conditions will likely change over time.

This number-crunching may take hours on a supercomputer. And simulating a system as chaotic as the weather is extremely difficult. In July 2023, for example, official forecasts a few days in advance of Typhoon Doksuri in the Philippines got its path wrong. Dozens of people died in flooding, landslides and accidents.

By contrast, machine learning models analyze large datasets on how weather patterns unfold. When it was built in 2023, Aurora took in more than a million hours' worth of information about Earth systems. Once this training was complete, Aurora could run on a typical desktop.

In a test, Aurora correctly predicted Typhoon Doksuri's track

↑ When Typhoon Doksuri struck the Philippines in July 2023, it didn't follow the predicted storm path.

NASA

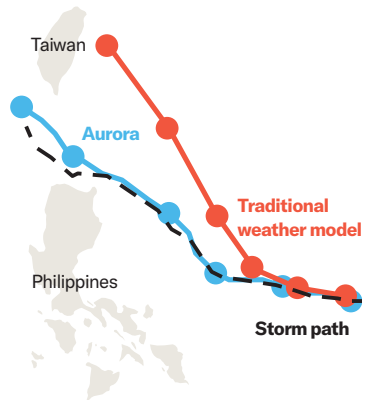
from data collected four days in advance. In addition, the AI model's predictions of cyclones in the North Atlantic and East Pacific in 2022 and 2023 were 20 to 25 percent more accurate than those from seven major forecasting centers at lead times of two to five days.

Outperforming official forecasts for cyclones that far in advance "has never been done before," says machine intelligence researcher and study coauthor Megan Stanley of Microsoft Research in Cambridge, England.

Aurora also accurately predicted air pollution and ocean waves, as well as global weather at the scale of towns or cities in seconds.

Such high-resolution predictions are impressive, says Peter Dueben, who heads the Earth system modeling group at the European Centre for Medium-Range Weather Forecasts in Bonn, Germany. "I think [Stanley and her colleagues] have been the first to push that limit," he says. ✖

**FOLLOW THE PATH**




A new AI model called Aurora (blue) plotted the trajectory of Typhoon Doksuri (black) better than traditional weather models (red).

C. BODNAR *ET AL*/*NATURE* 2025; C. CHANG

HEALTH & MEDICINE

# PLASTICS CHEMICAL IS TIED TO HEART DISEASE DEATHS

BY SKYLER WARE

A common chemical in household plastics has been linked with heart disease deaths.

In 2018, about 14 percent of the more than 2.6 million deaths from cardiovascular disease among people ages 55 to 64 globally could have been related to exposure to a type of chemical called a phthalate, researchers report in *eBioMedicine*.

Phthalates are a group of chemicals found in shampoos, lotions, food packaging and medical supplies. The chemicals are often added to plastics to make them softer and more flexible.

Phthalates can enter the body when people consume contaminated food, breathe them in or absorb them through the skin. Once inside, they act as endocrine disruptors, which means they affect hormones. Previous research has also linked the chemicals to diabetes, obesity, pregnancy complications and heart disease.

The new study looked at a phthalate called DEHP. Sara Hyman, a research scientist at NYU Langone Health, and colleagues focused on the relationship between DEHP exposure levels and cardiovascular disease, the leading cause of death worldwide. Hyman and colleagues compared estimated DEHP exposure in 2008 with death rates from cardiovascular disease 10 years later in different parts of the world. By studying how the two changed together, they determined what portion of those deaths might be attributable to phthalates.

More than 350,000 excess deaths worldwide in 2018 were associated with DEHP exposure, the team found. About three-quarters of those occurred in the Middle East, South Asia, East Asia and the Pacific islands. This concentration might be due to the regions' growing plastics industries, the researchers suggest. The new work does not show that DEHP exposure directly causes heart disease, though — only that there's an association between the two.

Still, the percentage of cardiovascular deaths worldwide that are linked to DEHP exposure is "quite alarming," says Changcheng Zhou, a biomedical scientist at the University of California, Riverside who was not involved in the study.

Further research is needed to understand CONT. ON PAGE 16

CONT. FROM PAGE 15 the true global health effects of DEHP and other phthalates. DEHP isn't the only phthalate people encounter on a regular basis. "Coexposure to other phthalates and chemicals is extremely likely, and our model was not able to take this into account," Hyman says.

The analysis also didn't account for other factors that contribute to heart disease risk, like individual lifestyle choices or other medical conditions, Hyman says. "More research is needed that accounts for these factors."

Scientists are still studying how phthalates might affect the body at the molecular level. Different phthalates have different chemical structures, so they may affect different processes within the body. And they might not operate in isolation.

"You do need to study the effect of the mixture" of phthalates people encounter regularly, says Mahua Choudhury, an epigeneticist at Texas A&M University in College Station who was not involved in the new study.

The findings offer yet another reason to decrease plastic use, researchers say. "We're going to become the plastic planet," Zhou says. "We need to start to really address this serious issue." ✖

**13.5 percent**

Portion of global deaths from cardiovascular disease among people ages 55 to 64 linked to phthalates

TIM KUIPER

ANIMALS

# Cutting off rhinos' horns cuts down on poaching

*By Jake Buehler*

● **Rhinoceros poaching may be** curtailed by removing the reason rhinos are poached in the first place: their horns.

Dehorning rhinos in South Africa reduced poaching by nearly 80 percent, researchers report in *Science*. No other anti-poaching intervention — such as protective fencing or more park rangers — had a measurable effect.

The illegal trade of rhino horn, which is used in traditional medicines in parts of East Asia, has driven the rapid decline of Africa's black and white rhinoceroses over the last decade,

despite substantial conservation efforts. "The expense of protecting rhinos is immense," says Markus Hofmeyr, a wildlife conservationist in Western Cape, South Africa, and director of the nonprofit Rhino Recovery Fund. Roughly $74 million was spent on anti-poaching measures in South Africa's Greater Kruger region from 2017 to 2023.

Hofmeyr and colleagues wanted to test which anti-poaching practices are the most effective so that conservation dollars could go to the best approaches. Tactics include dehorning, which doesn't hurt the animal, as well as cameras, poacher-tracking dogs and ranger patrols.

↖ This black rhinoceros had its horn removed to deter poaching. The horn, made of keratin, is starting to regrow.

Hofmeyr's group compiled data on poaching incidents from 2017 through 2023 in 11 reserves in the Greater Kruger region. Using a series of mathematical models, the team compared the intensity of each local anti-poaching intervention with the poaching rate. In all, the researchers documented the poaching of 1,985 rhinos over those seven years and the proactive dehorning of more than 2,200 rhinos in eight of the reserves.

Dehorning costs made up only 1.2 percent of the total amount spent on anti-poaching efforts, but it was associated with a 78 percent drop in poaching rates. Other approaches didn't have an effect. The team also found that the risk of a given rhino being poached within the year decreased from 13 percent to 0.6 percent if its horn was removed.

But dehorning isn't a perfect solution, nor permanent. Because some horn is left behind and can regrow, poaching can't be totally eliminated. The team noted 111 cases of a dehorned rhino being poached. But in places where there is much corruption in law enforcement, conservation staff and the judiciary — which can sabotage conservation efforts — dehorning is a quick but temporary method of cost-effectively curbing rhino poaching, Hofmeyr says.

Jasper Eikelboom, a wildlife ecologist at Wageningen University & Research in the Netherlands, says it's difficult to compare the effects of dehorning with interventions such as ranger patrols, which were likely happening extensively during the entire study period.

"But still," he says, "the clear benefit of dehorning to reduce local poaching rates is striking and finally provides some good news regarding rhino poaching."

Given that poachers will take the stumps of dehorned rhinos, Eikelboom wonders what would happen if the preventive practice spread more widely. If all rhinos in southern Africa were dehorned, perhaps poaching levels would just rise again, he says.

For Jo Shaw, CEO of the U.K.-based charity Save the Rhino International and a coauthor of the study, the findings show that dehorning is effective when used alongside a suite of other tools. "Dehorning is a short-term solution," Shaw says, "and our long-term vision is to have rhinos with their horns on in safe habitats." ✖

ARCHAEOLOGY

## PRECOLONIAL FARMERS THRIVED IN AN UNEXPECTED PLACE

*By Bruce Bower*

● A laser eye-in-the-sky has uncovered vast, ancient farm fields in an unlikely place: the frosty forests of Michigan's Upper Peninsula.

Ancestors of Menominee people, a Native American tribe, grew maize and other crops in clustered earthen ridges from about 1,000 to 400 years ago, researchers report in *Science*.

After clearing trees from large tracts of land, mobile communities accomplished this feat in the face of temperatures unfriendly to maize cultivation, a short growing season and poor soil, say archaeologist Madeleine McLeester of Dartmouth College and colleagues.

"What is likely based on this new finding, from an area where we would not expect intensive agriculture, is that much of the eastern U.S. was once covered in Native American agricultural ridges," McLeester says.

A drone-mounted lidar, or light detection and ranging, device peered through trees and ground cover at Michigan's Sixty Islands archaeological site to reveal the largest preserved system of agricultural fields in the eastern United States. Precolonial agricultural ridges covered a total of at least 2 square kilometers, McLeester estimates.

Radiocarbon dates indicate that farming had occurred over roughly 600 years.

Archaeologists informed only by sparse remnants of ancient farm fields visible on the ground and historical accounts have previously downplayed the extent of precolonial farming in eastern North America. For instance, researchers have assumed that Menominee ancestors mainly gathered wild rice.

Instead, they may have cultivated large amounts of crops as a hedge against food shortages, as trade items or to feed a growing population, McLeester says.

These farmers also found ways to enrich their soil. Excavations uncovered remains of composted household refuse and wetland soils used as fertilizer. Burial mounds, ritual structures and residences also dotted the farm fields. ✖

NOIRLAB/AURA/NSF

↑ The Large Magellanic Cloud (shown) may save the Milky Way from a head-on collision with the Andromeda galaxy.

ASTRONOMY

## A TINY GALAXY MIGHT PREVENT THE MILKY WAY'S DEMISE

BY NIKK OGASA

It may come down to a coin toss as to whether the Milky Way collides with the Andromeda galaxy within 10 billion years. While scientists have previously reported that a convergence is certain, an analysis of the latest data suggests the odds are only about 50 percent, researchers report in *Nature Astronomy*. The Milky Way's largest satellite system — the Large Magellanic Cloud — may be our galaxy's saving grace.

A little over 100 years ago, astronomer Vesto Slipher first observed that Andromeda, the closest major galaxy, appeared to be approaching the Milky Way. A century later, researchers used NASA's Hubble telescope to measure Andromeda's movement across the sky, leading them to report in 2012 that it was bound for a direct strike with the Milky Way.

"The idea of the collision has been accepted for a long time," says Elena D'Onghia, an astrophysicist

at the University of Wisconsin–Madison.

But those studies had not fully considered the influence of the Large Magellanic Cloud, says astrophysicist Till Sawala of the University of Helsinki in Finland. It's the fourth largest galaxy in the Local Group, a gravitationally bound neighborhood of galaxies that's dominated by the Milky Way and Andromeda. The Large Magellanic Cloud may have been left out because the data available at the time led researchers to believe it was relatively insignificant, Sawala says. But over the last decade, observations have revealed that the galaxy is more massive than once thought.

Curious as to how the latest and most accurate data from Hubble and the European Space Agency's Gaia telescope might shift the odds of a galactic smashup, Sawala and colleagues simulated the movements of the Milky Way, Andromeda, the Large Magellanic Cloud and Messier 33 — the Local Group's third largest galaxy — over 10 billion years. The team performed roughly 100,000 simulation runs to test every possibility across the full range of uncertainty in the data.

Simulations of just the Milky Way and Andromeda produced collisions a little less than half the time. Adding in Messier 33 increased the collision odds to about 66 percent. But when the team also incorporated the Large Magellanic Cloud, the odds dropped to just over 50 percent.

The gravity of the Large Magellanic Cloud appears to introduce some sideways momentum to the Milky Way's path, tugging it out of Andromeda's way in half of the simulation runs, Sawala says. But the save may be a thankless one, as the results suggest the Milky Way is certain to engulf the much smaller Large Magellanic Cloud in about 2 billion years.

"The situation is more uncertain than previously thought," says D'Onghia, who was not involved in the study.

Others disagree. It's good to consider these other galaxies, but "I can't see how they would actually change the course of the merger," says astrophysicist Sangmo Tony Sohn of the Space Telescope Science Institute in Baltimore, a coauthor of the 2012 study that predicted the convergence. Sohn and colleagues' interpretation of the data suggests the total mass of the Milky Way and Andromeda is greater than what's assumed in the new paper, which would make them more prone to coalesce.

Consensus may be reached in the next decade, both Sawala and Sohn say, as better instruments and more observations become available. Part of that will involve refining estimates of how much dark matter each galaxy possesses, as the invisible substance is thought to dominate their masses.

If the collision does occur, it may not matter much to Earth. The sun is expected to swallow up the inner planets and collapse into a white dwarf in 8 billion years. "There's a fairly good probability that even if that merger happens, it will happen after the solar system doesn't exist anymore," Sawala says. ✖

PLANTS

## 'BAD BREATH' MAKES PUTRID PLANTS REEK

*By Tina Hesman Saey*

**● Some plants stink of rotting meat or dung, which helps attract flies for pollination. How plants make the carrion stench, which is usually produced by bacteria feasting on decaying corpses, has been a mystery until now.**

**The answer: Several types of plants independently evolved the ability to make the fetid odor thanks to a few tweaks in one gene, researchers in Japan report in *Science*.**

**A gene called *SBP1* codes for an enzyme that breaks down methanethiol, a stinky chemical known to cause bad breath. Typically, the enzyme breaks methanethiol into hydrogen peroxide, hydrogen sulfide and formaldehyde. But putrid plants (including the aptly named skunk cabbage, shown below) have a variant that instead joins two methanethiol molecules, forming dimethyl disulfide. That's the compound responsible for a lot of the stench that wafts from rotten meat.**

**Three unrelated plant lineages hit on this same evolutionary trick to produce the foul smell, the researchers found. First, the gene was duplicated (a pretty common occurrence in the evolution of most organisms). And then the extra copy mutated. Though the specific mutations varied among the plants, the effect was the same: a version of the enzyme that causes the plant to reek. ✖**

ASTRONOMY

# A passing star could fling Earth out of orbit

*By Ken Croswell*

● **Bad news, earthlings.** Computer simulations of the solar system's future reveal a new risk facing us all: The gravitational tug of a passing star could either cause another planet to smack into Earth or else fling our planet into the sun or far away from it, where any inhabitants would freeze.

Blame Mercury. Astronomers have long known that the innermost planet's orbit, which is fairly oval-shaped, can become even more elliptical due to gravitational jiggles from Jupiter. Passing stars exacerbate this danger. Nathan Kaib, an astronomer at the Planetary Science Institute who is based in Iowa, and Sean Raymond, an astronomer at the University of Bordeaux in France, report the newfound threat in a paper published in *Icarus*.

In agreement with previous work, the pair's simulations show that once Mercury goes haywire, its orbit becomes so elliptical that the planet typically collides with either the sun or Venus. Then the resulting chaos can cause Venus or Mars to crash into Earth or Earth to crash into the sun. Or Venus and Mars can fling our world toward Jupiter, and the giant planet's gravity ejects Earth from the solar system altogether.

Now the good news. "None of these things are probable," Kaib says with a laugh. Over the next 5 billion years — most of the remaining life span of the sun — the chance of such a catastrophe afflicting Earth is only 0.2 percent, based on the number of stars passing near the solar system. Still, that's a much greater risk than in previous studies, which had neglected the long-term influence of passing stars.

"It's a little scary how vulnerable we may be to planetary chaos," says Renu Malhotra, a planetary scientist at the University of Arizona in Tucson who was not involved with the study. She thinks past stellar encounters have already influenced the solar system. In particular, they may explain why the giant planets have somewhat elliptical orbits rather than the nearly circular paths they should have inherited

↖ **Although the chances are low, the gravitational tug of a passing star could someday result in Earth being ejected from the solar system.**

RYAN SNOOK

from the protoplanetary disk that gave them birth.

The most dangerous stars, Kaib says, are those that come nearest, less than 100 times as far from the sun as is Earth. Over the next 5 billion years, there's about a 5 percent chance of such a close encounter. Also risky are stars that move slowly, at less than 10 kilometers per second relative to the sun, prolonging their gravitational tugs on the planets.

The new simulations offer another reason to be glad you don't live on Pluto.

In the absence of passing stars, Kaib says, Pluto was thought to be safer than Earth, even though Pluto cuts across Neptune's path while orbiting the sun. The secret to Pluto's success? It's in a 3:2 resonance with its giant neighbor, meaning Neptune orbits the sun three times for every two times that Pluto does. As a result, Pluto currently has no chance of hitting Neptune: Whenever Pluto is as close to the sun as Neptune is, the two worlds are always far apart. In fact, Pluto comes closer to Uranus than it ever does to Neptune.

"But once you allow stars to alter the solar system and push things around, you can actually knock Pluto out of its resonance with Neptune," Kaib says. Then Pluto would be in trouble. It can skirt by the giant planets and their gravity can kick it out of the solar system, or Pluto can smash into one of them. Over the next 5 billion years, the chance of such an ejection or collision befalling Pluto is about 4 percent. That's 20 times greater than the risk facing Earth.

On the positive side, the calamity might just end the long-standing debate over whether Pluto is really a planet. ✖

PARTICLE PHYSICS

# MUONS' MAGNETISM MATCHES THEORY, EASING CONUNDRUM

BY EMILY CONOVER

One of the most enduring mysteries of particle physics may be finally resolved, two new studies suggest. The oddities of muons, subatomic particles that are relatives of electrons, are starting to make sense.

Muons have an internal magnetism that scientists have struggled to pin down: Measurements of a magnetic quirk of the particles have long clashed with theoretical predictions.

Now, scientists report the most precise measurement yet of the anomalous magnetic moment of the muon, a property that tweaks the strength of muons' internal magnets. Meanwhile, a team of physicists updated its theoretical prediction of that tweak based on the standard model, the highly successful theory that describes subatomic particles and their interactions. That prediction shifted enough from the previous estimate to erase the long-standing discrepancy. "That's another triumph of the standard model," says Bhupal Dev, a theoretical physicist at Washington University in St. Louis who was not involved with the studies.

Muons' magnetism causes them to wobble when traveling through a magnetic field. The Muon g–2 experiment (pronounced "g minus two," the term used in equations to represent the anomalous magnetic moment) measured the rate of these wobbles in a giant doughnut-shaped magnet, revealing the anomalous magnetic moment.

The new measurement has an uncertainty of just 127 parts per billion, or about 13 millionths of a percent. "It's one of the most precise measurements that humans have ever made about our fundamental world," says theoretical physicist Tom Blum of the University of Connecticut in Storrs, who was not involved with the measurement. The precision surpassed expectations, researchers reported during a scientific seminar at Fermilab in Batavia, Ill., where the experiment is located. "We have done it," says Muon g–2 collaborator Thomas Teubner, a theoretical physicist at the University of Liverpool in England.

The result was consistent with previous measurements of the muon's anomalous magnetic moment. But "from the theory side … things have changed dramatically," says Blum, a member of the Muon g–2 Theory Initiative, CONT. ON PAGE 22

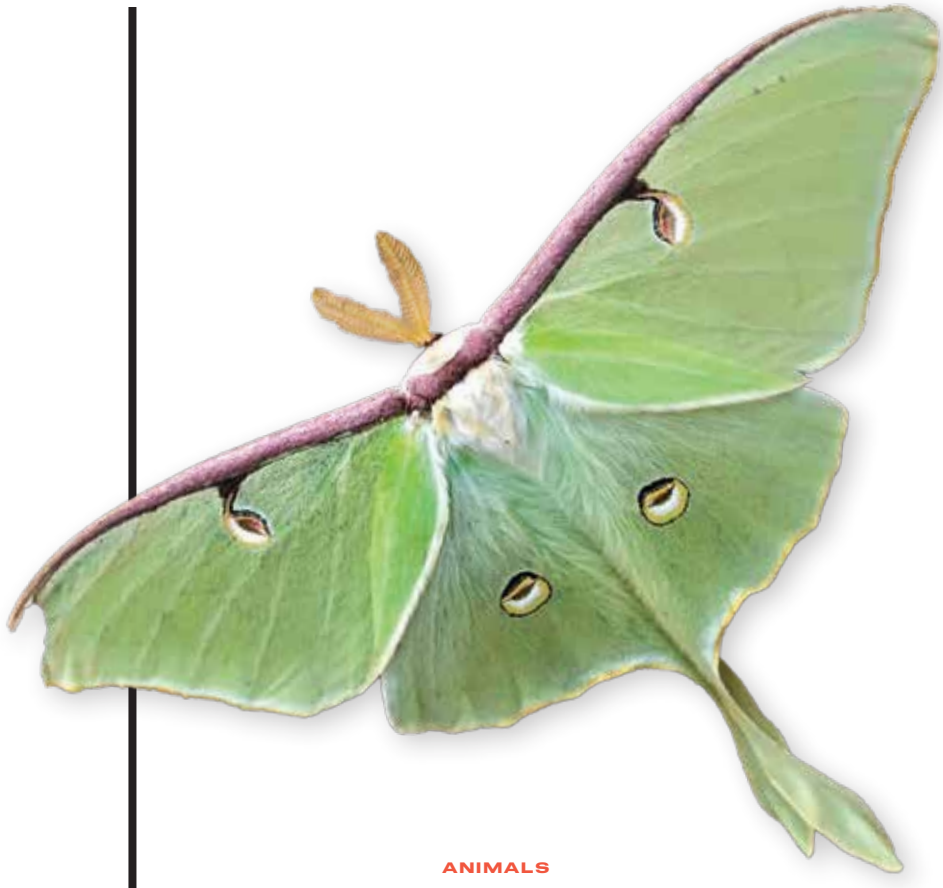
CONT. FROM PAGE 21 which compiled the theoretical prediction. New developments have brought that prediction in line with experimental measurements, the group reports in a paper posted at arXiv.org.

The shift comes from one particularly challenging bit of the calculation, which accounts for an effect called hadronic vacuum polarization. To fill in that piece of the puzzle, scientists previously relied on experimental data as an input to the calculation, collected from a variety of experiments. But a recent experiment called CMD-3, at the VEPP-2000 particle collider in Novosibirsk, Russia, threw a wrench in that data-driven strategy when its data disagreed with those of older experiments. That meant that the data wasn't understood well enough to use as an input to the calculation.

As an alternative, physicists have now calculated the hadronic vacuum polarization term from scratch, without input data, using lattice quantum chromodynamics. Also known as lattice QCD, the technique is based on the theory of quantum chromodynamics, which describes the business of quarks and gluons, subatomic constituents of protons, neutrons and other particles.

Importantly, when the lattice QCD value is used for the tricky part of the calculation of the muon magnetic moment, the prediction matches the experimental measurement and the conundrum is resolved.

The newfound results don't quite wrap everything up with a neat little bow, however. Scientists still don't understand why the CMD-3 experiment's results don't match older experiments. Now, physicists aim to refine the prediction, both by working to resolve that discrepancy and by improving the lattice QCD calculations. ✖



KEITH RAMOS/USFWS

↑ Long, skinny streamers on the hind wings of luna moths help protect against hungry bats.

ANIMALS

# Cozy climates let luna moths grow elaborate wings

*By Susan Milius*

● **For the first time**, biologists have linked the ribbony "tails" streaming from big, green luna moths' hind wings with, of all things, a cozy climate.

Those dangling tails rank among such evolution-was-drunk novelties as the narwhal's single unicorn tusk or the peacock's giant feather train. Wing streamers with twisting or cupped ends have evolved independently at least five times in the Saturniidae family of luna and other moon moths, says behavioral ecologist Juliette Rubin, now at the Smithsonian Tropical Research Institute in Balboa, Panama. Her new data crunch of environmental factors links the ribbony tails with growing up with long, plant-friendly seasons, she

and colleagues report in *Proceedings of the Royal Society B*.

Moon moths can grow wings big enough to cover a human palm "and often have beautiful colors," Rubin says. This winged phase lasts only the final week or so of the moths' lives, when they flirt and mate.

The streamers, however, don't seem to matter for seduction, Rubin's earlier experiments on the moth *Actias luna* showed. Instead, tails help confound bats. Unlike some other flying prey, luna moths can't hear a bat's sonar clickings as it swoops and hunts around the night sky. Nor are these moths known to make any "Back off, bat!" sounds. Instead, the fluttery wing ends can fool bats into biting at the thin, scaled tail tissue instead of some more vital body part.

In the evolution of big, novel body parts, though, "generally there are these hazards," Rubin says. Finding what those are hasn't been easy. Hauling extra, flappy wing bits doesn't seem to make flight harder, although more experiments still might turn up a flight cost.

What may matter more are the physical costs of growing the wings to begin with. Using photos, many posted by citizen scientists on iNaturalist, Rubin and colleagues looked at where moths have extravagant wings and where they don't. Antenna length let Rubin compare sizes in photos.

One result was expected: Having local insect-eating bats favored evolving longer wing tails. A less obvious factor favoring longer wing tails turned out to be prolonged warm and relatively steady temperatures. Those conditions let a moth larva spend time feeding. The supernourished larvae then can grow super wings for a grand adulthood finale. ✖

P. ROHILLA *ET AL*/*INTERFACE FOCUS* 2025

PHYSICS

# HOW TO GET THE BIGGEST SPLASH USING SCIENCE

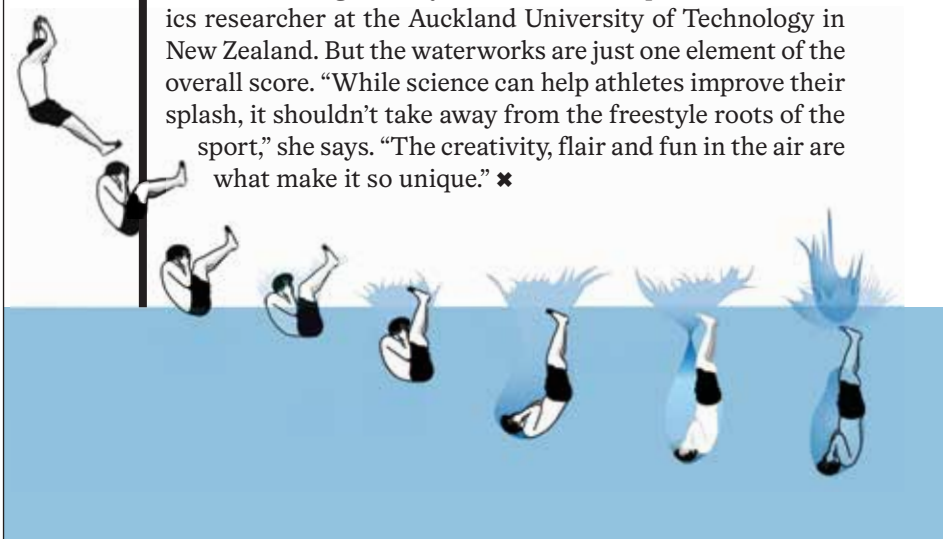
BY ELIE DOLGIN

When it comes to making a splash, technique tops brute force. In the competitive sport of Manu jumping — a flamboyant, cannonball-style splash sport from the Māori and Pasifika communities of New Zealand — the secret to record-setting splashes hinges on a butt-first V-shaped entry and a well-timed underwater follow-through, researchers report in *Interface Focus*.

Most previous splash research focused on minimizing surface disruptions. Popping a Manu is "the diametric opposite scenario," says biophysicist Saad Bhamla of Georgia Tech in Atlanta. The goal there is to make the most splash.

Bhamla and colleagues extracted movement data from 50 online videos and performed controlled splash tests with 3-D printed projectiles, robotic divers and high-speed cameras. The tests showed that a precisely angled, bum-first entry forms a deep air cavity in the jumper's wake (illustrated below). A rapid backward roll and leg extension stretches out the body — and, with it, the pocket of trapped air. When the air cavity collapses and pinches off, a towering jet of spray shoots skyward.

The timing of this maneuver is critical, highlighting how even milliseconds can separate a good Manu jumper from a record-breaking one, says Patria Hume, a sports biomechanics researcher at the Auckland University of Technology in New Zealand. But the waterworks are just one element of the overall score. "While science can help athletes improve their splash, it shouldn't take away from the freestyle roots of the sport," she says. "The creativity, flair and fun in the air are what make it so unique." ✖



ANTHROPOLOGY

# ANCIENT PROTEINS REVEAL EARLY HOMINID SURPRISES

BY BRUCE BOWER

For the first time, molecular clues have been extracted from an ancient, distant human cousin from southern Africa called *Paranthropus robustus*.

Proteins preserved in four *P. robustus* teeth from different individuals indicate that larger and smaller fossils of this hominid species, which lived roughly 2 million years ago, cannot always be classed as male or female, as previously thought, researchers report in *Science*.

Scientists identified two teeth as having belonged to males based on the presence of a protein that in present-day people is located on the Y, or male, sex chromosome. One of those teeth was previously thought to have come from a female, based on its small size, according to molecular biologist Palesa Madupe of the University of Copenhagen and colleagues. Closer analyses of the two teeth lacking that male-specific protein indicated that those fossils, which are about the same size as the smaller male tooth, came from females.

"Paleoanthropologists have long known that our use of tooth size to estimate sex was fraught with uncertainty, but it was the best we had," says Paul Constantino, a paleoanthropologist at Saint Michael's College in Colchester, Vt. "Being able to accurately identify the sex of fossils using proteins will be hugely impactful."

↑ Contrary to expectations, males of the ancient hominid *Paranthropus robustus* (skull shown) weren't always larger than females, a new analysis finds.

Proteins survive far longer in fossils than DNA does, especially in hot climates where genetic material degrades rapidly. The oldest DNA recovered in Africa dates to about 18,000 years ago.

The work by Madupe's group represents a first step toward using ancient proteins to check whether larger- and smaller-bodied fossil hominids belonged to different sexes or even different species, says paleoanthropologist Bernard Wood of George Washington University in Washington, D.C. Wood calls this advance "a big deal."

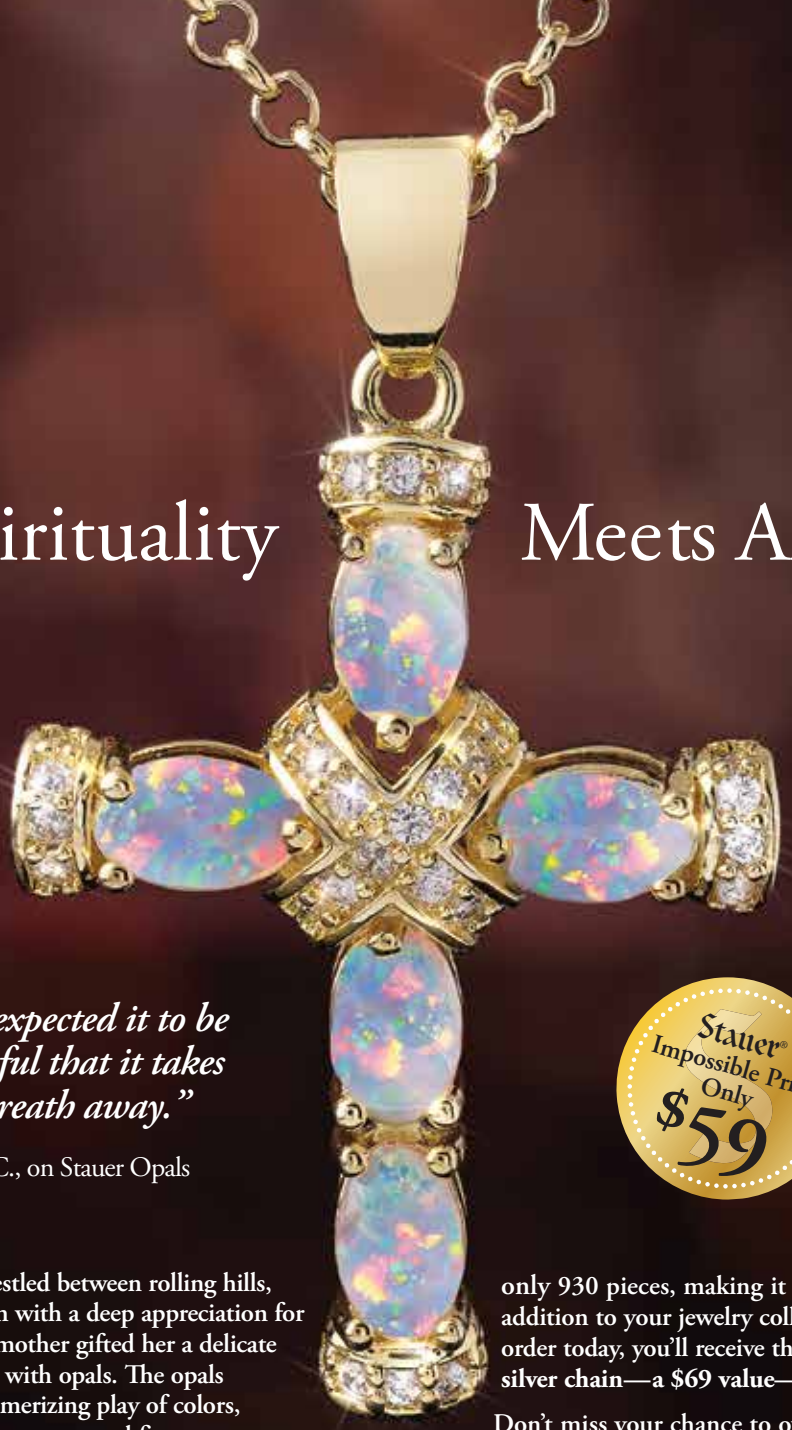
*Paranthropus* fossils date to between about 2.7 million and 1 million years ago and are thought to represent three species: *P. aethiopicus* and *P. boisei* in East Africa and *P. robustus* in South Africa. These species had large jaws and teeth, wide faces and bony crests atop the skull that anchored chewing muscles.

Proposed evolutionary relationships between *Paranthropus* species and comparably ancient but more humanlike species, such as *Australopithecus africanus* in South Africa, are controversial. Madupe and colleagues suspect that protein comparisons of these species will take place. In another investigation, the team extracted preserved protein from an *A. africanus* tooth fragment that identified it as male.

If protein sequences can be recovered from East African *Paranthropus* fossils, comparisons with *P. robustus* will help to clarify whether these geographically distant populations were closely related, Wood says. ✖

BERNHARD ZIPFEL

# Spirituality Meets Artistry



*"I never expected it to be so beautiful that it takes your breath away."*

— Kaya C., on Stauer Opals

Stauer® Impossible Price Only $59

In a quaint village, nestled between rolling hills, lived a young woman with a deep appreciation for gemstones. Her grandmother gifted her a delicate cross pendant adorned with opals. The opals shimmered with a mesmerizing play of colors, reflecting hues of blues, greens, and fiery oranges. Her grandmother shared the legend of the opals, believed to bring hope, purity, and luck to those who wore them.

Using this story as inspiration, Stauer brings you the **Opal Spirit Cross Pendant.** With over 2 total carats of Kyocera lab-created opals set in .925 sterling silver encased in yellow gold, this pendant is a radiant celebration of beauty and craftsmanship. Each opal captivates with a kaleidoscopic dance of fiery oranges blending into oceanic blues, streaked with flashes of vibrant green that seem to come alive with every movement. The shimmering opals are skillfully arranged to create an enchanting, otherworldly glow, embodying the spirit of hope and harmony.

This breathtaking combination of color and craftsmanship is available as a limited availability of only 930 pieces, making it a rare and treasured addition to your jewelry collection. Plus, when you order today, you'll receive the **gold-finished sterling silver chain—a $69 value—absolutely free!**

Don't miss your chance to own this exclusive tribute to timeless elegance and meaningful symbolism.

**Necklace Specifications:**

- 2 ½ ctw. Kyocera lab opals and Diamond*Aura*® accents
- Yellow gold-finished .925 sterling silver setting
- 18" gold-clad .925 sterling silver chain

## Opal Spirit Cross Pendant *plus* FREE Chain

~~$499~~ $59* + S & P *Save $440*

**Special price only for customers using the offer code.*

## 1-800-333-2045

**Your Insider Offer Code: OCR176-01**

Stauer®

14091 Southcross Drive W.
Dept. OCR176-01, Burnsville, MN 55337
**www.stauer.com**

MATH

## THERE'S NO CHEATING THIS RANDOM NUMBER GENERATOR

*By Celina Zhao*

● If your name gets picked for jury duty, it's because a computer used a random number generator to select it. But how can you trust that the draw was truly fair? A new cheat-proof protocol for generating random numbers could provide that confidence — preventing hidden tampering or rigged outcomes, researchers report in *Nature*.

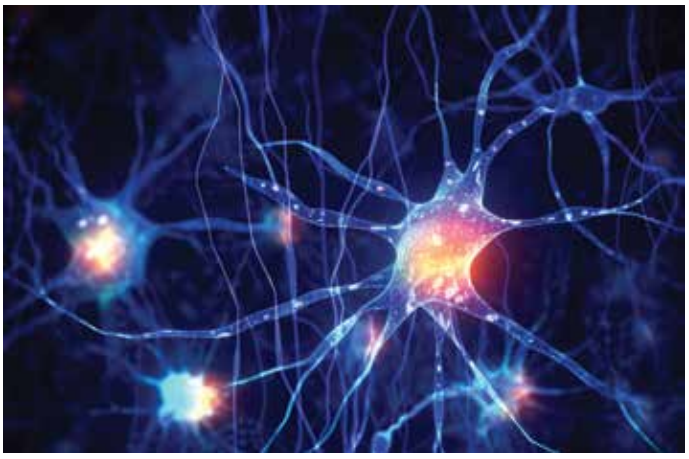
Most classical methods of generating random numbers aren't truly random. Genuine unpredictability can be found only in the quantum realm, where the tiniest particles exist in indefinite states until measured.

Physicist Gautam Kavuri of the National Institute of Standards and Technology in Boulder, Colo., and colleagues designed a system that combines quantum physics with cryptography. The process uses several points of measurement to ensure reliable randomness and builds data structures called hash chains, where each hash is like a cryptographic fingerprint, to create something like a tamper-proof receipt.

First, a laser zaps a crystal, knocking off a pair of entangled particles of light, or photons, that share mysteriously linked properties. The entangled photons whiz over optical fibers to two measurement stations spaced 110 meters apart. While the photons travel, each station randomly chooses how to measure the incoming photon and converts the result into a bit: either a 0 or a 1.

This process repeats 15 million times in about a minute, creating a massive stream of raw random bits. Computers combine the stream with a random number sample from a third institution. Everything is processed through an algorithm that filters out any patterns. The result is 512 binary digits of certified pure randomness.

The entire process is "a really paranoid way to make sure things are really random," Kavuri says. "You would need to communicate faster than the speed of light to be able to spoof this." ✖



JUAN GAERTNER/SCIENCE PHOTO LIBRARY/GETTY IMAGES

NEUROSCIENCE

## 'Silent' cells play a surprising role in how brains work

*By Laura Sanders*

● **Brain cells named for stars** are getting their time to shine. Three studies published in *Science* show that astrocytes, once thought of as support cells, powerfully shape how brains work.

These findings, from the brains of fruit flies, zebrafish and mice, open new possibilities for therapies aimed at mental illnesses such as depression and schizophrenia. They could also lead to a deeper understanding of how current therapies work.

Astrocytes used to be thought of as helpers, assisting with grunt work like waste removal in the brain. Shaped like starbursts, these cells are everywhere, possibly constituting about 20 percent of brain cells, says Kevin Guttenplan, a coauthor of one of the new studies and a neuroscientist at Oregon Health and Science University in Portland. Astrocytes grow until they meet another astrocyte and form thousands of connections with other cells, "which means that every square millimeter of the brain is within the domain of an astrocyte," he says.

Recent discoveries have revealed that the roles of astrocytes include a more sophisticated job: influencing messages at synapses, the connections between two nerve cells, or neurons, and influencing behaviors. But how astrocytes were contributing to these neural conversations wasn't clear.

Unlike neurons, astrocytes don't generate obvious pulses of electrical

↑ Astrocytes (illustrated) may play major roles in the brain's operations and influence behavior.

activity. "They were considered to be silent," says cell biologist and neuroscientist Cagla Eroglu, a Howard Hughes Medical Institute Investigator at Duke University. That silence may have misled scientists into believing astrocytes weren't important in sending signals.

The new results, along with a growing body of research, suggest that astrocytes sense key chemical messages that were commonly thought to be intended for neurons and, in response, change the activity of neurons around them.

In the spinal cord equivalent of a fruit fly, for instance, a chemical signal called tyramine acts as a "pay attention" signal, enabling astrocytes to respond to other chemical messages, including dopamine. Without the tyramine signal, astrocytes don't respond to dopamine and other messages.

The existence of this switch is "stunning," says study coauthor Marc Freeman, also of Oregon Health and Science University. "The fact that an arousal cue could take an astrocyte from ignoring all of those major neurotransmitters to suddenly listening to everything ... it boggles the mind when you think about the implications."

Astrocyte signaling, other experiments revealed, is deeply involved in a survival move. In this test, researchers flip larval fruit flies onto their backs and see how long it takes them to flip themselves back over. Guttenplan compares the maneuver to a person trying to roll over while zipped tight in a sleeping bag. It sounds trivial, but "for larvae, it's a life-or-death behavior." When scientists artificially primed astrocytes to be sensitive to dopamine, larvae were faster at righting themselves. And when astrocytes weren't able to sense dopamine, larvae were slower to flip over.

Similar findings came from a study on larval zebrafish, which found that astrocytes could change brain cell activity and control the animals' behavior. And even more evidence comes from mouse brain cells, where astrocytes sensed norepinephrine, the mammalian counterpart of tyramine, and then altered nerve cell behavior.

Together, these studies offer a more holistic view of how information can move through brains, Eroglu says. "You need the astrocyte intermediary."

This intermediate step raises questions about drugs commonly thought to target neuron behavior, such as selective serotonin reuptake inhibitors, or SSRIs. These medications might be working on astrocytes as well. Given astrocytes' far reach, that's an intriguing possibility, Guttenplan says.

Understanding why brains evolved to include this layer of astrocyte oversight is a big question, Eroglu says. "There is something really beautiful here that remains to be understood." She points to a warning issued from her former adviser, the late Ben Barres, a brain cell pioneer at Stanford University: Ignoring the astrocyte is always a mistake. ✖

HEALTH & MEDICINE

## RSV WASN'T AS HARD ON U.S. BABIES LAST WINTER

*By Aimee Cunningham*

● Respiratory syncytial virus, or RSV, is the leading cause of infant hospitalizations in the United States. But last winter's RSV season wasn't as brutal for babies. A new study reports two preventive tools — a maternal vaccine and a monoclonal antibody for infants — may have helped.

The 2024–2025 RSV season was the first in which the tools were widely available. A study of two hospital surveillance systems found that RSV hospitalization rates last winter for babies up to 7 months old were lower than in two combined RSV seasons before the COVID-19 pandemic, researchers report in *Morbidity and Mortality Weekly Report*.

The two datasets saw drops in hospitalization rates, one of 28 percent and the other 43 percent, from the 2018–2020 seasons to this last winter. The biggest drop was seen for the youngest infants, those up to 2 months old.

The U.S. Centers for Disease Control and Prevention recommends using either of the preventive tools. The RSV vaccine for pregnant people is a one-time shot given during a specific window in the last trimester. The antibodies transfer to the fetus and can protect the baby for about six months after birth. The monoclonal antibody is given to babies up to 7 months old born during RSV season or entering their first season and is protective for at least five months. Both tools target a protein the virus needs to enter cells.

"I think we'll soon see a day when RSV hospitalizations in young infants will be much rarer than it is today," says Kawsar Talaat, a vaccine researcher and infectious disease physician at Johns Hopkins University, who was not involved in the new study. As most RSV hospitalizations and deaths happen in countries where children have less access to health care, Tallat says, it's also "important to find ways to have these products available to the most vulnerable children." ✖

HEALTH & MEDICINE

# Many babies may lack helpful gut bacteria

*By Tina Hesman Saey*

● **About three-quarters** of babies born in the United States may not have enough friendly microbes in their guts to protect against developing allergies, asthma and eczema.

In a study of over 400 babies, about 76 percent had low levels of *Bifidobacterium*, gut microbes that digest sugars in breast milk, researchers report in *Communications Biology*. That includes 24 percent with no detectable microbes. "Nondetectable levels of the most fundamental family type of bacteria for the infant was really surprising," says Stephanie Culler, cofounder and CEO of Persephone Biosciences, the San Diego–based company that ran the study. "It was just not there."

The result also surprised microbiologist Jack Gilbert of the University of California, San Diego, but for different reasons. Extrapolating from previous studies, he expected "more like 50 or 60 percent of infants" to lack the bacteria, he says. The finding is "maybe more reassuring than my prior estimates, but it's still quite depressing."

Those gut microbes help train the immune system. Without them, children are prone to allergic conditions, Culler and colleagues found. Babies who had low levels of *Bifidobacterium* were at least three times as likely to develop allergies, eczema or asthma by age 2 as babies with normal levels of bacteria.

Babies who took antibiotics had 3.3 times the risk of developing allergies as those who didn't need the drugs. Antibiotics are one reason *Bifidobacterium* is disappearing from infant guts, Culler says.

Changes in dietary habits, use of antibacterial soaps and other factors have also reduced the amount of *Bifidobacterium* in the environment. "We've started to see this organism being eradicated from the maternal population, and hence it would not be available to colonize the child," Gilbert says.

Children born by C-section were more likely to have low or missing levels of *Bifidobacterium*. Breastfeeding didn't restore the bacteria in these babies. Instead, the lack of *Bifidobacterium* allowed some potentially harmful bacteria to thrive. The long-term consequences of that replacement aren't yet known.

Persephone Biosciences is testing whether a product containing *Bifidobacterium*, human milk sugars and vitamin D can raise levels of the bacteria in infants. Results are expected later this year.

Many trials suggest that probiotics reduce the risk of developing inflammatory diseases, Gilbert says. But the U.S. Food and Drug Administration has warned against probiotics for premature babies after one preterm baby died in 2023. It is not certain that *Bifidobacterium* in the probiotic caused the baby's death, and "hundreds of thousands of people are using this as a probiotic every day with no instances of infection," Gilbert says. He adds that there is "probably no risk and quite a lot of potential benefit" for pregnant and lactating people to take *Bifidobacterium* probiotics to help transfer the organisms to their babies. ✖

Many babies born in the United States lack important gut microbes that digest breast milk and help train the immune system. ↓

VICKI SMITH/GETTY IMAGES

# Forged In Fire, Inspired By Myth — The Dragon Blade

Stauer Impossible Price ONLY $99

Forged in fire and built for legends, this Damascus steel blade is more than a knife — it's a statement of power. Featuring a dragon's head handle, this masterpiece channels the spirit of mythical beasts, embodying their strength, wisdom, and ferocity. The carefully sculpted handle captures the intricate details of a dragon in mid-roar, its eyes gleaming with intensity, its form poised for battle.

A.


But the true marvel lies in the blade itself — a wavy Damascus steel edge, reminiscent of a dragon's fiery breath frozen in time. Each ripple in the steel tells a story of heat, pressure, and expert craftsmanship, creating a blade that is both razor-sharp and mesmerizingly unique. The layered steel technique not only enhances durability but, gives each knife a one-of-a-kind pattern, ensuring that no two are ever alike.

**Now, available for a limited time at just $99** (regularly $299), this is your chance to own a true masterpiece — a limited edition of just 1,999 — and once they're gone, they're gone for good.

Complete the look with the Stauer **Men's Legendary Dragon Bracelet** — a bold, sculpted piece designed to match the knife's mythic energy and craftsmanship. Together, they form a set worthy of any modern-day warrior.

Whether displayed proudly or wielded with purpose, this men's blade is a tribute to adventurers and those daring enough to hold the fire in their hands.

**Knife Specifications:**
- 12" Damascus steel blade, overall length: 18"
- Includes genuine leather sheath

**Bracelet Specifications:**
- Oxidized-finished stainless steel setting
- 8" length with clip clasp

★★★★★

*"This is an EPIC blade for the avid collector"*

— Tim M.
Schaumburg, IL

## A. Power of the Dragon Damascus Knife

~~$299~~ **$99*** + S & P *Save $200*

## B. Men's Legendary Dragon Bracelet

~~$299~~ **$99*** + S & P *Save $200*

**Special price only for customers using the offer code.*

# 1-800-333-2045

**Your Insider Offer Code: PDK124-01**

Stauer®

14091 Southcross Drive W.
Dept. PDK124-01, Burnsville, MN 55337
**www.stauer.com**

*California residents please call 1-800-806-1484 regarding Proposition 65 regulations before purchasing this product.*

GSA
Publications
gsaservice@geosociety.org
+1-800-472-1988

GEOLOGY ROCKS!

# TEXAS ROCKS!


***A Guide to Geologic Sites in the Lone Star State***
**Nathalie Brandes • Photographs by Paul Brandes**

Unearth the secrets of Texas's billion-year history with this captivating guide to 80 easily accessible geologic sites. With geology as diverse as the state, the sites include dinosaur tracks embedded in limestone, thick lava flows cut by vertical columns, sand dunes composed entirely of gypsum, and blue quartz crystals sparkling in llanite, an unusual rock found only in the Llano region.

Beautiful color photographs complement the engaging discussion, and detailed maps guide you to sites hidden in deep canyons, forested hills, and urban parks.

With this book in hand, explore mining districts and fossil reefs in the western mountains, dike-laced granite of Enchanted Rock, springs and caves along the Balcones Escarpment, salt domes and ever-changing barrier islands along the coastal plain, and layered sedimentary rock of Palo Duro, Seminole, and Santa Elena Canyons.

**396-GRKTX, 168 PAGES, 9 × 8 ⅜**
**ISBN 9780813741253, $26.00 PAPER**
**174 COLOR PHOTOGRAPHS, 125 COLOR ILLUSTRATIONS AND MAPS**
**GLOSSARY, SUGGESTED READING, INDEX**

Visit the Store: **store.geosociety.org**

USE CODE **2025GEOSAVE15** TO SAVE 15% OFF THIS TITLE ONLINE

# Features

ABRAM POWELL/AUSTRALIAN MUSEUM

EARTH

## THE RISE OF OXYGEN, AS RECORDED IN ROCK

● Oxygen is essential for most life. But Earth's supply was low until photosynthetic microbes, which release oxygen, became abundant in the ocean a couple billion years ago. Scientists know about this milestone and others in Earth's history thanks to the geologic record (see Page 32). Colorful slabs of rock called banded iron formations (one shown) formed on the seafloor when oxygen reacted with dissolved iron in the sea. The reactions created iron oxides that sank to the seabed to form red sheets interspersed with layers of silica-rich sediment. —*Erin Wayman*

# Earth's Turbulent Eons of Climate Change

**A trip through our planet's history offers clues to how life will survive global warming, or not**

By Elise Cutts | Illustrations by Andy Lovell

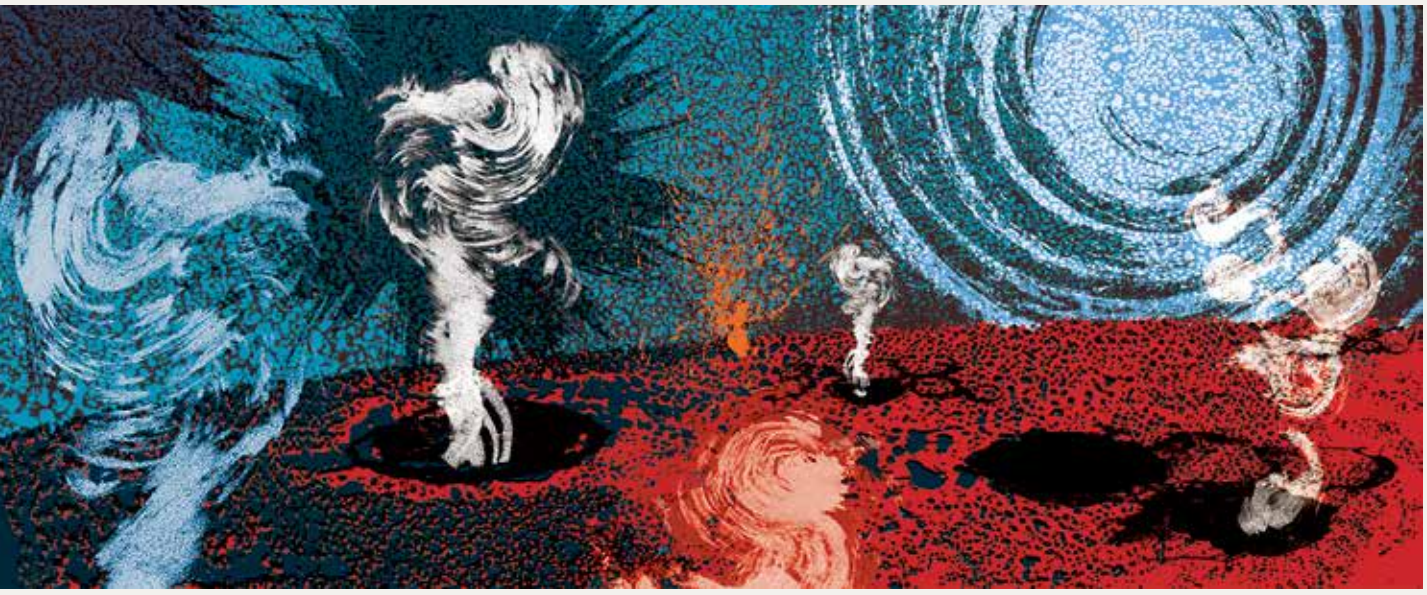
## Our species likes it cold.

*Homo sapiens* evolved in — and still inhabits — one of Earth's rare and fragile ice ages, periods distinguished not by an abundance of saber-toothed cats and woolly mammoths but by ice caps at the poles. For most of its 4.5-billion-year history, our planet was too warm for polar ice. *Tyrannosaurus rex*'s steamy Cretaceous kingdom 66 million years ago was in many ways a more representative slice of history than our own. Back then, reefs blanketed the beds of shallow seas as warm as bathwater, and jungle creatures watched the southern lights dance behind gaps in the thick canopies of Antarctic rainforests.

Not every warm period was so pleasant. In the Permian Period, some 270 million years ago, all animal life on Earth very nearly ended in a catastrophic mass extinction accompanied by intense, rapid global warming. But while the Permian world ended in fire, life on Earth has nearly perished more than once — and sometimes, it ended in ice. The polar ice caps crept down to the equator and the planet froze over in states known as "Snowball Earth," which each lasted for millions of years.

Earth's history confronts us with the fleeting fragility of our moment: Earth doesn't have to look like it does now. In fact, it usually doesn't. Between our world's fiery infancy and its (for now) chilly present, it has been many planets, thanks to a multitude of geologic forces.

Understanding why Earth's climate changed in the past — and what happened to life when it did — can help us understand our unusual moment today. Because while our species likes it cold, we've taken the reins of climate in hand and veered our planet onto a hot new trajectory. What does the past have to teach about where we might end up?



## Hell on Earth

Hadean Eon: *4.6 billion to 4 billion years ago*
Peak temperature: *~10,000° Celsius (18,000° Fahrenheit)*
Climate influences: *Planetary collisions, primordial heat*

An ocean of magma stretches to the horizon in every direction, an expanse of liquid rock beneath a cracked crust of black-gray basalt. The sunlight beating down on this dead expanse is weak, dim — but heat rises from the depths below.

This is the Hadean Eon, Earth's turbulent infancy, which began some 4.6 billion years ago when clumps of material coalesced out of the disk of hot dust and gas that swirled around the young sun. This disk was toasty, at least a few hundred degrees Celsius where the rocky planets formed. But it got a lot hotter when, about 100 million years later, a Mars-sized rock called Theia smacked into the young Earth. That run-in released the energy equivalent of trillions of H-bombs — enough "to pretty much vaporize most of Theia and melt what becomes the Earth," says planetary scientist Norman Sleep of Stanford University.

That collision left the planet a hellish ocean of magma beneath a sky of rock vapor. And in the sky hung yet another ball of magma, an incandescent orb: the moon, which had coalesced out of impact debris potentially within a few short hours of the collision. Depending on exactly how the moon kaboom played out, the hottest vaporized bits of whatever was left in the impact's aftermath could have reached temperatures of about 10,000° C, says geologist Mark Harrison of UCLA. "No part of the Earth would ever have subsequently reached more than about 7,000 kelvins," or about 6700° C.

Surface temperatures on the solid rock that survived the impact were far lower, probably around 2000° C. Anything above that, and there wouldn't have been a surface at all.

Over the next 1,000 years, Earth cooled enough for the rock vapor in the atmosphere to condense out; perhaps in showers of lava, perhaps in flakes of rocky snow. It took longer for the magma ocean to solidify. The freshly formed moon heated Earth via gravitational forces, which kneaded Earth's interior and kept the planet molten for millions, perhaps tens of millions, of years. But when the magma ocean finally crystallized into rock, the planet crossed a threshold, Sleep says.

The sun overtook Earth's smoldering heart as the most important source of energy. From there on out, Earth's climate would be dictated by how much solar energy the planet received, reflected and retained.

## Earth's thermostat turns on

Archean Eon:
*4 billion to 2.5 billion years ago*
Temperature range:
*0° to 40° C (32° to 104° F)*
Climate influences:
*Greenhouse effect, carbon cycle*

As the Hadean Earth cooled, it eventually started to rain. And rain. And rain. Water vapor poured out of the atmosphere and over the barren plains until Earth's surface drowned beneath a global ocean

once more — this time, of water.

The Archean Eon begins with the rock record itself, when the surface finally cooled enough for rock to stay solid. And the rocks from this time, when land first peeked above the seas in arcs of volcanic islands, paint a picture of a world that's a bit chilly, especially the poles. Simulations suggest that surface temperatures ranged between a frosty zero degrees and a toasty 40° C — perfectly habitable. In fact, the earliest signs of life date to this period.

But the Archean presents a climate conundrum. At its onset, the sun was only about 70 to 80 percent as bright as it is today. The sun's energy comes from the fusion of hydrogen to helium. As hydrogen gets used up, the core gets denser, which speeds up fusion and makes the sun brighter and hotter over time. The energy coming from the faint young sun on its own would not have been enough to keep the planet as warm as it was. So in theory, Earth should have transformed into the ninth circle of Dante's hell — iced over.

The answer to the paradox? Greenhouse gases like carbon dioxide and methane. These gases allow sunlight to beat down on Earth's surface, which heats it up, but don't allow heat to radiate back out as infrared light. This traps heat around Earth like a blanket. "There was a bigger greenhouse effect" than today, says planetary scientist David Catling of the University of Washington in Seattle. "That sort of is the basic story of the Archean: fainter sun, more greenhouse gases."

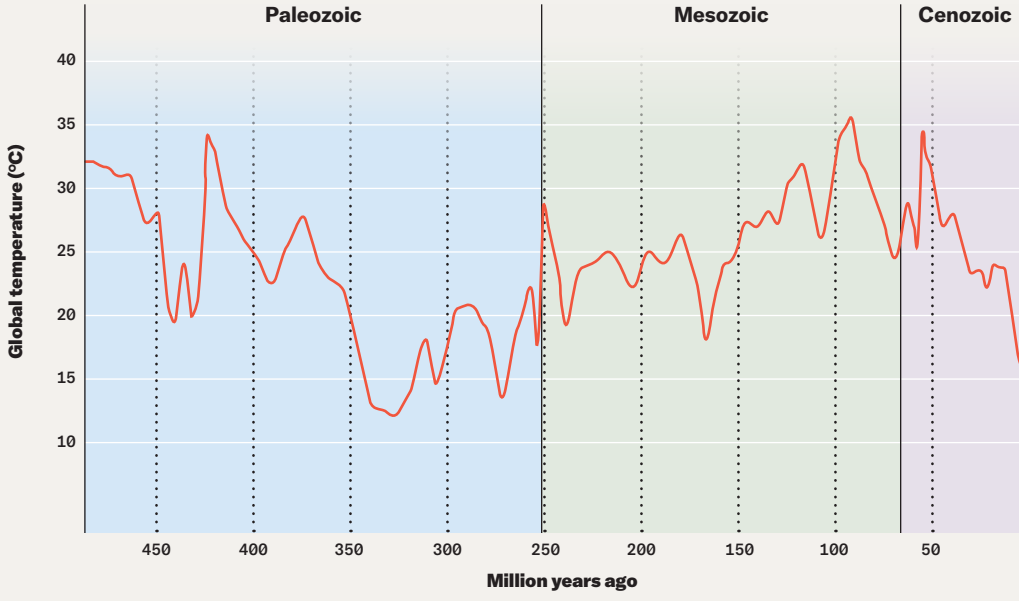
As the Hadean magma ocean cooled, it outgassed a thick, steamy atmosphere rich in water vapor and carbon dioxide. Despite the faint sun, temperatures could have been around 200° C right after the magma ocean solidified. However, sometime between the hellish Hadean and clement Archean, the planet's natural thermostat came online: the carbon cycle.

Atmospheric carbon dioxide gets transformed into chalky white carbonate minerals through chemical weathering. This process traps carbon dioxide in rock, but it doesn't stay trapped forever. Over hundreds of thousands of years, Earth constantly recycles its surface into the interior through plate tectonics. When carbonates end up in the mantle, they eventually break down and get belched back up by volcanoes as carbon dioxide. This cycle is sensitive to temperature: Chemical weathering speeds up in warm climates and slows down in cold ones.

At least by the beginning of the Archean, the carbon cycle had locked away enough carbon dioxide to bring the planet's surface temperature into a habitable range. With carbon dioxide levels between 10 and 1,000 times as high as today and methane levels 100 to 10,000 times as high, the Achaean Earth was alien but livable, its seas strewn by lumpy mounds

E. J. JUDD *ET AL*/*SCIENCE* 2024, ADAPTED BY C. CHANG

**AVERAGE GLOBAL SURFACE TEMPERATURE OVER THE LAST 485 MILLION YEARS**




Throughout Earth's history, the planet has experienced both hot and cold periods, though warm times have been more common. That's true of the last 485 million years, as seen in this timeline developed last year by combining geologic data with computer simluations. Our genus, *Homo*, evolved nearly 3 million years ago during one of the rare cold spells. Today, humans are on the verge of sending the planet back into a warm period.

of microbes huddled together below the hazy, orange sky. The geologic thermostat has regulated Earth's temperature ever since and never once has it gotten hot or cold enough to end all life.

But it has come close.

## An ice planet

The first Snowball Earth: *2.4 billion to 2.1 billion years ago*
Temperature low: *–50° C (–58° F)*
Climate influence: *Life*

Between 2.4 billion and 2.1 billion years ago, near the beginning of the Proterozoic Eon, Earth froze over. Thick sheets of ice encased the planet from pole to equator. Temperatures may have plummeted to as low as –50° C — low enough to cause frostbite within minutes — and stayed low for tens of millions of years. It was, perhaps, the scene of one of Earth's first mass extinctions. But since the only casualties were microbes, almost no fossils remain to record the death toll.

This climate cataclysm was one of several icy episodes called Snowball Earths. Those episodes bookend the otherwise toasty Proterozoic Eon, which stretched from 2.5 billion to 541 million years ago. They were the result of a runaway feedback loop: Sparkling white ice is more reflective than land or seawater. So, the more ice grows, the more sunlight Earth reflects. This increase in reflectivity, or albedo, lowers temperatures, encouraging more ice to form in a positive feedback loop. Once polar ice creeps past a latitude of about 30° North or South, the planet will become a snowball.

"Once you reach that tipping point in the area of sea ice, then it takes on the order of 200 or 300 years to reach the fully glaciated state," says field geologist Paul Hoffman of the University of Victoria in Canada. "That's pretty quick on a geological time scale."

Earth's thermostat won't let a Snowball go on forever. With the land frozen over, chemical weathering shuts down. But volcanoes don't. They keep pumping carbon dioxide into the atmosphere. Eventually, the greenhouse effect will thaw out the planet. Ice melts, the planet becomes less reflective, the planet warms even more and then more ice melts.

We know that the Snowballs happened thanks to glacial rock deposits left behind in areas that were near the equator back then. How they started is more mysterious, but one theory blames biology for the very first deep freeze.

The transition from the Archean to Proterozoic is, in some places, an almost literal red line in the rock record. Thick bands of red, iron-rich stone appear about 2.5 billion years ago. These banded iron formations probably formed with the emergence of photosynthetic microbes that started to fill the oceans with oxygen. Iron dissolved in the seas rusted out as solid particles, which accumulated on the seafloor in sediments that would become the banded iron formations.

As the oceans bloomed with photosynthetic organisms, more and more oxygen rose into the air. The oxygen oxidized the methane, which had served as an atmospheric blanket keeping Earth warm for 1.5 billion years.

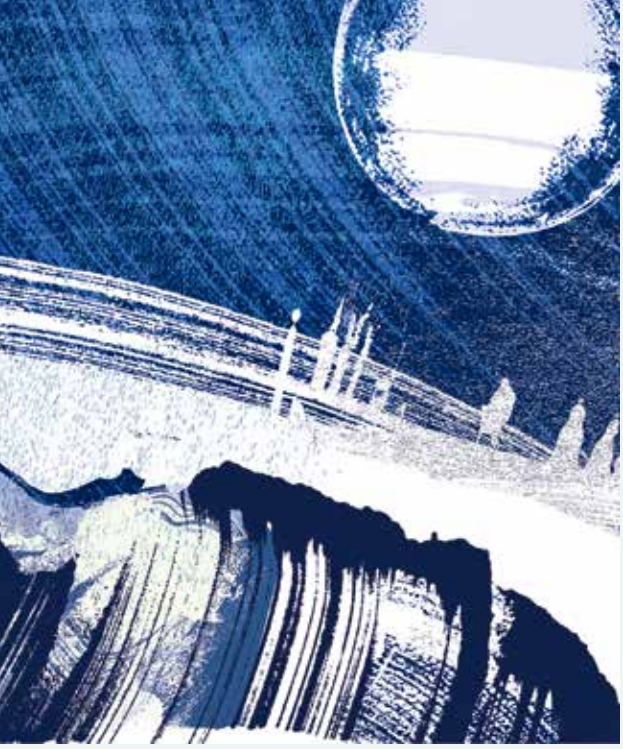
"On a timescale of 10,000 years, you destroy your methane as oxygen rises," Catling says. "That can't be compensated for by the geologic carbon cycle, because that's slow. So then you can get into the runaway albedo, and you could grow ice sheets and make a Snowball Earth."

## Deadly global warming

The Permian extinction:
*252 million years ago*
Peak temperature: *73° C (163° F)*
Climate influences: *Volcanic eruptions, position of the continents*

Near the end of the Permian Period some 252 million years ago, the supercontinent Pangaea would have been a good setting for a Western: It was a sunbaked, dusty wasteland from horizon to horizon. Daytime air temperatures in the tropics hovered around 50° C. On the hottest days, they climbed to 73° C — hot enough to denature protein. Any animal that hadn't yet fled to the poles, where forests sprung up despite the long polar nights, would have been cooked alive.

The climate had been becoming less hospitable to life for some



*Our species has never seen an iceless planet.*

20 million years, in part thanks to the assembly of Pangaea, says geologist Neil Tabor of Southern Methodist University in Dallas. With more land crammed together, coastlines shrunk, sea levels dropped, everything dried out and temperatures in the desiccated continental interior swung wildly.

"In marine environments, you still have functional ecosystems in the tropics and at high latitudes," Tabor says. "But on land, it just goes to hell." At least, that is, before the death blow.

The mass extinction at the end of the Permian was the worst our planet has ever seen. And while marine ecosystems initially remained mostly unscathed, they were ultimately hit hardest. In a climate meltdown that lasted a few hundred thousand years, 95 percent of marine and 70 percent of terrestrial species disappeared.

About 300,000 years before the peak of the extinction, volcanoes in what's now Siberia erupted and didn't stop for 1 million years. This volcanic region, called the Siberian Traps, belched up enough lava to bury an area as large as the continental United States in 50 meters of molten rock. With all that lava came lots and lots of carbon dioxide.

In a geologic blink, perhaps as quickly as 60,000 years, Earth's average surface temperature soared by up to 10 degrees C to around 30° C. Oceans sweltered and grew too sluggish to circulate oxygen. Much marine life suffocated, and bacteria that thrived in the anoxic depths poisoned the water with hydrogen sulfide. That deadly gas might have bubbled up to poison the land, too. Volcanic gas mixed with water to rain acid on the barren, dusty wastes.

"It's just these toxic, salty, shallow acid lakes and lots of windblown, red dust," says geologist Kathleen Benison of the University of West Virginia in Morgantown, who uses bubbles of liquid trapped in salt left behind by ancient lakes to study the Permian climate. It took life 5 million years or more to recover.

But perhaps the most chilling aspect of the Permian is what it might suggest about our current moment. "Icehouse" periods like the one we're in now, when Earth has polar ice, are few and far between.

To reach the previous icehouse, you have to go back to the early Permian, when the average temperature was probably 15 degrees C cooler than today. Ice sheets reached the midlatitudes. Earth might have looked a bit like it did at the height of the last glacial period 20,000 years ago when woolly mammoths roamed the frosty steppes of Paris. Just swap our continents for Pangaea and the saber-toothed cats for lizard-like protomammals.

This cold spell lasted for 105 million years before climate change transformed Pangaea into a scorched, parched and quite possibly toxic wasteland. Scientists still aren't exactly sure why Earth stayed so cool for so long. Perhaps Pangaea itself was the culprit. Stitching together a supercontinent involves building mountain ranges, which exposes fresh rock to chemical weathering and ultimately contributes to cooling.

Plants might have played a role, too. After true trees evolved, it took about 60 million years before biology caught up and evolved ways to break them down. Since they didn't decompose well, dead trees ended up getting buried over geologic time. That stored an enormous amount of organic carbon as coal; 90 percent of all coal deposits date back to this time.

We don't know why this ice age began, but we do know how it ended: in the greatest mass extinction of all time.

"We're still technically in an icehouse, but we're rapidly going towards a greenhouse," Benison says. "Looking back at the [end of the Permian] is a good way to try to say what happens with these big changes — and not just what happens with climate, but what happens to life."

## The warmest living world

Cretaceous hot greenhouse: *94 million to 82 million years ago*
Peak average surface temperature: *36° C (97° F)*
Climate influences: *Greenhouse gases*

Given the deadly consequences of the Permian, it might be surprising that Earth's hottest period since the evolution of complex life was more Garden of Eden than Paradise Lost.

Ninety million years ago in the Cretaceous Period, the planet was a verdant jungle world. Vast swaths of the continents, including huge strips of the American West, were flooded by shallow seas. In some areas, carnivorous dinosaurs like *Spinosaurus* prowled the shores. At 36° C, the average surface temperature was a degree shy of human body temperature. You could barely cool off by taking a dip in polar seawater; it was a soupy 27° C.

But given all that, "there's no mass extinction" during this hot part of the Cretaceous Period, says geologist Brian Huber of the Smithsonian National Museum of Natural History in Washington, D.C.

Last year, Huber and colleagues published the results of a project that pooled paleoclimate data to reconstruct the last 485 million years of surface temperature. According to this new temperature timeline, the Cretaceous super-greenhouse was the hottest Earth has ever been since the evolution of life more complex than a microbe. Scientists aren't sure what drove temperatures so high. But it's clear, at least, that the walk-up to the peak temperatures was much more gradual than the 10-degree jump that rocked the Permian. Earth had been hot for a long time. In fact, it never really cooled down after the Permian extinction. The poles were effectively ice-free for the entirety of the dinosaurs' nearly 180-million-year reign, and global mean surface temperatures mostly remained above 20° C (5 degrees C hotter than in 2024). Perhaps the transition from icehouse to greenhouse during the Permian put ecosystems under additional stress. That would be bad news, considering what's happening today.

## Into the future

The last several million years of Earth's climate — and the entire history of our genus, *Homo* — is written in ice. That's why climate scientists are so eager to hunt for old ice, including a 6-million-year-old sample retrieved from Antarctica last year. The ice tells a story echoed in seafloor sediments and countless other clues from the rock record and computer modeling. For the last 2.3 million years, the climate has swung to the rhythm of several long-term variations in Earth's orbit. These Milankovitch cycles subtly change the amount of sunlight Earth receives and where it is distributed. So, at first every 40,000 years and later every 100,000 years, Earth has cycled between clement interglacial periods and frosty glacial periods some 5 degrees C cooler.

The cyclical freeze and thaw of our current icehouse period began at the tail end of a long-term cooling trend that started 50 million years earlier. Perhaps due to the rise of the Himalayas, which exposed an enormous amount of fresh rock to chemical weathering, atmospheric carbon dioxide levels steadily declined. By 34 million years ago, Antarctica was cold enough for permanent ice to collect at the south pole. By 800,000 years ago, carbon dioxide levels dropped to below about 300 parts per million. As the planet cooled, it crossed a threshold: It became sensitive enough to subtle variations in sunlight to respond dramatically to Milankovitch cycles.

Our species has never seen an iceless planet. But within two short centuries, industrial carbon emissions from coal-fired power plants and gas-fueled cars have nearly

doubled the carbon dioxide level from 280 ppm to 426 ppm. Average temperature has ticked up by 1.47 degrees C. We're on track to blow past the 1.5-degree warming target set by the Intergovernmental Panel on Climate Change. Meeting that ambitious target might not even be enough to prevent total ice sheet collapse.

If nothing significant changes in our approach to climate change, that will be just the beginning: Carbon dioxide levels will reach 600 ppm by 2100, or soar above 1,000 ppm, under less optimistic scenarios. That could result in 4 degrees C of warming relative to the preindustrial average temperature.

A period 55 million years ago called the Paleocene-Eocene Thermal Maximum, or PETM, offers a view on a world with carbon dioxide levels that high. It was the hottest period in the history of *our* Earth; the planet we know, with its familiar continents and ecosystems dominated not by dinosaurs but by mammals. Leading up to the PETM, temperatures rose between 5 and 8 degrees C to an average of up to 34° C. Unlike us, the creatures that endured this hot period were already accustomed to an iceless planet. The PETM didn't see a mass extinction, but it did reshuffle ecosystems. Local extinctions were common, even if a species could hold on elsewhere. And some species did disappear entirely.

If we'd been around in the PETM, we'd have had to migrate to the poles to survive. But cities can't exactly get up and move. That's a problem, because the world in 2100 will not be the world we know today. By the end of the century, billions of people will routinely endure heat and humidity extremes beyond the limits of human survival, even if we limit warming to 2 degrees C. We've already delayed the next glacial period, if not canceled it. And by 2500, 40 percent of all land area will have become unsuitable for its current biome, scientists predict.

This will be the end of the world as we know it, but not *the* end of *the* world. Even if we do create a climate catastrophe on the scale of the Permian mass extinction, Earth's history shows that the planet will recover. The carbon thermostat will correct our error — just not nearly fast enough for it to matter for our species. Perhaps we'll push Earth into a new greenhouse regime, like the jungle world of the dinosaurs. That would be anathema to our species, but it's nothing Earth hasn't seen before. Life will go on, with or without us. At least, for a while.

Temperatures today aren't too different from what they were all the way back in the Archean. Because chemical weathering speeds up when it's hot, Earth's natural thermostat has trapped more and more carbon dioxide in rock as the sun warms — and it'll keep doing that as the sun continues to heat up. Eventually, that'll be a problem for plants; if carbon dioxide gets too low, they can't photosynthesize.

About 500 million years from now, atmospheric carbon dioxide will dip below 100 ppm, scientists predict — low enough to kill 95 percent of plants alive today. About 1 billion years from now, carbon dioxide will sink even lower, and the sun will be about 10 percent brighter than today. At that point, any remaining plants will disappear. With photosynthesis shut down, oxygen will rapidly disappear from the atmosphere.

Eventually, the thermostat will break altogether, Hoffman says. "There will come to be a time when we will lose that $CO_2$ lever." Like a beachgoer on a hot day who's run out of clothes to take off, Earth will run out of carbon dioxide to strip away. But the sun will keep getting hotter.

Temperatures will soar higher than ever since the Hadean, and Earth will spend about 3 billion years as a hellscape before the sun starts dying and takes our planet with it.

That's just about as long as Earth has been habitable up until now — and far longer than it will support life complex enough to consciously engineer a climate crisis. ✖

**Elise Cutts** is a freelance science journalist based in Austria.

THE CASE OF

# SHAKEN BABY SYNDROME

Defense lawyers have tried to discredit the diagnosis in the courtroom. But the medical community says the science is sound

BY TARA HAELLE

ILLUSTRATIONS BY PETE RYAN

ABOUT FIVE YEARS AGO, Nicole, a mother of two, had friends over for dinner while her husband, Sean, watched 3-year-old Courtney and 2-month-old Sarah. Fifteen minutes into dinner, Sean interrupted Nicole to ask for a pacifier and then interrupted again later because Sarah had pooped through her diaper and left a mess on the floor. After he took the baby to her room to change her, Sean called for Nicole again. "I could tell something was wrong in his voice," recalls Nicole, who is using only her middle name and pseudonyms for her family to protect their privacy. Sarah was having a seizure and then went completely limp. Nicole and Sean called 911.

At the hospital, a CT scan revealed a large brain hemorrhage, and Sarah was airlifted to a children's hospital. On the half-hour drive there, Nicole asked Sean what had happened.

"Courtney had been jumping on the couch and then hit Sarah on the head," he told her. It had been an accident.

Sarah spent four days in the ICU, where she had hour-long seizures. Exams found severe brain swelling, injuries to her neck ligaments and significant bleeding behind the eyes called a retinal hemorrhage. But there was no evidence of blunt force trauma, as would be expected if Sarah had been hit on the head by her sister.

To put Sarah's injuries in context, a pediatrician interviewed her parents at length about her medical history and the circumstances leading up to the injury. A few days later, a police detective requested an interview. When Sean left for the police station, he seemed nervous, Nicole says. It was the first indication to her that something was off.

A little while later, Sean called. He was crying. "I'm so sorry. I shook her. I shook her twice," Nicole remembers him saying. "My whole heart just shattered like glass all over the floor," she says. "I just felt like everything in our lives changed right there in that moment."

Sarah was diagnosed with abusive head trauma, the medical name for shaken baby syndrome, which can be caused by shaking, an intentional impact against a surface, or both. Shaking is particularly dangerous for babies because of their relatively large head and weak neck muscles.

Each year in the United States, about 25 to 35 infants per 100,000 infants under 1 year old suffer abusive head trauma — about 1,300 babies a year — and 10 to 20 percent of them die. The most common injuries include brain and retinal hemorrhaging, brain swelling, neck-ligament injuries, difficulty breathing, rib or other bone fractures, and bruising on the torso, ear or neck. Roughly 80 percent of survivors experience lingering harms that can include learning disabilities, blindness, seizures, hearing or speech problems, and behavioral disorders.

Shaken baby syndrome was first described in 1971, when the medical understanding of child abuse was in its infancy. As research accrued, physicians and forensic pathologists fine-tuned the diagnostic process, which relies heavily on determining whether the physical injuries match caregivers' descriptions of what

**1,300**

Number of infants who suffer abusive head trauma in the United States each year

happened. But in the early 2000s, doubt about the diagnosis crept into the legal system.

In 2009, the American Academy of Pediatrics, or AAP, updated the condition's name to abusive head trauma to be more inclusive of cases where blunt force trauma may be present, with or without shaking. Some defense lawyers have argued that the change suggested a lack of scientific consensus over the cause of injuries typically associated with shaken baby syndrome. Although the name changed, the diagnostic process did not.

Yet today, when criminal cases land in court, defense attorneys often attack abusive head trauma as a "junk science," no different than other debunked forensic fields like microscopic hair analysis and bite-mark comparisons. The Innocence Project, a nonprofit that works to overturn wrongful convictions, includes the diagnosis on its list of "misapplied forensic science."

Doctors disagree. "The courtroom has become a forum for speculative theories that cannot be reconciled with generally accepted medical literature," six radiology and pediatric medical groups noted in a 2018 consensus statement published in *Pediatric Radiology* and later endorsed by 11 additional medical organizations as of 2021. "There is no controversy concerning the medical validity of the existence of [abusive head trauma]."

And in February, a new AAP technical report laid out the extensive science supporting the diagnosis and described the complex process by which doctors diagnose it.

Today, the false narrative that the diagnosis is debunked and controversial continues to make headlines. That makes doctors concerned that the public will conclude that shaking an infant is not necessarily as harmful as claimed.

"I'm worried ... that this effort to discredit the validity of the diagnosis is going to undermine efforts to keep children safe because shaking a baby is dangerous, and that's a message that needs to be out there," says Andrea Asnes, a child abuse pediatrician at Yale School of Medicine. Perpetuating the idea that it's a disputed diagnosis, Asnes says, could make it harder for judges and other officials "to understand the degree of danger that a caregiving situation may pose for a specific child and limit their ability to keep the child safe."

### A diagnosis disputed in court

Most criticism of the abusive head trauma diagnosis centers on a collection of three signs dubbed "the triad" by defense teams: brain swelling, brain hemorrhaging and retinal hemorrhaging. Critics claim that physicians diagnose abusive head trauma based solely on the presence of the triad. Yet each of these injuries has many other possible causes, skeptics say, so the diagnosis is invalid because it's not specific enough to eliminate all other possibilities.

But the triad is a straw man argument. "I've never used that term in all my life," says John Leventhal, a child abuse pediatrician retired from Yale.

Those three injuries are indeed common in

**HANDLE WITH CARE** **Babies are fragile. Their weak neck muscles can't support the weight of their relatively large heads. So if a baby is shaken, the brain will move back and forth inside the skull. That can result in injuries such as:**

▲ BLEEDING IN THE BRAIN AND THE RETINA
Violent motion can rupture blood vessels.

▲ BRAIN CELL AND SPINAL CORD DAMAGE
Violent motion can cut connections between nerve cells. If the infant experiences difficulty breathing, a lack of oxygen can further harm nerve cells.

▲ BRAIN SWELLING

▲ BONE FRACTURES AND BRUISING

abusive head trauma — brain and retinal hemorrhaging are present in some 80 percent of cases, research shows — but diagnosis is much more involved.

Alleging that pediatricians rely solely on the triad "is clever in the sense that it sort of implies a rush to judgment, because it's 1-2-3, done," says Leigh Bishop, director of the Babies and Toddlers Task Force at the New York City Office of Chief Medical Examiner. "And any practicing, credible doctor in the hospital or forensic pathologist will tell you that these cases are the opposite of 1-2-3 and done. They require layers of medical investigation."

The new AAP report compiles decades of research on how to accurately diagnose abusive head trauma, reviewing the prevalence of different signs and symptoms. It describes the medical tests — blood tests, CT scans, MRIs and more — that can rule out alternative diagnoses, including infections, metabolic conditions and rare genetic bleeding disorders. The report also emphasizes the importance of the caregiver's narrative of events in understanding the context in which the injury occurred.

When a clinician suspects abuse, a specialized child abuse pediatrician is called in. "We're not only looking for specifically strong associated findings with inflicted trauma, but we're trying to rule out other big things as well," says Sandeep Narang, a child abuse pediatrician at Children's Wisconsin hospital in Milwaukee and lead author of the AAP report. If trauma is the only reasonable cause of the injuries after ruling out other possibilities, the pediatrician, as part of a team of specialists, must determine if it's accidental trauma, birth trauma or inflicted trauma.

"Most of the trauma we evaluate is accidental, and it's accompanied by an explanation that makes sense," Asnes says. "We become concerned when kids present with trauma and there's no explanation. We don't start with a presupposition about what happened."

If the child died, forensic pathologists use the same process in determining the cause of death. "You're looking for something to explain the injury," says James Gill, a forensic pathologist and the chief medical examiner for Connecticut. That means the narrative a caregiver gives is crucial. "When you have inconsistencies, an anatomic finding that doesn't fit with the history," he says, "that's when it raises a red flag."

Often in court, however, "this complex medical thought process gets oversimplified and misstated," Narang says. And sometimes, defense attorneys go as far as providing invalid alternative explanations to discount the diagnosis.

Claims arose in the early 2000s that a lack of oxygen, including that caused by sudden intense coughing, could cause some of the signs seen with abusive head trauma. This notion was disproved with studies looking at internal injuries of near-drowning victims and children with temporary cardiac arrest, Narang says. In another instance, four medical defense experts put forth during a trial that if a baby coughed hard enough,

"I'm worried that this effort to discredit the validity of the diagnosis is going to undermine efforts to keep children safe."

**— Andrea Asnes**

brain vessels could rupture. That claim was based on their interpretation of one child's injuries.

Another claim is that a brain bleed from abusive head trauma is actually "re-bleeding" in a child who had brain bleeding during birth. But such re-bleeding has never been described in the medical literature, says Christopher Greeley, a child abuse pediatrician at Baylor College of Medicine in Houston. Reopening of a wound from a previous traumatic brain injury can happen, he says, but that previous injury would usually have been documented in the child's medical history.

"The vast majorities of defense experts will acknowledge the harms in shaking a baby, but then they'll talk out the other side of their mouth and say that shaken baby syndrome is not a real thing," Narang says. "There are a few who will admit that it's a real thing and then create the framework that it's too susceptible to error for us to be diagnosing."

Heather Kirkwood, an attorney in Seattle who works pro bono on cases she believes to be wrongful convictions, acknowledges that shaking a baby can cause harm. But she says she would expect to see certain signs, like neck injuries. Kirkwood says that in the 100 cases that she has reviewed, those signs were not present. A small research study in 2009, however, identified it in 71 percent of victims, and the new AAP report notes that spinal cord injury occurs in 30 to 80 percent of cases.

A small minority of both defense experts and lawyers claim that shaking simply cannot cause the severe injuries seen in these cases. "There's some people who just don't believe it, and they will go to extraordinary lengths to try and explain it away somehow," Gill says.

Russell Jones is a defense attorney in Milwaukee who has worked on a handful of shaken baby cases. He doesn't question that shaking a baby vigorously enough could cause serious injury. "If you tell me I've never found an instance [of a] shaken baby ever," he says, "I'd find that hard to be credible." He says juries tend to see through expert witnesses who outright discredit abusive head trauma versus those who raise doubts about whether the evidence in a specific case supports the diagnosis. "I would say, generally, juries get it right," Jones says.

Research backs that up. Narang led a study published in 2021 in *Child Abuse & Neglect* that reviewed all abusive head trauma convictions in the United States that had been appealed and ruled on by a judge from 2008 through 2018.

**CONSEQUENCES** **About 80 percent of infants who experience abusive head trauma suffer long-term disabilities such as:**

- ▲ CEREBRAL PALSY
- ▲ PARALYSIS
- ▲ VISION LOSS OR BLINDNESS
- ▲ INTELLECTUAL DISABILITY
- ▲ EPILEPSY
- ▲ SEIZURES

Out of 1,431 cases, only 49, or 3 percent, were overturned. A little less than half of those, 20, were overturned on grounds related to medical evidence — a dozen of which were due to "controversy" over the diagnosis.

But when the overturned cases were retried, nearly 42 percent of the defendants either pleaded guilty or were convicted again.

The notion that the diagnosis is controversial and discredited is so pervasive that the National Center for Prosecution of Child Abuse outlines nine common defense claims — such as the ideas that shaking alone cannot cause massive brain injuries — and how prosecutors can address them.

### What the evidence says

The ways in which critics have tried to discredit abusive head trauma mirror the tactics of skeptics who question human-caused climate change or the safety and efficacy of vaccines, Greeley says. These include the use of fake experts (ones who lack experience in child abuse or even pediatrics) and expectations of 100 percent certainty (demanding eyewitnesses or filmed proof of abuse). Another tactic is cherry-picking data.

Greeley points to a 2016 review by a Swedish government agency that concluded "there is limited scientific evidence that the triad and therefore its components can be associated with traumatic shaking." The authors excluded studies with children who had any other abusive injuries, such as fractures, except pure "triad" cases, which are very rare.

"It's really poorly done," Greeley says of the review. Its methodology has been critiqued as so flawed that some physicians and researchers have called for its withdrawal.

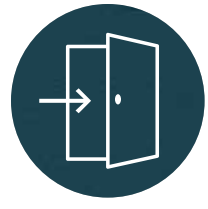
One argument made by critics that has some merit, Greeley says, is that some early studies of abusive head trauma relied on circular logic. Doctors diagnosed patients based partly on the presence of certain physical signs, and then researchers pointed to those cases as evidence of what the physical signs of abusive head trauma are.

More recent research has minimized potential circularity. A 2019 study, for example, started with determining whether abusive head trauma occurred in 500 cases based only on the caregiver's description of what happened, independent of physical injuries except for the presence of patterned bruising, abdominal injury or burns. The researchers then compared the injuries and symptoms in those cases to see which ones occurred most often in abusive cases versus nonabusive head injury or undetermined cases.

If only the triad symptoms were present, the likelihood that the case

**A CRYING BABY** **Many cases of shaken baby syndrome occur when a caregiver becomes frustrated with a crying infant. Experts offer these tips when a little one seems inconsolable.**

**Take a deep breath**
Count to 10 to calm down. Turn the lights down.



**Leave the room**
Place the baby in a safe spot, like an empty crib, and take a break. Check on the infant in 10 minutes. Many crying babies eventually fall asleep.

**Phone a friend**
Call a friend or family member for emotional support.

**Call the doctor**
Contact a pediatrician if the baby has a fever or other symptoms of an illness.

ICONS: THE NOUN PROJECT

was abuse was a little less than 75 percent. But the likelihood rose to well over 90 percent with the presence of six to seven specific medical injuries.

The strongest indication of abuse, with nearly 100 percent likelihood, included six physical signs — difficulty breathing at home, brain hemorrhage, a bone fracture, retinal hemorrhage, brain swelling, and bruising of the torso, ears or neck — but with no skull fracture.

That a skull fracture is not a strong predictor for abusive head trauma is key, Greeley says, because signs like internal brain and retinal bleeding without a skull fracture suggest an infant's injury was caused by forceful movement like shaking, instead of an impact against something, like falling onto the floor.

Researchers have also validated the abusive head trauma diagnosis by studying cases in which the caregiver admitted to shaking the baby. Although some critics question the reliability of these studies because police confessions can be coerced, in some 15 percent of cases caregivers voluntarily describe the act to health care providers, research shows. An understanding of injury patterns has also come from cases where someone witnessed the shaking.

Studies of bruising patterns have led to clinical tools that also help contribute to accurate diagnosis. TEN-4-FACESp is one such tool and was validated in a 2021 study with more than 2,000 children. If clinicians see certain kinds of bruising, it raises the suspicion of abuse. That's what the acronym stands for: bruising on the torso, ears, neck, frenulum (the tissue that joins the upper lip to the gum), angle of jaw (jawbone under the ear), cheeks, eyelids, subconjunctivae (broken blood vessels in the eyes), any bruising on children under 4 months old, or patterned bruising (such as in the shape of a handprint).

Tools like TEN-4-FACESp do not mean certain bruises are automatically classified as abuse — pediatricians still must consider the history and eliminate other possibilities. But they are an important part of the process, with accuracy rates on par with many lab tests used in screening for diseases.

> "When you have inconsistencies, an anatomic finding that doesn't fit with the history … that's when it raises a red flag."
>
> **— James Gill**

### A real harm

No one, including all the child abuse pediatricians interviewed for this article, has claimed that there has never been a wrongful conviction of shaken baby syndrome. That happens with any type of crime.

"Are there cases in the past where the science was wrongly applied? I'm sure there are, but [critics are] using that to discredit the entire diagnosis," Asnes says. "People misdiagnose appendicitis, and there are people who have appendectomies when they do not actually have an inflamed appendix. Does that mean appendicitis doesn't exist?"

When Nicole hears the claim that shaking can't harm an infant, she says it compounds the trauma she's already experienced. Although Sarah survived her injuries, she has needed physical and occupational therapy to overcome difficulty swallowing, a dragging foot and other challenges. "Her milestones are going to be harder to reach as she gets older," Nicole says. Nicole and Sean are now divorced. Sean ultimately pleaded guilty to a Class A misdemeanor, with six days in jail and some community service.

Nicole shares her story to counter the narrative that shaken baby syndrome is somehow debunked. "If anyone who is trying to explain it away as a random, spontaneous medical anomaly had to watch their own baby go through uncontrollable, nonstop seizures and have to wonder every hour, for days, whether or not their child was going to be alive," she says, "then I believe those people would stop talking about this nonsense." ✖

**Tara Haelle** is a freelance journalist based in Dallas.

Plans for the Golden Dome defense system include methods of intercepting missiles in space (one illustrated).

# Golden Dome has a major obstacle: Physics

President Donald Trump's proposed missile defense system has many scientists expressing skepticism

**By Emily Conover**

## In sports, the best offense is often a good defense. It's not clear if the same applies in nuclear war.

In the face of nuclear threats from adversaries like Russia, China and North Korea, some politicians are clamoring for a system to reliably protect the United States from incoming missiles. That's the aim of President Donald Trump's plan for a next-generation missile defense system, dubbed the Golden Dome.

Trump announced earlier this year that an architecture had been selected and that the system would be operational before the end of his term, at a cost of $175 billion. But some scientists say that implementing the system would be daunting.

The United States already maintains a nationwide missile defense system aimed at defending against a small-scale attack from intercontinental ballistic missiles, or ICBMs, launched by a rogue nation such as North Korea. But a February report from the American Physical Society, or APS, concludes that defense against even a small-scale attack is uncertain. And the system's capabilities will probably remain relatively limited within the next 15 years, the authors of the report argue.

The Golden Dome initiative aims to protect the country from more capable adversaries such as Russia and China — a more difficult task.

"Intercepting even a single nuclear-armed intercontinental-range ballistic missile or its warheads ... is extremely challenging," physicist Frederick Lamb of the University of Illinois Urbana-Champaign, chair of the group that produced the report, said at an APS meeting in March. "The ability of any missile defense system to do this reliably has not been demonstrated."

And as countries come up with new types of weapons that could skirt defenses, the situation is getting even more challenging. Golden Dome aims to defend against not just ICBMs, but also hypersonic weapons, advanced cruise missiles and more. And Golden Dome would take missile defense to space. In addition to ground-based systems, Golden Dome would use potentially thousands of defensive weapons called interceptors orbiting Earth, poised to neutralize attacks.

Golden Dome has drawn praise from missile defense proponents. "The initiative to elevate and prioritize air and missile defense ... that's long overdue and it's entirely appropriate," says Tom Karako, director of the Missile Defense Project at the Center for Strategic and International Studies in Washington, D.C. Lower launch costs, proponents argue, make space-based missile defense more realistic than in the past. "I think we're a lot closer than people recognize," says nuclear deterrence and missile defense expert Robert Peters of the Heritage Foundation, a think tank in Washington, D.C.

The U.S. Missile Defense Agency, part of the Department of Defense, has disputed the claims of the APS study, arguing that it relied on older data and unclassified reports that don't reflect recent improvements and upgrades to the missile defense architecture. "MDA's Missile Defense System stands ready and fully capable of defending the United States, deployed forces and allies from a rogue nation's missile attack," the agency said in a statement.

Missile defense has had some recent success. In the war between


Above: Posters at a White House news conference depict conceptual illustrations of a planned Golden Dome missile defense system. Right: An interceptor launches from Vandenberg Space Force Base, Calif., on December 11, 2023, during testing of the ground-based midcourse defense system, which aims to intercept missiles in space.

PREVIOUS SPREAD: MAXAL TAMOR/ALAMY; THIS PAGE, FROM LEFT: MARK SCHIEFELBEIN/AP PHOTO; U.S. MISSILE DEFENSE AGENCY

Iran and Israel that began in June, Israel's missile defense protected civilians from many ballistic missiles lobbed by Iran. But others got through, causing casualties. However, Iran's missiles were not ICBMs, and the challenges of defending against those missiles are different.

"One should not mix apples and oranges," says physicist and aeronautics engineer Paul Dimotakis of Caltech, who was not involved with the APS report. "Different types of attacking missiles and their number and sophistication will require different tailored defenses."

And critics note that the difficulty of the problem remains. "Technology has advanced tremendously," says Victoria Samson of the Secure World Foundation in Washington, D.C. "But the laws of physics have not changed, and that's really what the challenge is."

## Hitting a bullet with a bullet

ICBMs are a formidable target. An ICBM launches in a giant arc that sends the weapon it carries careening through space, traversing more than 5,000 kilometers to reach its target. The challenge of intercepting one has been compared to hitting a bullet with a bullet. But this understates the problem: At around 25,000 kilometers per hour, ICBM speeds are about seven times that of a bullet. What's more, they're generally armed with nuclear warheads, each capable of killing a million people, rather than one.

ICBMs have three phases of flight, and there are different possibilities for intercepting the missiles during each phase. In the boost phase, which lasts a few minutes, rocket engines lift the missile to high altitude and high speeds. In the midcourse phase, the engines are jettisoned. The missile enters space, releasing one or more warheads, which continue upward before falling back down again. This part of the trajectory, in which the warheads are moving in an arc under the influence of gravity alone, is what's known as ballistic motion — hence the missiles' name. That phase lasts about 20 minutes.

The terminal phase is the shortest: The warhead re-enters the atmosphere, descending to its target in under a minute. This period is so short that the only possibility for stopping a weapon is by placing interceptors very close to the point of impact. Such tactics can be used as one layer of missile defense, a backup protection for sensitive areas like military bases, but it's not practical for protecting a large country. So concepts for protecting the entire United States typically focus on the boost phase or the midcourse phase.

## Midcourse defense

The midcourse phase is the bread and butter of the United States' current missile defense system.

Forty-four interceptors in Alaska and California aim to block incoming missiles in space. That system — which by some estimates has cost over $60 billion — is known as ground-based midcourse defense. It's aimed at defending the United States against a small number of unsophisticated missiles from North Korea or another rogue nation.

Critics note that this system has been about 60 percent effective in tests. However, that statistic includes tests going back more than 25 years. The tests performed in more recent years have been more successful. "Any time you test a new system, there are going to be failures early on," Peters says. "That's how you learn what works."

> "Technology has advanced tremendously. But the laws of physics have not changed, and that's really what the challenge is."
>
> — Victoria Samson

Another complaint is that the tests aren't realistic, but proponents say it's not possible to fully re-create realistic conditions. "We have not had North Korea try to nuke the continental U.S. yet, so ... it's not an actual battle test," Peters says. He points to real-world uses of missile defense in conflicts in Ukraine and Israel. "We've been really effective with those tests in real-world operational environments." However, none of the weapons shot down in those conflicts were ICBMs.

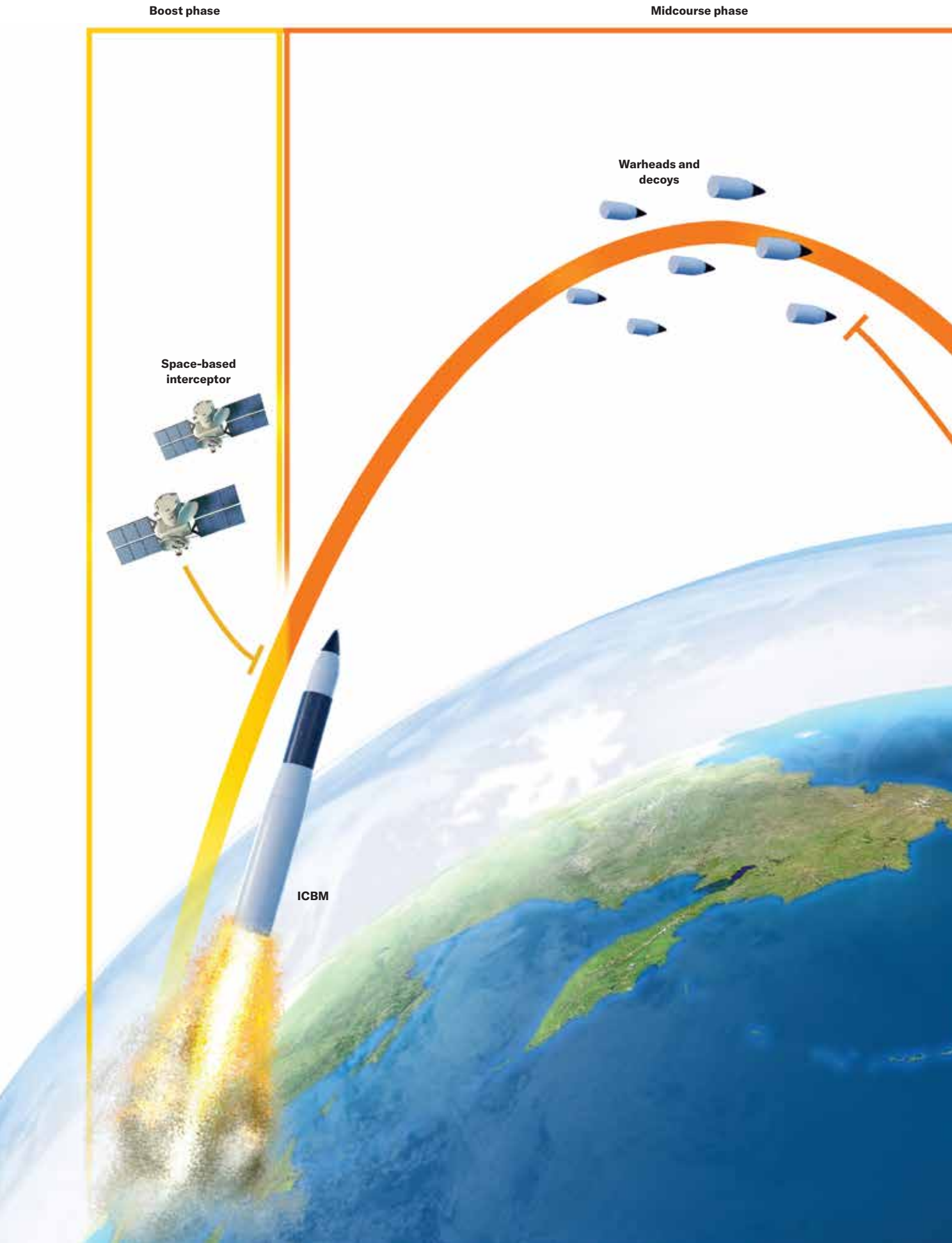
And there's one particularly thorny snag to missile defense in the midcourse phase: countermeasures. An adversary could release debris or decoys along with a real warhead, for example, thwarting attempts to intercept it.

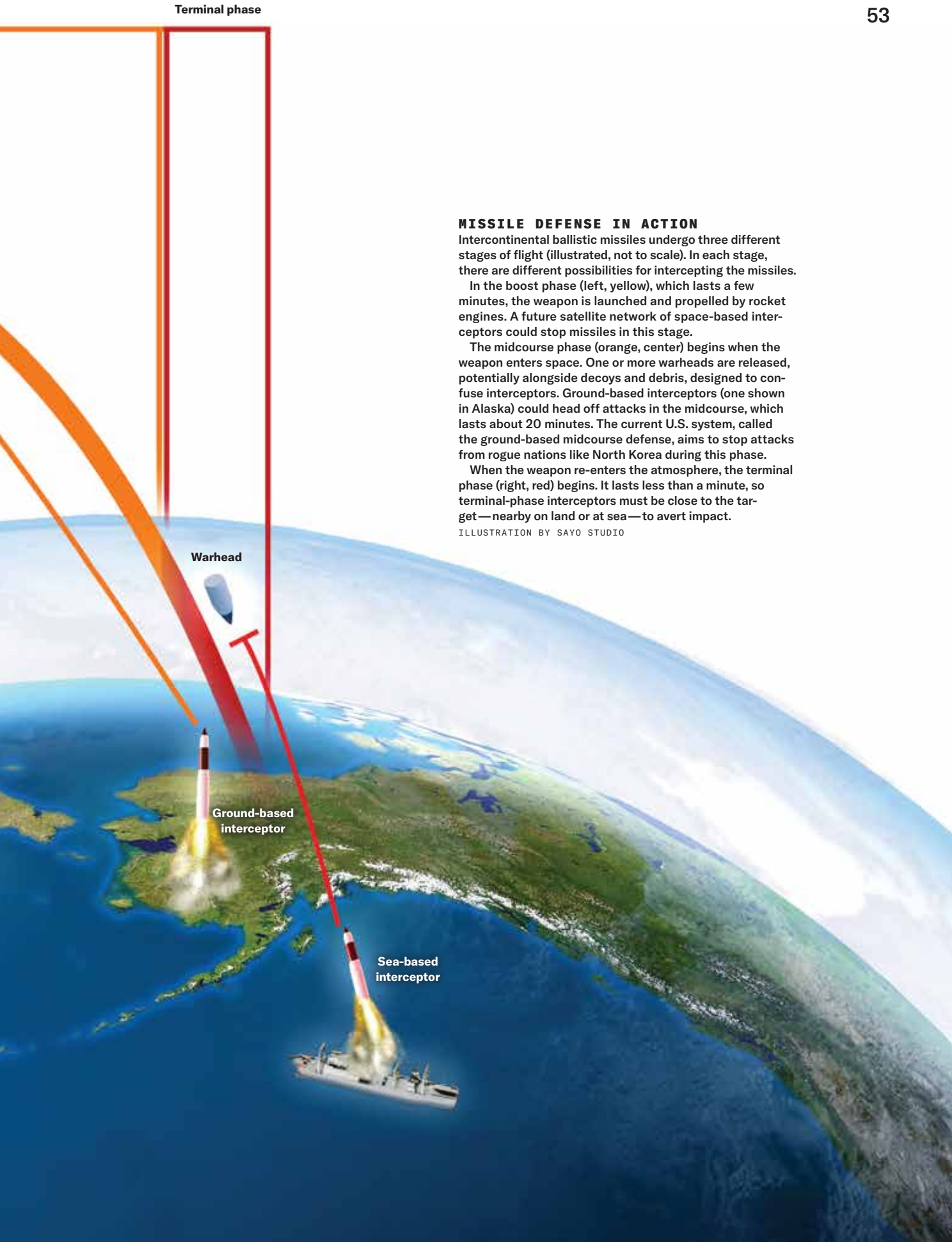
"One key reason why the midcourse phase is difficult is because you're in space, and different objects of different mass travel exactly the same," says James Wells, a physicist at the University of Michigan in Ann Arbor and a coauthor of the APS report. The lack of air in space means that a warhead will travel at the same speed as a balloon designed to mimic it, making them hard to distinguish.

That can make the concept of reliable missile defense in the midcourse phase a bigger task than it otherwise seems. "People say, 'We got to the moon, why can't we do this?' Well, the moon didn't suddenly move out of the way," Lamb said at the APS meeting. "It's a huge technical challenge to identify what the target is.... That's been the bugaboo of midcourse intercept from the very beginning."

## A boost from space

The trickster tactics of the midcourse phase aren't possible in


Boost phase
Midcourse phase
Warheads and decoys
Space-based interceptor
ICBM




**MISSILE DEFENSE IN ACTION**

Intercontinental ballistic missiles undergo three different stages of flight (illustrated, not to scale). In each stage, there are different possibilities for intercepting the missiles.

In the boost phase (left, yellow), which lasts a few minutes, the weapon is launched and propelled by rocket engines. A future satellite network of space-based interceptors could stop missiles in this stage.

The midcourse phase (orange, center) begins when the weapon enters space. One or more warheads are released, potentially alongside decoys and debris, designed to confuse interceptors. Ground-based interceptors (one shown in Alaska) could head off attacks in the midcourse, which lasts about 20 minutes. The current U.S. system, called the ground-based midcourse defense, aims to stop attacks from rogue nations like North Korea during this phase.

When the weapon re-enters the atmosphere, the terminal phase (right, red) begins. It lasts less than a minute, so terminal-phase interceptors must be close to the target — nearby on land or at sea — to avert impact.

ILLUSTRATION BY SAYO STUDIO

the boost phase, during which the warheads remain within the missile, and the entire package travels through the atmosphere.

"There's this perennial dream of intercepting in the boost phase," Wells says. But because the boost phase lasts only a few minutes, "that time pressure is enormous to get an interceptor there."

Boost phase is over so quickly that any interceptor would need to be positioned very close to the launch site. And for a large country with an inaccessible interior, like Russia or China, that's a no-go, on Earth's surface, at least.

Interceptors in low Earth orbit — an altitude of 2,000 kilometers or less — could do it. But those interceptors would be orbiting, rather than parked over the country of interest. To be certain of taking down a missile, a large constellation of satellites would be needed. And to protect the United States from salvos of multiple missiles at once, the number of satellites would have to increase further.

Ensuring protection from just one North Korean ICBM would require more than 1,000 interceptors in orbit, the APS report finds. Protection from 10 might demand more than 30,000 interceptors, depending on missile type and other assumptions. For comparison, some 12,000 active satellites are in orbit around Earth, most in SpaceX's Starlink telecommunications network.

Golden Dome aims to protect not just from North Korea but also from attacks by Russia and China, who together have hundreds of ICBMs. But Golden Dome is not intended to be impenetrable, Peters says. "I don't know anyone who is credibly making that argument." Instead, Peters says, it would prevent a small-scale attack, with a few low-yield nuclear weapons. To thwart Golden Dome, the idea is that an adversary would need to launch a substantial barrage — one certain to provoke a massive nuclear war. The catastrophic implications of such a war, for both the instigator and the entire world, are thought to be enough to deter such an attack.

It's unclear how many ICBMs Golden Dome would aim to neutralize and how many satellites would be needed. But even for small-scale attacks, defending from Russia and China would demand more satellites simply to cover a wider geographic area than needed for North Korea alone.

"It really is an enormously huge difference to be defending against a small region [versus] a large continent," says astrodynamicist Thomas González Roberts of Georgia Tech.

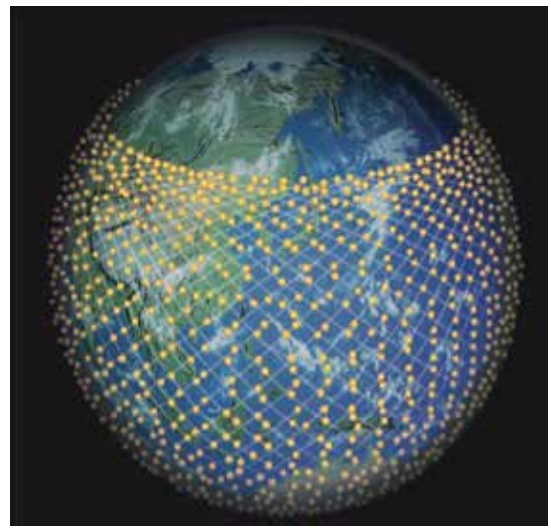
Depending on the specific objectives, Golden Dome could require an untenable number of satellites, he says. "I would call a lot of these proposals infeasible, but in reality, we don't know what these proposals are really asking." Without specific goals for the numbers of ICBMs to be intercepted, from which countries, it's unclear how plausible the plan is.

Trump shared few specifics in the May 20 news conference where he announced the system's architecture, saying "Golden Dome will be capable of intercepting missiles even if they are launched from other sides of the world and even if they are launched from space."

That, Roberts says, suggests an extensive system. "You would be hard-pressed to find a system that could do that for $175 [billion]. Even the most optimistic assumptions behind boost-phase missile defense would suggest that that is impossible." And, Roberts says, to do it in three years would require a faster launch cadence than ever before.

The price tag is bound to be a thorny issue. Already, over the last 70 years, the United States has spent more than $400 billion on missile defense, according to the APS report. As of press time, the budget bill for fiscal year 2025 was working its way through Congress. It would lay out $25 billion for Golden Dome. And a May 5 Congressional Budget Office report suggests that, even with lower launch costs, the space-based effort alone would cost between $161 billion and $542 billion over a period of 20 years.

"It's really complicated," Samson says. "It's like a bumper sticker type thing. It's easy to say ... 'Do you want to be defended against ballistic missiles?' And everyone says, 'Yes, of course, I'd love to.' Great, but here's all the things you need to look at." ✖



A constellation of 1,600 space-based interceptors (locations in low Earth orbit, shown) would be needed to intercept just four North Korean ICBMs launched simultaneously, according to an American Physical Society report.

APS 2025, ADAPTED FROM NRC 2012

# Fundamentals First Fund

An ETF
Symbol KNOW

**Your money Carefully managed**

**Abstract**

**The Fundamentals First Fund, an ETF, is part owner of approximately 100 publicly traded worthy companies, and it owns publicly traded debt. These worldwide companies are vital, important, useful, or just plain nice to have around, and most have been pursuing their business course for decades. We individually select these companies with care and in a manner as to spread our risk so that no single company event can cause more than a bruise. Mason Capital has managed money this way for more than three decades. If you are more specifically interested in who we are, how we do it, and how you might participate, read on.**

**www.FundamentalsFirstFund.com**

**(Our Website Has a Lot About Us)**

| | |
|---|---|
| **2/21/24 IPO Market Open:** | **$10.00** |
| **2/28/25 Market Close:** | **$10.90** |
| **Dividends Paid:** | **$ 0.14** |

*Investors should consider the investment objectives, risks, charges and expenses carefully before investing. For a prospectus or summary prospectus with this and other information about the Fund, please call 617-228-5190 or visit our website at www.fundamentalsfirstfund.com*
Investments involve risk. Principal loss is possible.
Quasar Distributors LLC.

# MAKE A DIFFERENCE
# BENNET YEE DOES


According to Bennet, in lieu of becoming a science teacher, donating to Society for Science is one of the best ways to help cultivate scientific thinking in future generations. Through science, we can understand the world and improve lives. That is why Bennet gives to the Society through his donor advised fund at Vanguard Charitable.

> "Science News is wonderful because it allows me to stay broadly informed about advances in many scientific fields."
>
> **BENNET YEE**

### Join Bennet in supporting Science News

You can make a gift to the Society that will support Science News, our STEM competitions for young people around the world and our growing outreach programs.

### Ways to give

- Contribute through your donor-advised fund
- Make a distribution from your Individual Retirement Account (IRA)
- Give appreciated securities
- Leave Society for Science in your will or estate plans

**For more information on giving, visit www.societyforscience.org/waystogive or email us at give@societyforscience.org**

SOCIETY FOR SCIENCE

**Society for Science is a 501(c)(3) nonprofit organization. Our Federal Tax ID is 53-0196483. Your contribution is tax-deductible as allowed by law.**

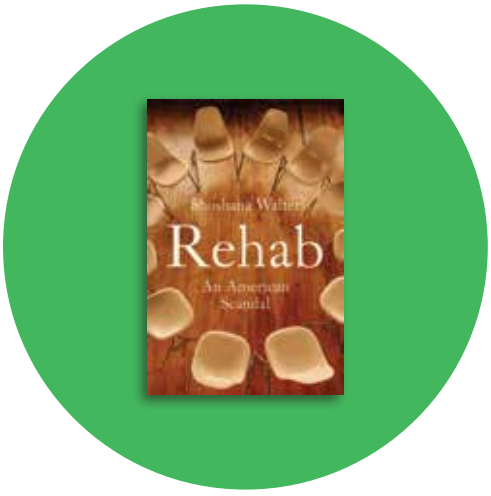
# Curiosities

NATIONAL ARCHIVES

OCEANS

## A JOURNEY TO THE BOTTOM OF THE SEA

● In 1875, winds knocked the British research vessel H.M.S. *Challenger* off course on its way to Guam. During that detour 150 years ago, the crew dropped weighted lines into the water and discovered the Challenger Deep, Earth's deepest seabed, which sits about 11 kilometers beneath the surface of the western Pacific Ocean. In 1960, humans visited the trench for the first time, aboard a U.S. Navy diving vessel named *Trieste* (shown above in a 1963 photo). The 2-meter-wide spherical crew cabin sat below a larger ship-shaped float. —*Karen Kwon*




## THE DARK SIDE OF DRUG TREATMENT CENTERS

*By Meghan Rosen*

**REHAB** | *Shoshana Walter*
**Simon & Schuster | $29.99**

**A doctor, a mother,** a pregnant teen, an adolescent boy who broke his ankle. All have had lives irrevocably influenced by drugs and their aftermath, and all are portrayed in Shoshana Walter's hard-hitting new book, *Rehab: An American Scandal*. Walter, an investigative journalist at the criminal justice news organization the Marshall Project, weaves together their stories with the evolution of drug treatment programs in the United States.

Walter spent hundreds of hours interviewing doctors, patients and their families about the twisting and often dead-end channels for drug treatment in the country. "Treatment helps people recover," she writes. But people frequently can't access it for a number of reasons, including program scarcity and a lack of childcare. Even if people can find a program, it's "often prohibitively expensive and short-lived, punitive and transactional."

Take Chris Koon, who first used opioids at 15 after an ankle injury and then got hooked on heroin and meth. Years later, he ended up at Cenikor in Louisiana, a program truly mind-boggling in its cruelty. Cenikor hired patients out to various companies that used them as labor sometimes 100 hours a week — without pay and at times in sweltering heat. Koon shoveled gravel for a construction company, among other jobs.

The exploitation of patients for profit is a common theme in the book. Rehab programs sometimes bill thousands of dollars for unnecessary services and trap patients in a cycle of relapse and treatment, Walter writes. She describes one sober living organization in California that took on more patients than allowed, housing people in the backyard, to maximize profits.

Even reputable programs face significant hurdles. One is that insurance companies often pay for limited stays. That treats "recovery and complete abstinence like something that could be achieved in a matter of weeks," Walter writes. In reality, recovery requires continued support, which means access to food, housing, jobs and medication.

Some patients, like Koon, had medication and a supportive family that helped pay for housing and bills. Despite his stint at Cenikor, he ultimately recovered from his addiction and graduated from welding school. Others, like April Lee, had much less help. Lee got pregnant at 15, had a mother addicted to crack cocaine and developed her own addiction to heroin. She lacked family and financial support, had no education or job and had children to care for. She bounced in and out of

*People with addictions can get left behind by a society that turns its eyes away. Walter forces us to look.*

treatment programs for years but eventually earned her GED.

Walter delves deep into the lives of Lee, Koon and others to craft a narrative that's both heartbreaking and illuminating. At the core of her book are hardworking people trying to pull themselves away from the grasp of addiction — a feat she makes clear could be attainable for more people with just a little more support. People with addictions can get left behind by a society that turns its eyes away. Walter forces us to look. She gives voice to those in recovery, painting them as whole people, worthy of respect and the chance to rebuild their lives. ✖


## THE AI INDUSTRY IS A MODERN-DAY EMPIRE

*By Shi En Kim*

**EMPIRE OF AI** | *Karen Hao*
**Penguin Press | $32**

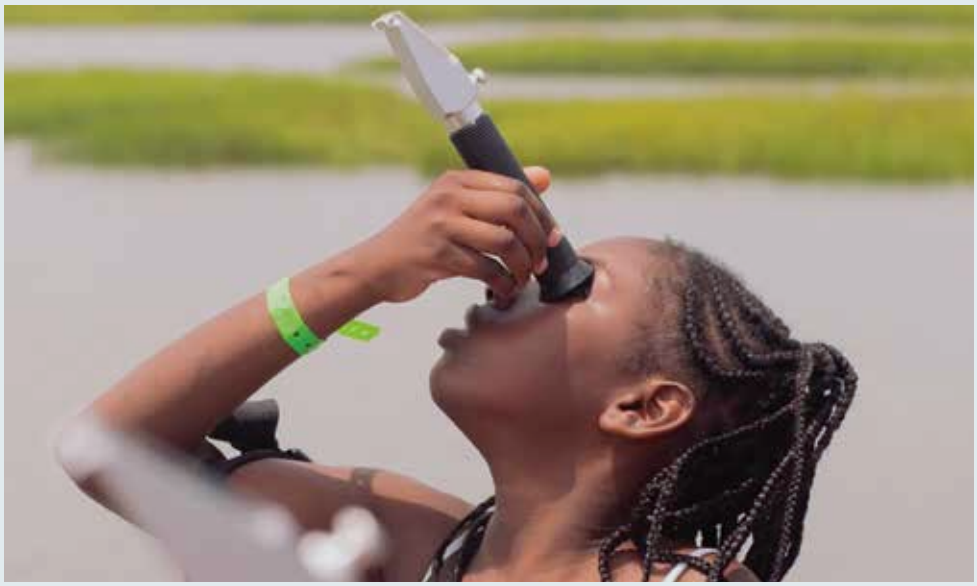
**If you've been following** the meteoric rise of artificial intelligence in the last decade, you may have read articles by tech journalist Karen Hao in the *Atlantic* or the *Wall Street Journal*. In her new book, *Empire of AI*, Hao uses her expertise to investigate the cutthroat world of AI. The result is a jaw-dropping indictment of an industry that operates with little check.

The book chronicles the breakneck pace of modern AI development, which has largely been set by OpenAI, the Microsoft-backed startup behind ChatGPT. OpenAI begins as a nonprofit, vowing to share its research and be transparent in its operations for the benefit of humankind. But today, the company has reneged on those commitments. In pursuit of profit and supremacy among its competitors, it bends ethical norms and runs roughshod over its workers, Hao writes.

Hao makes it clear that AI itself isn't the problem. Instead, it's the culture of developing AI at all costs, driven by OpenAI and an exclusive clutch of companies with the financial and political power to ensure regulators don't look too closely at their operations. Hao likens this modus operandi to that of a colonial empire that tramples over marginalized communities to feed its own expansion. The collateral damage includes the depletion of natural resources in developing countries to power AI, as well as Venezuelan and Kenyan workers who annotate AI training data and moderate content for scant compensation.

AI can be more democratic, Hao argues. She points to a small, Indigenous-driven effort in New Zealand to use AI to revive a dying Māori language. But we must educate the public, tighten regulations for developers and discourage the model of industry dominance. The embers of revolution already burn in us, Hao writes. They come from our sense of community and humanity — something that AI will be hard-pressed to grasp. ✖

# Expanding STEM Access Through Action



**Coastal Expeditions Foundation, a grassroots organization based in Mount Pleasant, S.C., aims to educate the public about environmental protection. Its programs provide students with access to field trips and workshops to experience South Carolina low country ecosystems and wildlife conservation efforts.**

Through the STEM Action Grants program, Society for Science, publisher of Science News, is helping make Coastal Expeditions Foundation's vital work possible. The program awards grants of $2,000 to $5,000 to mission-driven organizations that are increasing STEM access in their communities. Last year, the Society awarded $320,500 to 66 organizations across 22 states, Washington, D.C., and Puerto Rico. And since the program's launch in 2016, it has awarded a total of $1.15 million to 144 impactful organizations.

Coastal Expeditions Foundation partners with the Kids on Point program, a South Carolina–based nonprofit that provides year-round educational programming. Through the collaboration, Coastal Expeditions Foundation provides students in kindergarten through eighth grade with experiences designed to increase their STEM literacy. Activities, such as measuring water salinity with handheld refractometers (pictured above), help young people better understand and connect with nature by teaching them about local wildlife, ecology and practical stewardship. Coastal Expeditions Foundation's STEM Action Grant allowed them to hire a local crabbing expert to supplement their programming.

"Our mission is to ensure that experiences with wildlife and the habitats we all share are accessible to all," says Brittany Freeman, administrative director of Coastal Expeditions. "By channeling our collective passion for the environment, we can preserve these ecosystems for generations to come."

Combining science with local action, Coastal Expeditions Foundation embodies the mission of the STEM Action Grants: to inspire participation in STEM educational programs and drive community-level change.

SOCIETY FOR SCIENCE

**WWW.SOCIETYFORSCIENCE.ORG/STEMACTIONGRANTS**

Society for Science is a nonprofit organization best known for our award-winning journalism, world-class STEM competitions and STEM outreach programming. For more than a century, our mission has been to promote the understanding and appreciation of science and the vital role it plays in human advancement: to inform, educate, and inspire.

VOL. 207 NO. 08 | AUGUST 2025

**A quantum query**

● *A century ago, physicists laid the foundation of quantum mechanics. Today, with greater control of quantum systems, scientists are making major leaps in quantum computing, quantum gravity and more, senior physics writer Emily Conover reported in "The next quantum frontier."*

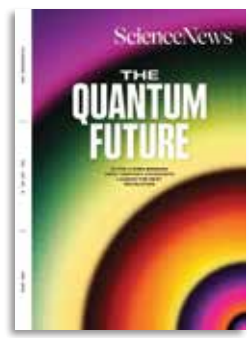
Some physicists are exploring the possibilities of quantum biology, the idea that quantum effects influence living things. For instance, some have proposed that birds use a quantum compass to sense magnetic fields, Conover wrote.

Reader Linda Mayer wondered whether quantum biology might one day lead to medical breakthroughs. Mayer imagined *Star Trek*'s Dr. McCoy using tricorders to diagnose diseases, or remote healing devices that could instantly cure cancer or broken bones.

It's yet to be confirmed whether quantum effects are indeed relevant in biology. But if they are, Clarice Aiello, a physicist at the Quantum Biology Institute in Los Angeles, has ideas. For instance, if weak magnetic fields can alter biological processes via quantum mechanics, it might be possible to tweak certain biological functions by applying tailored magnetic fields. And those magnetic fields could be produced by simple electronic devices, Aiello says. "Right now, this is completely science fiction. But maybe one day, this way of actuating biology could be at the hands of anyone with a cell phone."

*"Right now, this is completely science fiction. But maybe one day, this way of actuating biology could be at the hands of anyone with a cell phone."*

June 2025




**Do you remember?**

● *A brain-scanning study revealed that a structure called the hippocampus can encode early memories, senior neuroscience writer Laura Sanders reported in "Babies form memories like adults do."*

Reader Monika Goodwin shared her earliest memory from 6 months old. "At that time, only a few years after World War II, my family [was displaced] from East to West Germany. We lived in a darkish, large attic room divided by curtains. I remember the surroundings from that day and that I was sitting and playing with colored wood blocks in my crib with white steel bars. I put a wood block into my mouth, and I could not breathe. It became total darkness for me, and I passed out. I have always remembered this and mentioned it actually seldom," wrote Goodwin. Decades later, Goodwin's older sister, who was 6 years old during the event and had sought help from the neighbors to save her, corroborated the memory. She "was so surprised that I remembered this at such a young age."

**Bird brain**

● *Brain activity of vocalizing budgerigar parrots echoes that of humans in key ways, senior neuroscience writer Laura Sanders reported in "Budgie brains parrot human speech centers."*

The story reminded reader Gail Bruce of their pet budgie, who often tags along on camping trips. When the tradition first started, "we'd put her outside in her cage, so she wouldn't get lost but could enjoy the sunshine and fresh air. To our surprise, she started picking up other bird songs," Bruce wrote. Bruce thinks camping has increased the budgie's sounds and songs. "We've never really worked on teaching her human sounds because bird sounds are so much more beautiful."

Do you have any burning science questions you'd like our staff to answer? Send us an email at **feedback@sciencenews.org**.

# COULD TREES EVER GET UP AND WALK AWAY?

BY SOPHIE HARTLEY

In the second *The Lord of the Rings* movie, *The Two Towers*, an army of treelike creatures called Ents marches to war, walking for miles through dark forests. Once they arrive at the fortress of the evil wizard Saruman, the Ents hurl giant boulders, climb over walls and even rip open a dam to wipe out their enemy. Mobile trees like the Ents are found throughout science fiction and fantasy worlds. The treelike alien Groot in *Guardians of the Galaxy* uses twiggy wings to fly. Trees called Evermean fight the main character Link in *The Legend of Zelda: Tears of the Kingdom* video game. And *Harry Potter*'s Whomping Willow — well, it whomps anyone who gets too close.

The trees in our neighborhoods may seem immobile compared to these fictional wanderers, but real trees and forests move too. They just do it really, really slowly.

All trees move as their seeds grow into saplings, stretching up toward the sun to convert sunlight into nutrients. But when they sprout in a shady place, they have to work harder. By slowly stretching their branches in a sunny direction, trees orient themselves to get the most sunlight possible, a phenomenon called phototropism.

Tree roots move too. When they sense moisture in the soil, trees push their roots toward the likely water source. While searching for water underground, roots may tap into wells and plumbing. "Sometimes they get into people's toilets," says Gerardo Avalos, a plant physiologist at the University of Costa Rica in San José.

While individual trees can't cross rivers and climb mountains, entire forests can. And climate change is making their journeys treacherous.

"Trees have been migrating forever," says Leslie Brandt, an ecologist formerly with the U.S. Forest Service in St. Paul, Minn. During the last ice age, when an ice sheet covered most of Canada and the northern United States, many tree species took refuge in warmer, southern climates. As northern habitats got colder, seeds thrived in the warmer south. More new

DDING

trees grew on the southern edges of forests, while older trees up north died out. Slowly, forests migrated, moving around 100 to 500 meters a year, Brandt says.

But now, human-caused climate change is altering habitats faster than forests can move. Rising oceans are threatening coastal mangrove forests worldwide. Higher temperatures in Canada are making it difficult for white spruce to grow. And drier conditions in the American Southwest are harming pinyon pines.

"Trees just cannot keep up," says Brandt. "So, humans are helping them out by moving them."

Some scientists are planting seeds in areas with favorable conditions. Sometimes, scientists even replace species that are no longer equipped to handle a changed landscape with species better suited to the new conditions.

In Minnesota, Brandt has studied trees on the banks of the Mississippi River. The area is flooding more frequently and severely these days, and invasive beetles are destroying the forests. Floodplain trees like silver maples are dying and struggling to grow.

"We're looking to replace the trees that are lost with those that are better adapted to the current climate," Brandt says, like cottonwoods and willows.

For the Superior National Forest in northern Minnesota, Brandt and colleagues created a guidebook to help forest managers prepare for climate change. The team has been working with scientists and local Indigenous tribes to make sure the forest migration plan aligns with community needs.

"We don't want to completely change the forest," Brandt says, because people "rely on those trees." ✖

# CAN YOU MEET ME AT THE MALL?

BY ZACH WISSNER-GROSS

You and a friend have arranged to meet at a popular downtown mall between 3 p.m. and 4 p.m. one afternoon. However, you neglected to specify a time within that one-hour window. Therefore, each of you will be arriving at randomly selected times between 3 p.m. and 4 p.m. Once each of you arrives at the mall, you will be there for exactly 15 minutes. When the 15 minutes are up, you leave.

WALTER BIBIKOW/THE IMAGE BANK UNRELEASED/GETTY IMAGES PLUS

1. During the hour, there may or may not be an overlap between your and your friend's visits. At some point, how many of you are present will reach a maximum number for the hour. This maximum could be one (sad!) or two. On average, what do you expect this maximum to be? The answer is between one and two.

   Hint: If you're not sure where to start, think of the two arrival times on a coordinate plane. Your arrival time is the $x$-coordinate and your friend's is the $y$. Which region in the coordinate plane are you considering in this puzzle? Which region results in the two of you meeting up?
2. Instead of you and a friend, now suppose there are three total friends, yourself included. As before, you and the friends arrive at random times during the hour and each stay for 15 minutes.

   Again, at some point during the hour, there will be a maximum number of friends at the mall. This maximum could be one, two or three. On average, what would you expect this maximum number of friends to be?
3. What about four total friends? On average, what would you expect the maximum number of friends meeting up to be?

   Hint: If you can't find the exact answer, try finding an estimate. A computer might help.
4. Suppose there are $N$ friends. As $N$ grows increasingly large, what would you expect the maximum number of friends meeting up to be, in terms of $N$? ✖

Visit **sciencenews.org/puzzle-answers** for answers. We will publish science-themed crossword puzzles and math puzzles on alternating months. We'd love to hear your thoughts at **puzzles@sciencenews.org**.

# COLLEGE ESSAY MENTOR

## An Ivy Plus Admissions Specialist

### ONE-ON-ONE ESSAY ADVISING

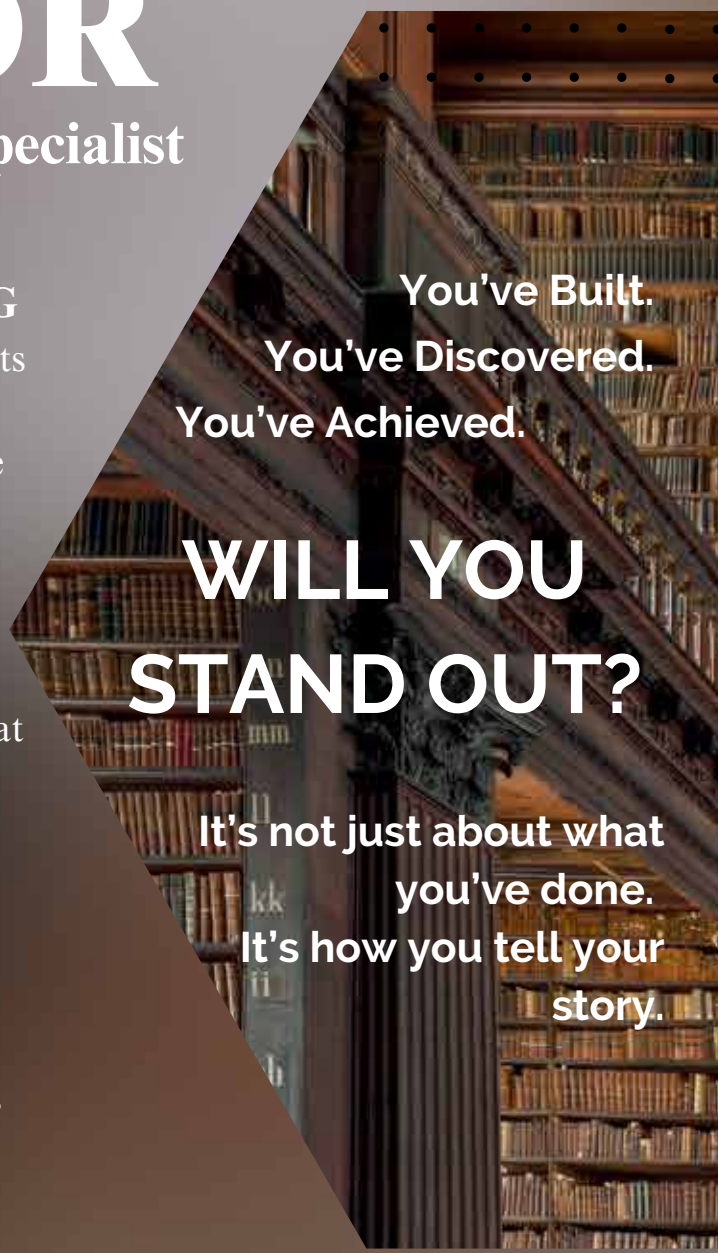
Zoom meetings tailored to STEM students who want admissions officers to see the curiosity behind their questions, the drive behind their work.

### COLLEGE COUNSELING

I demystify the process, create personal application plans, and share strategies that open the doors to Stanford, MIT and the Ivy League.

### COLLEGE ESSAY WEBINARS

Affordable, half-day sessions that teach students how to write poignant personal statements and unique supplement essays for Ivy Plus applications.




**Get started at**
CollegeEssayMentor.com

THE GREATEST CHALLENGES OF OUR TIME

THROUGH THE EYES OF THE GLOBAL HERO WHO CHANGED THE COURSE OF HISTORY

HISTORIC EVENT

AN EVENING WITH PRESIDENT

# LECH WALESA

## NOBEL PEACE PRIZE WINNER AND FORMER PRESIDENT OF POLAND

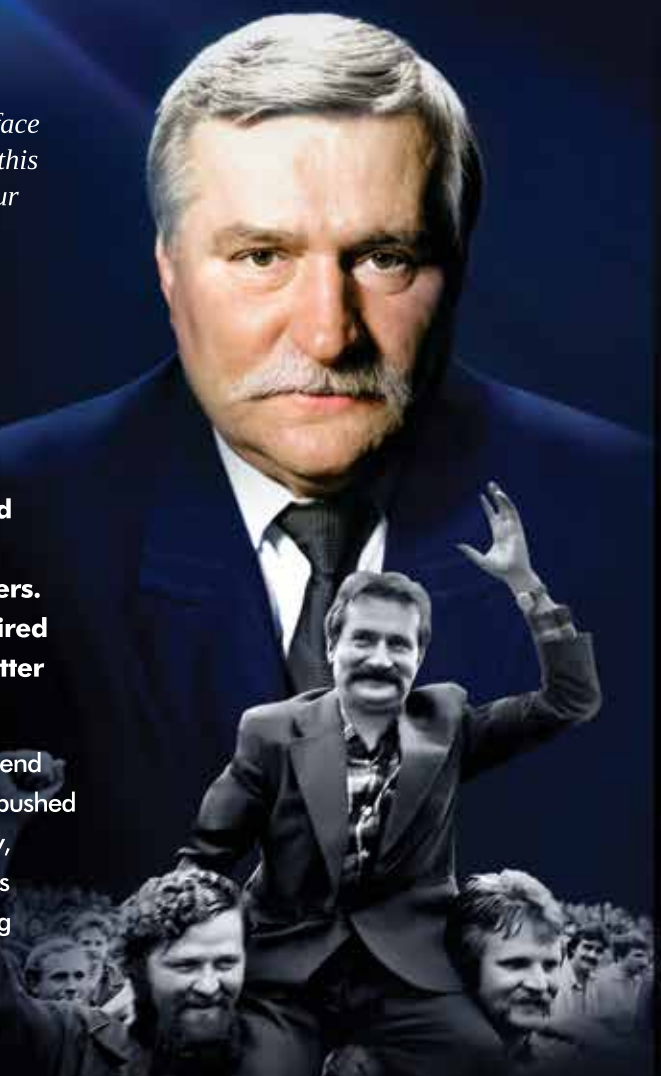
**USA & CANADA GRAND LECTURE TOUR | AUGUST 31 – OCTOBER 30, 2025**

"

***We, the people,***

*live in challenging times and face a turning point in history. On this lecture tour, I will reflect on our past, confront our present and offer ideas for a better future. Join me for this historic conversation. Together, we can create the change we need.*

**Lech Walesa**



**Meet the man who defended freedom and became one of the world's greatest leaders. His courage and vision inspired millions to believe that a better world is possible.**

Now, Lech Walesa, the living legend who defeated communism and pushed the world toward democracy, will take you behind the scenes of one of history's greatest turning points – and into the future we must build together.

| | |
|---|---|
| Aug 31 | Los Angeles, CA |
| Sep 2 | Phoenix, AZ |
| Sep 4 | San Diego, CA |
| Sep 6 | Oakland, CA |
| Sep 8 | Seattle, WA |
| Sep 12 | Denver, CO |
| Sep 14 | Houston, TX |
| Sep 18 | Austin, TX |
| Sep 20 | Dallas, TX |
| Sep 22 | Atlanta, GA |
| Sep 24 | Columbus, OH |
| Sep 26 | Pittsburgh, PA |
| Sep 27 | Baltimore, MD |
| Sep 28 | Cleveland, OH |
| Sep 30 | Minneapolis, MN |
| Oct 2 | St. Louis, MO |
| Oct 4 | Chicago, IL |
| Oct 5 | Milwaukee, WI |
| Oct 9 | Miami, FL |
| Oct 11 | Orlando, FL |
| Oct 13 | Boston, MA |
| Oct 15 | Charlotte, NC |
| Oct 17 | Philadelphia, PA |
| Oct 18 | New York, NY |
| Oct 24 | Montreal, QC |
| Oct 25 | Toronto, ON |
| Oct 26 | Detroit, MI |
| Oct 30 | Vancouver, BC |

HISTORY EXPLORER

PEACE AND LEADERSHIP | THE FIGHT FOR FREEDOM AND HUMAN RIGHTS | CHALLENGES TO DEMOCRACY
THE SOLIDARITY MOVEMENT | THE FALL OF COMMUNISM | RUSSIA AND UKRAINE | OUR VALUES
NEW SOLUTIONS FOR A NEW WORLD

**REGISTER NOW for lessons from the past and inspiration for tomorrow**

www.HistoryExplorer.com contact@historyexplorer.com 917-722-5050