JANUARY 2022

SCIENTIFICAMERICAN.COM

SCIENTIFIC AMERICAN

Rethinking Borderline Personality Disorder

The Evolution of Animal Sounds

Inside America's Militias

WONDER OF THE ANCIENT WORLD

New insights decipher the Antikythera mechanism's ingenious astronomical calculations

JANUARY 2022

VOLUME 326, NUMBER 1

SCIENTIFIC AMERICAN

ON THE COVER

More than 120 years ago divers pulled what remains of the Antikythera mechanism out of a Greek shipwreck. A new study has revealed insights into how the front gears measured astronomical time. It is now clearer than ever that it was the most advanced computing machine of the ancient world. **Photograph by © 2005 National Archaeological Museum in Athens.**

Kilili Yuyan

SCIENTIFIC AMERICAN


8


12


78

Scientific American (ISSN 0036-8733), Volume 326, Number 1, January 2022, published monthly by Scientific American, a division of Springer Nature America, Inc., 1 New York Plaza, Suite 4600, New York, N.Y. 10004-1562. Periodicals postage paid at New York, N.Y., and at additional mailing offices. Canada Post International Publications Mail (Canadian Distribution) Sales Agreement No. 40012504. Canadian BN No. 127387652RT; TVQ1218059275 TQ0001. Publication Mail Agreement #40012504. Return undeliverable mail to Scientific American, P.O. Box 819, Stn Main, Markham, ON L3P 8A2. **Individual Subscription rates:** 1 year $49.99 (USD), Canada $59.99 (USD), International $69.99 (USD). **Institutional Subscription rates:** Schools and Public Libraries: 1 year $84 (USD), Canada $89 (USD), International $96 (USD). Businesses and Colleges/Universities: 1 year $399 (USD), Canada $405 (USD), International $411 (USD). Postmaster: Send address changes to Scientific American, Box 3187, Harlan, Iowa 51537. **Reprints inquiries:** RandP@sciam.com.
To request single copies or back issues, call (800) 333-1199. Subscription inquiries: U.S. and Canada (800) 333-1199; other (515) 248-7684.
Send e-mail to scacustserv@cdsfulfillment.com.

Introducing ATEM Mini Pro

The compact television studio that lets you create presentation videos and live streams!

Blackmagic Design is a leader in video for the television industry, and now you can create your own streaming videos with ATEM Mini. Simply connect HDMI cameras, computers or even microphones. Then push the buttons on the panel to switch video sources just like a professional broadcaster! You can even add titles, picture in picture overlays and mix audio! Then live stream to Zoom, Skype or YouTube!

Create Training and Educational Videos

ATEM Mini's includes everything you need. All the buttons are positioned on the front panel so it's very easy to learn. There are 4 HDMI video inputs for connecting cameras and computers, plus a USB output that looks like a webcam so you can connect to Zoom or Skype. ATEM Software Control for Mac and PC is also included, which allows access to more advanced "broadcast" features!

Use Professional Video Effects

ATEM Mini is really a professional broadcast switcher used by television stations. This means it has professional effects such as a DVE for picture in picture effects commonly used for commentating over a computer slide show. There are titles for presenter names, wipe effects for transitioning between sources and a green screen keyer for replacing backgrounds with graphics.

Live Stream Training and Conferences

The ATEM Mini Pro model has a built in hardware streaming engine for live streaming via its ethernet connection. This means you can live stream to YouTube, Facebook and Teams in much better quality and with perfectly smooth motion. You can even connect a hard disk or flash storage to the USB connection and record your stream for upload later!

Monitor all Video Inputs!

With so many cameras, computers and effects, things can get busy fast! The ATEM Mini Pro model features a "multiview" that lets you see all cameras, titles and program, plus streaming and recording status all on a single TV or monitor. There are even tally indicators to show when a camera is on air! Only ATEM Mini is a true professional television studio in a small compact design!

ATEM Mini **US$295**
ATEM Mini Pro **US$495**
ATEM Mini Pro ISO **US$795**

Learn more at www.blackmagicdesign.com

Blackmagicdesign

Laura Helmuth is editor in chief of *Scientific American*.
Follow her on Twitter @laurahelmuth

Planetary Motion Machine

The Antikythera mechanism is one of the most astonishing discoveries in archaeology. Salvaged from a 2,000-year-old shipwreck in Greece in 1900, the intricately geared contraption was quickly recognized as a machine for calculating the movement of the moon and planets. It continues to surprise, as researcher Tony Freeth reveals on page 24. The gears are more delicate and complex than we knew when Freeth shared his team's results in 2009, predicting more celestial events with precision and ingenuity.

This isn't the first issue of *Scientific American* to share the Antikythera device on the cover; it was our lead story in June 1959 as well. That edition, available in our digital archives, is bursting with ads for new plastics—Marlex from the Phillips Chemical Company, Delrin from DuPont—asbestos fiber from Johns-Manville, rocket navigators from Northrop, and the "first all transistorized analog computer" for $4,000 from Electronic Associates, Inc. Many of these products are long forgotten, but the Antikythera (pronounced with stress on the syllable "kyth," like "pith") mechanism and research on it will probably outlast them all.

Going back much further in time, paleontologist Michael B. Habib on page 42 takes us to the dawn of animal noises. The first buzzes from insects started around 250 million years ago, followed by vertebrates evolving the ability to produce and detect sounds, and then birds' exquisite singing apparatuses. I found myself noticing and appreciating animal noises more than usual after reading the article, and it might give you a smile next time a squirrel chatters at you.

On January 6, 2021, when armed insurrectionists stormed the U.S. Capitol and tried to prevent the peaceful transition of power after the presidential election, *Scientific American* editors started reaching out to experts who could help us understand what was happening. Sociologist Amy Cooter has been studying militia movements for years, and she warned in an opinion piece we ran online last January that the risk of continued violence is high. Her revelatory piece on page 34 explores the range and motivations of militia groups and the shift she and other experts have seen toward more extremism.

Algal blooms that contaminate sea life are becoming more common in Alaska (and everywhere), but unlike in other coastal states, there is no governmental monitoring system to safeguard people from potentially deadly shellfish. Now Alaskans, including many Indigenous people, are building their own networks of testing and monitoring stations to protect this crucial and traditional source of food. Follow along with journalist Karen Pinchin and photographer Kiliii Yuyan, starting on page 56.

One of the most controversial diagnoses in psychiatry is borderline personality disorder. Experts have disagreed on how to define, classify and especially treat the condition. Now, as journalist Diana Kwon reports on page 48, research is connecting borderline personality disorder with certain types of post-traumatic stress disorder, which might remove some of the stigma from the diagnosis and reveal better ways of understanding and treating it.

Quantum physics tells us that we can't predict exactly where a particle will, say, land on a screen. But stranger still is the fact that we also can't predict *when* the particle will land. As author Anil Ananthaswamy explains on page 70, a new experimental approach that requires exquisite precision could time particles' travel well enough to support "an underworld of unseen waves that guide particles from place to place." Let's hope the experiments are successful; the physicists involved say results could come in a year. SA

Illustration by Nick Higgins

It's just what the doctor ordered.

Scientific American Health & Medicine

Explore the cutting-edge science of everything from human health and epidemiology to biotechnology and medicine

6 issues per year

Select articles from *Scientific American* and *Nature*

Read anytime, anywhere

sciam.com/health-medicine

September 2021

"Cascading effects caused by natural hazards are responsible for a disproportionate number of serious outcomes with social and environmental justice consequences."

MICHAEL R. GREENBERG *RUTGERS UNIVERSITY*

ZERO-SUM SPACE?

In "Lifting the Venus Curse," Robin George Andrews writes about discoveries that expand our understanding of our close planetary neighbor Venus. Enormous sums of money are tossed about in that quest as if they were almost insubstantial. But explorations of outer space do more to satisfy our curiosity than advance the human condition on our own planet. One wonders if the gazillions spent on space exploration could instead have, at least in part, been focused on medical research and basic charitable work to help the still struggling human beings afflicted with illness and poverty.

It would be of interest for a NASA scientist to convince a mother who just lost her infant daughter to malnutrition why it was more important to learn about potential organisms floating in the upper atmosphere of Venus than to invest just a fraction of those sums in providing sufficient sustenance to help her child survive.

Let's be honest: These space explorations are exciting but represent a triumph of technology over purpose. They satisfy our curiosity while neglecting the very human needs we and our planet will require to solve our wearisome but crucial problems closer to the ground on which we tread.

BARRY MALETZKY *Portland, Ore.*

ANDREWS REPLIES: The notion that we can spend grand sums of money only on either space exploration or remedying the myriad ills faced by billions on terra firma is a false dichotomy. Not only does improving our understanding of the cosmos benefit our species both intellectually and practically, but the world's wealthiest nations are perfectly capable of funding both the exploration of our neighboring worlds and the amelioration of Earth's most imperiled people. The cost of a single mission such as VERITAS or DAVINCI+, one that is designed to gather scientific data for many years, is roughly $600 million. That may sound like a lot, but it's worth noting that the U.S. military got $778 billion in 2020 alone. So if there is a debate to be had on the federal government's funding priorities, perhaps this is where its focus should be.

DISASTER RESPONSE

Thank you for pointing to the problems with the U.S.'s recent responses to disasters in "Fix Disaster Response Now" [Science Agenda]. I would suggest that cascading effects caused by both storms and other natural hazards, initiated by industrial and transportation failures and disease events, are responsible for a disproportionate number of serious outcomes with social and environmental justice consequences. They do this by triggering other failures that cause more failures.

My colleagues and I have studied U.S. hazard-mitigation plans and find that only a few states and cities seriously consider them and even fewer develop their spending plans around them. We have proposed that this form of event receive special attention in risk assessment and management and be supported by special federal grants.

MICHAEL R. GREENBERG
Edward J. Bloustein School of Planning and Public Policy, Rutgers University

RASH REFLECTION

I read Claudia Wallis's piece on a vaccine for "Poison Ivy Relief" [The Science of Health] with great interest. My wife loves gardening but has terrible reactions to poison ivy, whereas I am rarely able to prioritize horticulture but am immune to the plant's effects. I wonder how common this kind of immunity is and how it develops. My father is also immune to poison ivy. Could the capacity for this trait be hereditary? And is it possible to develop immunity through exposure?

It's not just poison ivy in my case. As a teenager, I moved to the U.S. from a somewhat rural area in Scotland. When I was younger, I played all day in orchards and fields and bushes near where we lived. I had many painful encounters with stinging nettles. As I got older, however, I became immune to them. I assume it was through exposure.

GEOFFREY P. PALMER *via e-mail*

Wallis's article brought me back to a few years ago, when I had somehow gotten a poison-ivy-like rash around my mouth, and it swelled and spread down my neck. This oozing and crusting rash was a very scary situation, so I saw my allergist. He claimed to have never seen something this serious in his whole career and asked if I fell asleep in the woods! I told him I had been nowhere near any wooded area. After a bit of research, we were able to conclude that the reaction was caused by the urushiol oil on the skin of a mango! It was the first fresh mango I had ever eaten in my life.

With a vaccine such as the one detailed in this article, I might be able to enjoy mangos comfortably one day. In the meantime, for those prone to poison ivy reactions, beware the mango skin!

ALLY BROWN *Council Bluffs, Iowa*

I am in contact with poison ivy almost every day during my conservation work at a local park, where I teach my volunteers how to avoid it. While I did react to the plant with moderate intensity as a child,

I have never gotten a rash or itch from poison ivy in the past 50 years. Did my body develop the equivalent of a vaccine? Or did my brain figure something out?

MARC IMLAY *Bryans Road, Md.*

WALLIS REPLIES: The Centers for Disease Control and Prevention estimates that 80 to 90 percent of adults react to urushiol, the irritating chemical in poison ivy. That leaves 10 to 20 percent who, like Palmer, appear to be unaffected. That said, sensitivity to poison ivy can develop at any point. In fact, people often do not react to the plant the first time they are exposed to it. There is no good evidence that one can develop immunity to it through exposure. And there is so little research on poison ivy that we cannot explain Imlay's unusual loss of sensitivity.

Mangos, cashews and pistachios can contain small amounts of urushiol. Very sensitive people may have a reaction like that of Brown.

STUTTERING AND SINGING

In "The Stuttering Mind" [August 2021], Lydia Denworth reports on how stuttering originates in neural wiring and genes. She does not mention an effect shown by my friend who stutters when speaking but not when singing. Is this common? And if so, does the effect help us understand stuttering or suggest ways to reduce it?

RICHARD ARDEN SLOTTER
Highlands Ranch, Colo.

DENWORTH REPLIES: Singing has been found to increase fluency in people who stutter, if only temporarily. It may be that singing enhances auditory feedback loops in the brain. It is also possible that singing changes articulation patterns in ways that reduce disfluencies. In addition, it seems that the familiarity of favorite songs reduces stuttering. All these ideas are being explored therapeutically.

ERRATUM

"Lifting the Venus Curse," by Robin George Andrews, should have said that many exoplanets have been found far from our solar system, not our galaxy. It also should have said that the surface pressure of Venus is equivalent to being more than half a mile underwater, not a mile or more.

SCIENTIFIC AMERICAN®
ESTABLISHED 1845

EDITOR IN CHIEF
Laura Helmuth

MANAGING EDITOR **Curtis Brainard** COPY DIRECTOR **Maria-Christina Keller** CREATIVE DIRECTOR **Michael Mrak**

EDITORIAL

CHIEF FEATURES EDITOR **Seth Fletcher** CHIEF NEWS EDITOR **Dean Visser** CHIEF OPINION EDITOR **Megha Satyanarayana**

FEATURES

SENIOR EDITOR, SUSTAINABILITY **Mark Fischetti**
SENIOR EDITOR, MEDICINE / SCIENCE POLICY **Josh Fischman**
SENIOR EDITOR, SPACE / PHYSICS **Clara Moskowitz**
SENIOR EDITOR, SCIENCE AND SOCIETY **Madhusree Mukerjee**
SENIOR EDITOR, TECHNOLOGY / MIND **Jen Schwartz**
SENIOR EDITOR, EVOLUTION / ECOLOGY **Kate Wong**

NEWS

SENIOR EDITOR, MIND / BRAIN **Gary Stix**
SENIOR EDITOR, SPACE / PHYSICS **Lee Billings**
SENIOR EDITOR, HEALTH AND MEDICINE **Tanya Lewis**
ASSOCIATE EDITOR, TECHNOLOGY **Sophie Bushwick**
ASSOCIATE EDITOR, SUSTAINABILITY **Andrea Thompson**
ASSISTANT NEWS EDITOR **Sarah Lewin Frasier**

MULTIMEDIA

SENIOR EDITOR, MULTIMEDIA **Jeffery DelViscio**
SENIOR EDITOR, AUDIENCE ENGAGEMENT **Sunya Bhutta**
SENIOR EDITOR, COLLECTIONS **Andrea Gawrylewski**

ART

SENIOR GRAPHICS EDITOR **Jen Christiansen**
PHOTOGRAPHY EDITOR **Monica Bradley**
ART DIRECTOR, ONLINE **Ryan Reid**
ASSOCIATE GRAPHICS EDITOR **Amanda Montañez**
ASSOCIATE PHOTO EDITOR **Liz Tormes**

COPY AND PRODUCTION

SENIOR COPY EDITORS **Angelique Rondeau, Aaron Shattuck**
MANAGING PRODUCTION EDITOR **Richard Hunt**
PREPRESS AND QUALITY MANAGER **Silvia De Santis**

CONTRIBUTORS

EDITORS EMERITI **Mariette DiChristina, John Rennie**
EDITORIAL **Amy Brady, Katherine Harmon Courage, Lydia Denworth, Ferris Jabr, Anna Kuchment, Michael D. Lemonick, Robin Lloyd, Steve Mirsky, Melinda Wenner Moyer, George Musser, Ricki L. Rusting, Dava Sobel, Claudia Wallis, Daisy Yuhas**
ART **Edward Bell, Zoë Christie, Lawrence R. Gendron, Nick Higgins, Katie Peek, Beatrix Mahd Soltani**

SENIOR EDITORIAL COORDINATOR **Ericka Skirpan**
EXECUTIVE ASSISTANT SUPERVISOR **Maya Harty**

SCIENTIFIC AMERICAN CUSTOM MEDIA

MANAGING EDITOR **Cliff Ransom**
CREATIVE DIRECTOR **Wojtek Urbanek**
MULTIMEDIA EDITOR **Kris Fatsy**
MULTIMEDIA EDITOR **Ben Gershman**
ENGAGEMENT EDITOR **Dharmesh Patel**
ACCOUNT MANAGER **Samantha Lubey**

ACTING PRESIDENT
Stephen Pincock

EXECUTIVE VICE PRESIDENT **Michael Florek**
VICE PRESIDENT, COMMERCIAL **Andrew Douglas**
PUBLISHER AND VICE PRESIDENT **Jeremy A. Abbate**

CLIENT MARKETING SOLUTIONS

MARKETING DIRECTOR, INSTITUTIONAL PARTNERSHIPS AND CUSTOMER DEVELOPMENT **Jessica Cole**
PROGRAMMATIC PRODUCT MANAGER **Zoya Lysak**
DIRECTOR, INTEGRATED MEDIA **Matt Bondlow**
BUSINESS DEVELOPMENT **Stan Schmidt**
HEAD, PUBLISHING STRATEGY **Suzanne Fromm**

CONSUMER MARKETING & PRODUCT

DEVELOPMENT TEAM LEAD **Raja Abdulhaq**
SENIOR MARKETING MANAGER **Christopher Monello**
PRODUCT MANAGER **Ian Kelly**
SENIOR WEB PRODUCER **Jessica Ramirez**
SENIOR COMMERCIAL OPERATIONS COORDINATOR **Christine Kaelin**
MARKETING & CUSTOMER SERVICE ASSISTANT **Justin Camera**

ANCILLARY PRODUCTS

ASSOCIATE VICE PRESIDENT, BUSINESS DEVELOPMENT **Diane McGarvey**
CUSTOM PUBLISHING EDITOR **Lisa Pallatroni**

CORPORATE

HEAD, COMMUNICATIONS, USA **Rachel Scheer**
PRESS MANAGER **Sarah Hausman**

PRINT PRODUCTION

PRODUCTION CONTROLLER **Madelyn Keyes-Milch**
ADVERTISING PRODUCTION CONTROLLER **Dan Chen**

LETTERS TO THE EDITOR

Scientific American, 1 New York Plaza, Suite 4600, New York, NY 10004-1562 or editors@sciam.com
Letters may be edited for length and clarity. We regret that we cannot answer each one.
Join the conversation online—visit *Scientific American* on Facebook and Twitter.

HOW TO CONTACT US

Subscriptions
For new subscriptions, renewals, gifts, payments, and changes of address: U.S. and Canada, 800-333-1199; outside North America, 515-248-7684 or scacustserv@cdsfulfillment.com

Submissions
To submit article proposals, follow the guidelines at www.ScientificAmerican.com. Click on "Contact Us." We cannot return and are not responsible for materials delivered to our office.

Reprints
To order bulk reprints of articles (minimum of 1,000 copies): **RandP@sciam.com.** Reprint Department, Scientific American, 1 New York Plaza, Suite 4600, New York, NY 10004-1562; 212-451-8415. For single copies of back issues: 800-333-1199.

Permissions
For permission to copy or reuse material: Permissions Department, Scientific American, 1 New York Plaza, Suite 4600, New York, NY 10004-1562; RandP@sciam.com; www.ScientificAmerican.com/permissions. Please allow six to eight weeks for processing.

Advertising
www.ScientificAmerican.com has electronic contact information for sales representatives of Scientific American in all regions of the U.S. and in other countries.

THE IMMUNE SECRETS OF LUPUS UNVEILED

Research discoveries, expanded treatment options and a revolutionary approach to lupus care are helping people with a complex, unpredictable disease lead healthier lives.

Like snowflakes, no two patients with systemic lupus erythematosus (SLE) are exactly alike, making it one of the most difficult autoimmune diseases to diagnose and treat. Even in identical twins, the symptoms can vary widely and may change over time. Destructive, relentless and incurable, the disease can wax and wane unpredictably, with sudden flares wreaking havoc on every aspect of patients' lives.[1,2]

Compounding the disease's physical and emotional toll, it primarily strikes young women aged 19 to 44, says Roger A. Levy, global medical expert in immunology and specialty care at pharmaceutical firm GSK, which has been researching lupus and developing treatments for more than a decade.[1,3,4] "Patients don't know how they're going to feel next week, next month, next year. They tell us, 'I can't make any plans. How can I start a new job, go out on a date, or commit to a relationship if in the future, I'm not going to be able to fulfill their expectations? There are many unanswered questions that make them feel isolated."

Nine times more common in women than men,[1,3] lupus affects about five million people globally.[5] SLE is the most common form, accounting for 70 percent of cases.[2] The other forms are neonatal lupus, a rare condition found in babies born to women with lupus; cutaneous lupus, which only affects the skin; and drug-induced lupus, caused by taking certain prescription medicines.[3] SLE occurs more frequently and severely in women of color, including Black, Asian, Hispanic/Latina, Native American and Pacific Islander women.[1,3,6,7]

Decades ago, many people with SLE died within a few years of diagnosis. Today, the outlook is brighter than ever. Not only has long-term survival increased, thanks to breakthroughs in drug development, but also the use of a best-in-practice medical approach called "treat-to-target" is boosting outcomes and quality of life.[8,9]

A proactive approach to stave off serious complications

Although each patient experiences SLE differently, they all have one thing in common: their immune system is attacking their body, mistaking healthy cells and organs for foreign invaders. The disease can affect any part of the body, with the skin, joints, central nervous system and kidneys being common targets.

Traditionally, treatment revolved around managing symptoms. "The standard approach has been that you add medicines, try to improve the patient's status, and that's it," says David Roth, vice president and medicines development leader at GSK. Treat-to-target uses a more comprehensive strategy. "The goal is not only to help the patient feel better right now but also to help prevent really bad outcomes from occurring in the long term."

"IT'S AN EXTREMELY EXCITING TIME IN LUPUS RESEARCH"

Those bad outcomes include irreversible organ damage, which around half of SLE patients develop within five years of diagnosis. One of the most important manifestations is lupus nephritis (LN): inflammation of the kidneys. Within 10 years, up to 20 percent of LN patients will progress to end-stage kidney disease, a life-threatening condition that requires dialysis or a transplant.[10,11,12,13] To try to avoid these outcomes, treat-to-target sets a specific, objective goal for improvement. With SLE, the aim is to lower overall disease activity, as measured by a scoring system that assigns points to various manifestations, including skin rashes, seizures, inflamed joints and abnormal kidney function.[6,14] A drop in the score over time suggests that the treatment is working.

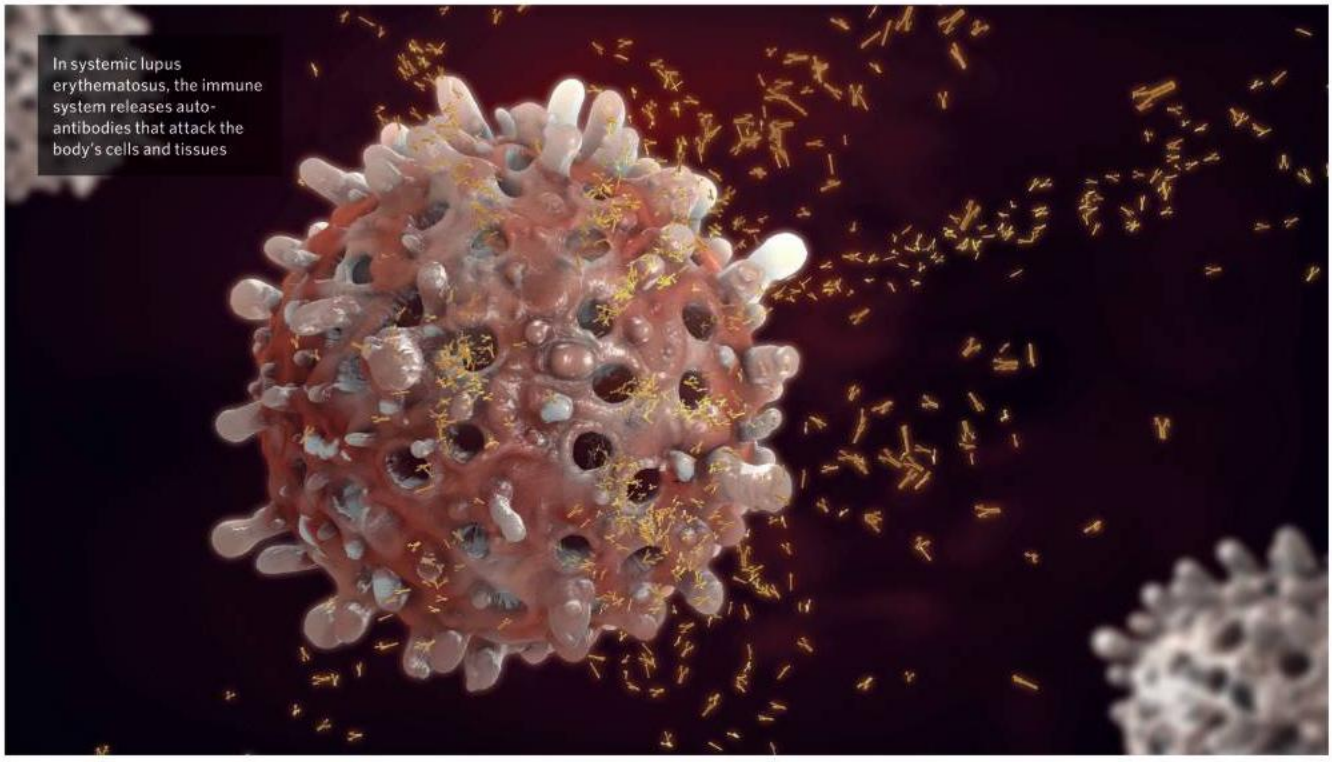
"Instead of focusing only on where the patient is right now, the treat-to-target approach looks at where they should be: in a state where their disease is controlled and they can lead a relatively normal life," says Roth. "High levels of disease activity—or flares—are major risk factors for permanent organ damage or even early death."

The search for effective, well-tolerated treatments

The driving force behind SLE drug development has been a hunt for therapies that are less toxic and work better than the two traditional mainstays of treatment: steroids and immunosuppressors. Both save lives and rapidly reduce symptoms but also have dangerous downsides.

Steroids can cause heart attacks, stroke, diabetes, hypertension, bone fractures and eye diseases such as cataracts and glaucoma.[15,16] They suppress the immune system, leaving patients easy prey for opportunistic infections, says Richard Furie, a rheumatologist at the Institute of Molecular Medicine at the Feinstein Institutes for Medical Research in Manhasset, New York. "Using these medicines is always a tug-of-war between doing good and doing no harm."

A burning question in research has been whether it's possible to selectively target the immune system



In systemic lupus erythematosus, the immune system releases autoantibodies that attack the body's cells and tissues

components that cause the damage in SLE. Since various types of autoantibodies have been implicated as key culprits, investigators set out to learn how these rogue antibodies are produced and the best ways to inhibit them.

In an intriguing scientific twist, researchers discovered that one of the best defenses against the autoantibodies involved in SLE may be to create antibodies against the cells that produce them and their stimulators. Investigators began to develop novel biologics that attack the B cells that unleash the immune system assault, thereby reducing disease activity. Think of this tactic as akin to blowing up the enemy's tanks before they can launch their shells.

The 50-year drought for lupus medicines ended in 2011 with the FDA approval of a monoclonal antibody therapy that targets the protein that stimulates the autoreactive B cells.[17] By binding to and inhibiting the protein, known as B-lymphocyte stimulator (BLyS), the therapy causes B cells to remain quiescent and not produce the destructive autoantibodies.

Today, a wide range of approaches to treat SLE are being explored, says Furie. "It's an extremely exciting time in lupus research, with an unprecedented number of clinical trials in progress." At the beginning of 2021, the FDA approved a drug for LN that targets T cells.[18] And in August of this year, the agency approved another SLE drug, this one targeting the interferon pathway.[19] "Treatments have improved so much that patients are starting to ask, 'Am I in remission?'" reports Furie. Prolonged, complete remission is still rare,[20] and making it routine "is the next frontier," he adds.

Although better tools are now available to improve disease activity, unmet challenges remain. One of the biggest is the need for more treatment options for SLE to avoid patients progressing to organ failure. Researchers are also working on optimizing current treatment options to see if they can help the patient feel well—not just less sick, says Levy. And there is progress, he adds. "When I started out, most people in the waiting room were on crutches or in wheelchairs. Now they're wearing gym outfits, going to yoga classes and rocking high heels." ■

REFERENCES

1. Us in Lupus. usinlupus.com/basics-of-lupus/what-is-lupus
2. CDC Lupus cdc.gov/lupus/basics/diagnosing.htm
3. Pons-Estel, G.J., Alarcón, G.S., Scofield, L., Reinlib, L. & Cooper, G.S. *Semin Arthritis Rheum.*39(4):257-268 (2010).
4. Lupus Foundation of America. lupus.org/resources/lupus-facts-and-statistics
5. Roper, G.F.K. Lupus Foundation of America (2012).
6. Somers, E.C., *et al. Arthritis Rheumatol.* 66(2):369-378 (2014).
7. Uribe, A.G., McGwin, G., Jr, Reveille, J.D. & Alarcón, G.S. *Autoimmun Rev.* 3(4):321-9 (2004).
8. van Vollenhoven, R.F. *et al. Ann. Rheumatic Dis.* 73:958-967 (2014).
9. Levy, R.A., *et al. Lupus,* First Published 8 Jul 2021.
10. Imran, T.F., *et al. Clin Exp Nephrol,* 20(1), 1-13 (2016).
11. Anders, H.J., *et al. Nature Rev Dis Primers.* 6(1):7 (2020).
12. Hanly, J.G., *et al. Rheumatol.* 55:252-62 (2016).
13. Tektonidou, M.G., Dasgupta, A. & Ward, M.M. *Arthritis Rheumatol.* 68(6):1432-1441 (2016).
14. Systemic Lupus Erythematosus Disease Activity Index 2000 (SLEDAI-2K). mdcalc.com/systemic-lupus-erythematosus-disease-activity-index-2000-sledai-2k
15. Mayo Clinic. mayoclinic.org/steroids/art-20045692
16. Pujades-Rodriguez, M., Morgan, A.W., Cubbon, R.M. & Wu, J. *PLoS Med.* 317(12):e1003432 (2020).
17. Ledford, H. *Nature* (2011).
18. Heo, Y.A. *Drugs* 81(5):605-610 (2021).
19. AstraZeneca Press Release. astrazeneca.com/media-centre/press-releases/2021/saphnelo-approved-in-the-us-for-sle.html
20. Urowitz, M.B., Feletar, M., Bruce, I.N., Ibañez, D. & Gladman, D.D. *J Rheumatol.* 32(8):1467-1472 (2005).

Hacking the Ransomware Problem

Organizations can act to protect themselves, but collaboration is the best defense

By the Editors

During a ransomware hack, attackers infiltrate a target's computer system and encrypt its data. They then demand a payment before they will release the decryption key to free the system. This type of extortion has existed for decades, but in the 2010s it exploded in popularity, with online gangs holding local governments, infrastructure and even hospitals hostage. Ransomware is a collective problem—and solving it will require collaborative action from companies, the U.S. government and international partners.

In 2020 the Federal Bureau of Investigation received more than 2,400 reports of ransomware attacks, which cost victims at least $29 million, not counting lost time and other resources. The numbers underestimate the total impact of ransomware because not all organizations are willing to report it when they fall victim to this crime—and if they do, they do not always share how much they paid. Even these limited statistics, however, demonstrate the increasing boldness of ransomware gangs: the number of attacks in 2020 increased by 20 percent compared with the previous year, and the amount of money paid out more than tripled.

These attacks harm more than the direct targets. Last May, for example, Colonial Pipeline announced that its data had fallen prey to a hacking group. As a result, the private company—which transports about half of the East Coast's fuel supply—had to shut down 5,500 miles of pipeline. When they heard the news, people panicked and began stocking up on gas, causing shortages. The company paid at least $4.4 million to restore its systems, although the government eventually recovered about half that amount from the attackers, a Russia-based ransomware gang called REvil.

As long as victims keep paying, hackers will keep profiting from this type of attack. But cybersecurity experts are divided on whether the government should prohibit the paying of ransoms. Such a ban would disincentivize hackers, but it would also place some organizations in a moral quandary. For, say, a hospital, unlocking the computer systems as quickly as possible could be a matter of life or death for patients, and the fastest option may be to pay up.

Other solutions are more straightforward and involve pushing organizations to protect themselves better. Cybersecurity defenses, such as multifactor-authentication requirements and better training in how to recognize phishing and other attacks, make it harder for hackers to access systems. Segmenting one's network means that breaking through to one part of the system does not make all data immediately available. And regular backups allow a company to function even if its original data are encrypted.

All these measures, however, require resources that not all organizations have access to. Meanwhile ransomware gangs are adopting increasingly sophisticated techniques. Some work for weeks to gain entry to a company's network and then worm their way through the system, finding the most vital data to hold hostage. Some groups, including REvil, deliberately compromise an organization's data backups. Others sell instructions and software to help other hackers launch their own attacks. As a result, security personnel must engage in a constant game of cat and mouse.

Collective action can help. If all organizations that fall victim to ransomware report their attacks, they will contribute to a trove of valuable data, which can be used to strike back against attackers. For example, certain ransomware gangs may use the exact same type of encryption in all their attacks. "White hat" hackers can and do study these trends, which allows them to retrieve and publish the decryption keys for specific types of ransomware. Many companies, however, remain reluctant to admit they have experienced a breach, wishing to avoid potential bad press. Overcoming that reluctance may require legislation, such as a bill introduced in the Senate last year that would require companies to report having paid a ransom within 24 hours of the transaction.

Striking back against ransomware will also involve bringing the fight to the criminals—and that requires international cooperation. Last October the FBI worked with foreign partners to force the REvil ransomware gang offline; in November international law-enforcement agencies arrested alleged affiliates of the group. Such collective action among organizations, government and law enforcement will be necessary to curb the boldest ransomware attacks. But it is an ongoing battle—and there is no end in sight. SA

JOIN THE CONVERSATION ONLINE
Visit *Scientific American* on Facebook and Twitter or send a letter to the editor: editors@sciam.com

Illustration by Yifan Wu

3,000-Year-Old Beauty Secret Revealed

Turquoise — the original fashion icon — comes full circle for an amazing price.

7 carats of genuine turquoise
ONLY $79

B.

A.

Pendant enlarged to show luxurious color

She's been around for thousands of years, but she's never gone out of fashion. We're talking turquoise, one of the world's most ancient gems. Egyptian queens adorned themselves with turquoise jewelry more than 3,000 years ago. And the blue beauty is even more coveted now than she was a millennia ago.

Do you know someone who's even more beautiful now than when you first met? Then the Timeless Turquoise Pendant is for them — a stylish circle formed from seven total carats of natural turquoise and exquisite sterling silver metalwork. And the price? Let's just say we made sure timeless was attainable for less than you'd think.

Time is running out for timeless turquoise. Just because turquoise is timeless, doesn't mean supplies of it will last forever. Turquoise is only found a few places on Earth. Typically unearthed in arid climates like the American Southwest and Egypt's Sinai Peninsula, turquoise requires a delicate balance of minerals and water to achieve its gorgeous range of blues. But even when conditions are optimal for turquoise to form, finding stones of gem-worthy quality is a challenge. There are very few turquoise mines left, and then, less than 5% of turquoise mined worldwide is of jewelry condition, making it rarer to come by than even diamonds.

There are turquoise and sterling silver pendants out there for over $1,200. And while genuine turquoise can garner a pretty penny, there's no reason to be paying a designer price when we can bring you designer pieces for a remarkable price.

100% Satisfaction Guaranteed. Try the Timeless Turquoise Pendant for 30 days. If it fails to delight, just send it back for a refund of the item price.

Limited Availability. These are handcrafted artisan pieces, and we only have so many. Call today.

"...turquoise is becoming rarer and more valuable because less of it is being discovered... the very best turquoise is more valuable than diamonds."
— The Jewellery Editor, 2021

Jewelry Specifications:
- ***Natural turquoise in .925 sterling silver settings***

Timeless Turquoise Collection

A. Pendant (7 ctw) ~~$299†~~ ..... $79 Save $220
B. 18" 3-Strand Sterling Silver Cable Chain $79
Pendant & Chain ~~$378†~~ ..... $99 Save $279
C. Earrings (14 ctw) ~~$399†~~ ..... $129 Save $270
Pendant, Chain & Earrings ~~$777~~ only $199 Best Value!

† Special price only for customers using the offer code versus the price on Stauer.com without your offer code.

C.

Call now and mention the offer code to receive your collection.

1-800-333-2045

Offer Code TTC191-01

You must use the offer code to get our special price.

BBB ACCREDITED BUSINESS Rating of A+

CONSUMER AFFAIRS ACCREDITED

Stauer®

14101 Southcross Drive W., Ste 155, Dept. TTC191-01,
Burnsville, Minnesota 55337 **www.stauer.com**

Stauer... *Afford the Extraordinary.®*

Medical Algorithms Need Better Regulation

Many do not require FDA approval, and those that do often do not undergo clinical trials

By Soleil Shah and Abdul El-Sayed

Medical algorithms are used across the health-care spectrum to diagnose disease, offer prognoses, monitor patients' health and assist with administrative tasks such as appointment scheduling. But the history of such technology's use in the U.S. is filled with stories of it running amok. From victims of sexual trauma being unfairly labeled as high risk for substance use to diagnostic failures by a sepsis-detection algorithm used by more than 100 health systems nationwide to clinical decision support (CDS) software discouraging necessary referrals to complex care for millions of Black patients, the problems abound. These issues might be extending the current pandemic as well: a 2021 review of dozens of machine-learning algorithms designed to detect or predict the progression of COVID found none to be clinically useful.

The kicker: many of the medical algorithms in use today did not require approval from the U.S. Food and Drug Administration, and the ones that did often did not undergo clinical trials.

To understand why, let us take a brief dive into history. In 1976, after the Dalkon Shield—an intrauterine contraceptive device—was implicated in several reported deaths and numerous hospitalizations, Congress amended the Food, Drug, and Cosmetic Act to mandate that medical devices demonstrate safety and effectiveness through clinical trials. To fast-track the device-approval process, a provision known as 510(k) was created to take advantage of the thousands of medical devices already being marketed. Under the 510(k)-clearance pathway, a device would not need clinical trial data if its manufacturers could demonstrate "substantial equivalence" in materials, purpose and mechanism of action to another device that was on

Illustration by Thomas Fuchs

Soleil Shah is a medical student at the Stanford University School of Medicine and a former researcher at the WHO's European Observatory on Health Systems and Policies.
Abdul El-Sayed is a physician and epidemiologist. He hosts the podcast America Dissected.

the market. At the time this seemed like a perfectly reasonable compromise for policy makers. Why make a surgical-glove manufacturer undergo rigorous clinical trials if surgical gloves have already been approved?

Of course, medical devices became more complex over time. Surgical gloves were overshadowed by surgical robots; knee braces were trumped by prosthetic knees. Eventually it became too hard to determine whether any two devices were truly equivalent. Beginning in the 1990s, the federal government moved to address the increasing complexity by simplifying some regulations, including by broadening the definition of substantial equivalence to include devices that had significantly different mechanisms and designs as long as they had similar safety profiles. The goal was to encourage innovation, but eventually this change led to a greater number of unsafe and ineffective devices.

To complicate matters, a device approved via 510(k) could remain on the market even if its predicate device was later recalled for quality and safety issues. This practice has led to a "collapsing building" phenomenon, with many devices that are currently used in hospitals having been based on failed predecessors. Of the more than 3,000 devices recalled between 2008 and 2017, 97 percent had received 510(k) clearance.

Under current law, medical algorithms are classified as medical devices and can be approved with the 510(k)-approval process. They are, however, less transparent, far more complex, more likely to reflect preexisting human bias, and more apt to evolve (and fail) over time than medical devices in the past. Additionally, Congress excluded certain health-related software from the definition of a medical device in the 21st Century Cures Act of 2016. Therefore, some medical algorithms, such as those used for CDS, can evade FDA oversight altogether. This is particularly concerning given the ubiquity of these algorithms in health care: in 2017 90 percent of hospitals in the U.S.—roughly 5,580 hospitals—had CDS software in place.

Ultimately regulation needs to evolve with innovation. Given the threats that unregulated medical algorithms pose for patients and communities, we believe that the U.S. must urgently improve regulations and oversight for these new-age devices. We recommend three specific action items that Congress should pursue.

First, Congress must lower the threshold for FDA evaluation. For medical algorithms, the definition of equivalency under 510(k) should be narrowed to consider whether the data sets or machine-learning tactics used by the new device and its predicate are similar. This kind of measure would prevent, for example, a network of algorithms for evaluating kidney disease risk from being approved simply because they all predict kidney disease. Furthermore, CDS systems that are ubiquitous among U.S. hospitals should not be exempt from FDA review. Although the results of CDS algorithms are not intended to be the sole determinants in care plans, health-care workers often rely on them heavily for clinical decision-making—meaning that they often affect patient outcomes.

Second, Congress should dismantle systems that foster health-care workers' overreliance on medical algorithms. Mandates for prescription-drug monitoring that require health practitioners to consult algorithms for scoring substance use prior to prescribing opioids, for example, should include comprehensive exemptions in all states, such as for cancer patients, emergency department visits and hospice care. And in general, unless their decisions lead to patient harm, doctors should not face significant penalties for using their own clinical judgment instead of accepting the recommendations of medical algorithms. An algorithm may label a patient as high risk for drug misuse, but a doctor's understanding of that patient's history of trauma adds critical nuance to the interpretation.

Medical algorithms are less transparent, far more complex, more likely to reflect preexisting human bias, and more apt to evolve (and fail) over time than medical devices in the past.

Third, Congress must establish systems of accountability for technologies that can evolve over time. There is already some movement toward this goal. A few years ago Representative Yvette Clarke of New York introduced the Algorithmic Accountability Act of 2019. This bill would require companies that create "high-risk automated decision systems" involving personal information to conduct impact assessments reviewed by the Federal Trade Commission as frequently as deemed necessary. For medical algorithms used in health-care settings, the FTC could require more frequent assessments to monitor changes over time.

This bill and several similar ones that were introduced have yet to reach the president's desk. Still, we remain hopeful that momentum will increase in the months ahead. The FDA is meanwhile taking initial steps to improve oversight of medical algorithms. Last year the agency released its first action plan tailored specifically to these technologies. It has, however, yet to clarify issues around CDS exemptions and appropriate 510(k) clearances.

We know algorithms in health care can often be biased or ineffective. But the U.S. must pay more attention to the regulatory system that lets them enter the public domain to begin with. If a decision affects a patient's life, "do no harm" must apply—even to computer algorithms. SA

JOIN THE CONVERSATION ONLINE
Visit *Scientific American* on Facebook and Twitter or send a letter to the editor: editors@sciam.com

ADVANCES

Madagascar's indri lemurs use repeating timing patterns in their dramatic family songs.

Nick Garbutt/Nature Picture Library/Alamy Stock Photo

INSIDE

ANIMAL BEHAVIOR

Lemur Rhythm

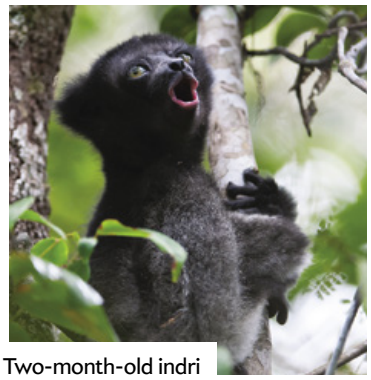
The indri is the first nonhuman mammal found to sing rhythmically

Mammals make all manner of sounds, but their calls rarely resemble music. The culprit? A lack of rhythm—the temporal sequence that organizes sounds, and the pauses between them, into a repeatable pattern. Humans were previously the only mammals known to use rhythm to create music. To discover how we could have acquired this ear for timing, scientists are exploring the musical capabilities of other species.

This is why a team of researchers recently trekked into the jungles of Madagascar, armed with microphones to record the remarkable calls of the indri lemur (*Indri indri*). Indris resemble gangly, black-and-white teddy bears with piercing green eyes. They often perch high in the rain forest canopy, where—despite being the largest species of lemur—they can be tough to spot. The animals are easy to hear, though; their bellowing cries are recognizable from more than a mile away. In addition to their prodigious pipes, indris sport a varied vocal repertoire, including a high-pitched, wail-like "song" that reverberates through the forest.

Indris live in family groups, and their distinctive songs help the groups communicate with one another. Like a family band, the adults perform sorrowful-sounding duets before offspring join in for a cacophonous chorus. These songs are "hauntingly beautiful," says Andrea Ravignani, a biomusicologist at the Max Planck Institute for Psycholinguistics in Nijmegen, the Netherlands.

Indri songs may seem chaotic at first,



Two-month-old indri

but University of Turin biologist Chiara De Gregorio says they begin to sound less so the more one hears them. "When you get used to them, you can really recognize a pattern in those songs," she says. "When they start a phrase, you know what to expect, note after note." In a new study published in *Current Biology*, *De Gregorio, Ravignani and their colleagues analyzed recordings of 636 individual indri songs collected from 20 different family groups to determine whether these vociferous lemurs do, in fact, possess rhythm.*

Because rhythm is all about timing, the team dissected each recording into its base elements to measure the duration of notes and the pauses between them. The researchers compared the lengths of the intervals between each sound and found that the songs often broke down into rhythmic ratios of 1:1 (when the intervals between sounds have the same duration, like singing along with a metronome) or 1:2 (when the first interval is half as long as the second). Both are common in human music.

The researchers say their study shows indris use these patterns to structure their songs—making this the first confirmed case of a nonhuman mammal possessing categorical rhythm. Their findings applied to all the indris they recorded; females and males sang at different tempos, but both employed the same rhythmic patterns. Indris also showed the ability to maintain a constant rhythm as they decreased the tempo of their songs—a process known in classical music as ritardando.

Although indris and human composers may utilize some similar structures, each likely developed musical abilities separately. It has been 77.5 million years since the common ancestor of humans and indris existed, a chasm of evolutionary time that makes it unlikely rhythm was an ancestral trait. Ravignani instead suggests similar social pressures molded both indris and humans into singers at different times—an example of convergent evolution. The exact benefits this ability confers to indris are still unknown, but the authors speculate that organizing songs into repeatable patterns may make them easier for young lemurs to learn, or it could help indri families quickly coordinate when they need to defend territory or gather together.

Elizabeth St. Clair, a biological anthropologist at Johns Hopkins University who studies the evolution of the primate vocal tract, says she was surprised by the rhythmic similarities between indri and human songs. "It seems like it's an individual characteristic of indris that is not seen in many other mammals or even birds," says St. Clair, who was not involved in the new study. She suspects that gibbons, small Southeast Asian apes known to coordinate their calls, may also use rhythm to structure their songs.

Dissecting indri songs indicates these animals share an underlying sense of rhythm with humans, but it raises more questions about how indris communicate. The researchers hope studying indri rhythm will add urgency to conservation efforts necessary to help the primates survive. Deforestation and hunting have devastated indri (as well as gibbon) populations; some experts estimate that as few as 1,000 indris remain in the wild, and all signs point to that number decreasing. Madagascar's forests are predicted to decline by as much as 93 percent by 2070.

As scientists attempt to untangle why primates began using music, hearing the songs of wild indris will be crucial. "Their communication system, it's an indirect window into their minds," Ravignani says. "They have a lot of secrets hidden in their heads, and by looking at their sound production, we can uncover them." —*Jack Tamisiea*

Bernard Castelein/Nature Picture Library/Alamy Stock Photo

ENTOMOLOGY

Beetle Mania

Oral courtship is key for desert beetle copulation

When researcher Xinghu Qin ventured through rangeland near Inner Mongolia's Hunshandake Desert, he spotted some puzzling behavior between two little beetles mating shamelessly in the open: one was constantly licking the other's tail.

"What on earth were they doing?" wondered Qin, then a graduate student at the Chinese Academy of Agricultural Sciences.

They were Mongolian desert beetles, or *Platyope mongolica*, which mostly hide underneath desert grasses and sands but occasionally emerge to mate. Reporting in *Ecology and Evolution*, Qin and his colleagues describe a newly discovered oral sexual ritual that males of the species apparently must perform before mounting females for copulation.

"We have observed self-licking behavior in many animals. But males or females licking genitalia of their

CLIMATE

Volcanic Boost

Prehistoric eruptions pushed the climate to a "tipping point"

Climate experts have warned for decades of "tipping points" at which modern global warming might cause a cascade of accelerating, irreversible effects. Now geologists are beginning to identify similar junctures in the fossil record. For example, around 56 million years ago—when our small primate ancestors still hopped through the trees—volcanic eruptions may have sparked hothouse conditions that altered processes ranging from evolution to the direction of ocean currents. By studying climate shifts of the past, geologists hope to anticipate how our current, human-caused climate change could dramatically alter our world.

Researchers have long known of the so-called Paleocene-Eocene Thermal Maximum (PETM), an exceptionally hot period in Earth's history, but its cause has been heavily debated. Now, in *Nature Communications*, British Geological Survey geologist Sev Kender and his colleagues offer evidence that volcanic eruptions in the North Atlantic provided a critical component to this burst of heat.

The researchers' key clues came from a thin core of sediment pulled from an accumulation of undersea rocks near Iceland. This area, called the North Atlantic Igneous Province, formed from magma flowing through and spilling out of Earth's crust more than 50 million years ago. Scientists had hypothe-

Mongolian desert beetles

Xinghu Qin

partner, especially in beetlelike insects, is actually rare," says Matjaž Gregorič, an entomologist at the Jovan Hadži Institute of Biology in Slovenia, who was not involved in the study.

When a male Mongolian desert beetle finds a potential mate, he begins rubbing a protruding mouthpart called a maxillary palp over her genitals. If his performance does not meet her standards, she runs away. And the longer the male performs the oral courtship ritual, the shorter time he needs for successful copulation later on.

Gregorič and his team had discovered similar behavior in Darwin's bark spider in 2016. Daisuke Yamamoto, an entomologist at Japan's National Institute of Information and Communications Technology, reported observing this phenomenon in fruit flies, too. "We believe male licking of female genitalia [in fruit flies] mediated pheromone detection," Yamamoto says. "It could also have served as a form of nutritional gift to females, also called a nuptial gift."

Understanding more about these behaviors can help researchers piece together how sexual selection has shaped the beetles' evolution. Though rarely observed, such complex sexual practices may be more common in the insect world than one might assume—but they are little known, Qin says, because "insects are still an understudied group."

Gregorič adds that "if people know something interesting about animals, even if they are beetles or spiders, they will have a little bit more positive attitude toward the animal—and this is always useful in conservation." —*Saugat Bolakhe*

sized that the volcanic activity that created these rocks was involved in the PETM, Kender says—so his team was immediately intrigued by mercury signals in the core sample.

Elevated mercury in rock cores is a measure of volcanic activity, and the levels the team found indicate North Atlantic eruptions occurred at the right time and intensity to raise carbon dioxide levels in the atmosphere. Then, when the volcanoes died down, the temperatures kept rising.

University of Connecticut geoscientist Ran Feng, who was not involved in the new study, says the results are "quite intriguing" when it comes to the timing of the eruptions and the PETM onset. The study posits that volcanic greenhouse gases warmed the global climate enough to hit a tipping point, sparking a release of carbon locked away elsewhere—which further intensified global warming. Additional lines of evidence, such as geologic indicators of atmospheric and oceanic carbon dioxide during this period, could help further test the hypothesis, Feng says.

Looking at the mercury signatures in rocks from the PETM is a promising approach to understanding what happened at that time, says City College of New York geologist Benjamin Black, who was not involved in the new study. Geologists hope to move beyond identifying volcanic activity's role in the PETM, Black says, to understand how that process actually played out: "Moments in Earth's deep past like the PETM provide valuable points of comparison to understand the behavior of climate systems under stress"—including our modern climate. —*Riley Black*

Giant's Causeway in Northern Ireland is part of the North Atlantic Igneous Province.

Clearview/Alamy Stock Photo

DISASTER PREVENTION

Shock Absorber

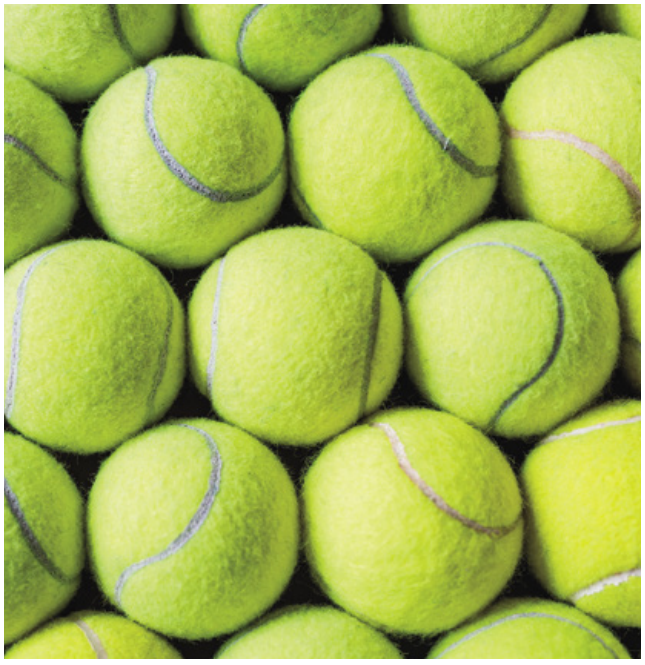
Low-cost earthquake protection recycles old tennis balls

Earthquakes cannot be forecast, but engineers can prepare for them. Seismic-isolation systems built into the bases of certain buildings in high-risk areas, such as San Francisco's City Hall, use complex structures of concrete, rubber and metal to reduce quake damage by absorbing the ground's horizontal oscillations, like a car's suspension does with vertical motion.

But such adaptations are expensive. Engineer Jian Zhang of the University of California, Los Angeles, says incorporating seismic isolation can increase construction costs by up to 20 percent. Although these systems might save more than they cost over time, builders in some earthquake-prone regions may not have the budget for them up-front.

A new seismic-isolation method uses the physics of rolling to create a simpler, lower-cost alternative with readily available materials: recycled tennis balls. "Everyone plays tennis, and they don't know what to do with the tennis balls after each game," says ETH Zürich seismic engineer Michalis Vassiliou.

Vassiliou's team based its method on an early form of seismic isolation that rolls a shaking building to a stop the way a skater in a half-pipe eventually comes to rest. By separating a building from the ground with a layer of spheres or cylinders in concave indentations, rolling isolation converts erratic horizontal shaking into a gentle rocking motion and uses friction to further dampen these oscillations. This method was used in 5,000-year-old Peruvian pyramids, but today builders favor expensive, standardized isolation systems.



DJI Photography/Getty Images

For their modern take on rolling seismic isolation, detailed in *Frontiers in Built Environment*, the researchers injected cementlike mixes into hundreds of balls from nearby tennis clubs that had lost their bounce. They built an inexpensive prototype consisting of four filled tennis balls sandwiched between two concrete slabs, and they found that it withstood simulated earth-

CULINARY SCIENCE

Laser-Focused Chef

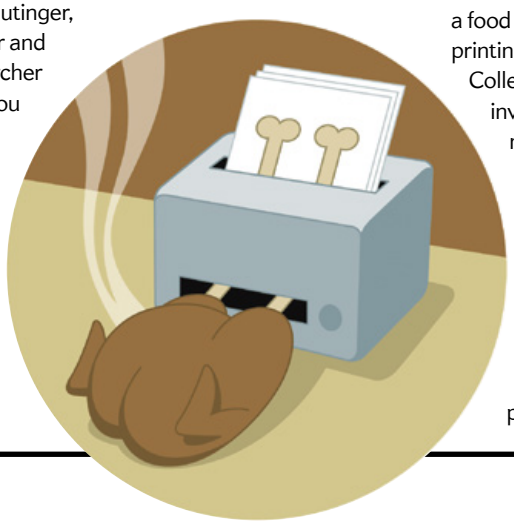
3-D food printer can create and cook foods at once

Tomorrow's gourmet menus could feature items prepared with complex cooking techniques and intricate presentation—all at the push of a button. Columbia University mechanical engineers have designed a 3-D printer that can simultaneously produce and cook dishes with details at the millimeter scale.

The proof-of-concept design, described in *npj Science of Food*, combines a multiwavelength laser cooker, roughly the size of five smartphones stacked together, with a microwave-oven-sized food printer. As the device's robotic arm deposits fine layers of chicken puree, a high-powered beam zigzags over them and cooks the meat—with literally laser-focused precision. "It's almost like having a crème brûlée torch," says Jonathan Blutinger, lead author of the paper and a digital-cooking researcher at Columbia. "It gives you a lot more control and customization." The researchers tested only chicken for this study, but the system can work with other foods as well.

Beyond applying sophisticated texture and presentation motifs, this type of software-controlled setup could someday scan a QR code to automatically prepare dishes tailored to individual eating habits and dietary restrictions, Blutinger says.

The system, which the researchers say is the first to combine a laser cooker with a 3-D food printer, uses various light wavelengths to cook in different ways: a short-waved blue laser penetrates deep inside meat, for example, while infrared beams (which have longer wavelengths) broil or brown the surface. Thus, users can achieve elaborate results—say, a machine-made burger that alternates between rare and well done in a checkerboard pattern.



The new technology is "astounding," says Megan Ross, a food scientist who studies 3-D printing at Ireland's University College Cork and was not involved in the study. Ross notes that the design is still at a nascent stage and that many technical challenges remain, such as preventing cross contamination between layers of raw and cooked meat.

Still, Ross is impressed by the device's

Illustrations by Thomas Fuchs

quake shaking while supporting eight kilonewtons of force per ball—about twice what isolation systems might experience under one-story houses. The balls had to contain precisely the right amount of the mixture (the researchers used a pastry bag to fill them) to dampen vibrations without cracking during tests.

Zhang, who was not involved in the study, says that the work is worthwhile and that such technology might serve an unmet need. But she notes that the results are preliminary. Vassiliou agrees; next steps will mean creating and testing a larger prototype with hundreds of tennis balls at a research center in earthquake-prone Cuba—an example of a place where such systems could make isolation feasible in ordinary construction.

Vassiliou says that he has received funding to field-test the system and partner with scientists on the ground to refine the invention. "For this to actually be implemented," he adds, "you need to develop it with engineers from low-income countries so that it actually addresses their needs." —*Maddie Bender*

ability to produce foods outside the realm of conventional cooking. "Is this going to be sold in shops everywhere in the next few years? No," she says. "But everyone has to start somewhere."

Compared with 3-D-printed chicken cooked in a traditional oven, the laser-cooked version retained nearly twice as much weight and volume, the researchers found. "That chicken is going to be juicy," says Liam MacLeod, a Denver-based chef and former 3-D food printing specialist at the Culinary Institute of America, who was not involved in the study. MacLeod does not think such technology will ever replace chefs, but it might "add a tool to their arsenal" to deliver a new sensory experience. "Cooking is a skill set that has been practiced and perfected for thousands of years," he says. "It's very exciting to come up with something new and unique that people haven't experienced yet." —*Huanjia Zhang*

ANIMAL BEHAVIOR

The Call of Nature

Messy stories from the animal kingdom

Cows can learn to use a latrine.

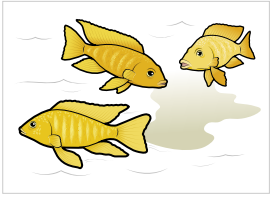
Urinating is easy. Holding it in, however, is tough. While some animals, such as wolves, control their bladders to selectively mark their territories, cattle roam blithely around pastures peeing with abandon. "You get the impression that these animals have no control over their urination," says Jan Langbein, an animal psychologist at the Research Institute for Farm Animal Biology in Germany. "But you can train dogs, and you can train horses. So we thought, why not cattle?"

For a study in *Current Biology*, Langbein and his colleagues worked on potty training 16 calves for 45 minutes every other day. They first restricted the animals within a specially designed latrine (called a MooLoo), offering food through a hole in the wall when the calves urinated. After the animals learned they would receive a reward for making use of the setup, they were allowed outside. If the calves voluntarily reentered the latrine and urinated, they were again rewarded—but if they relieved themselves outside, they were sprayed with water for three seconds.

After 10 days of training, 11 of the calves were using the latrine about 77 percent of the time—demonstrating that cattle can indeed quickly learn to urinate in a lavatory. The team now aims to automate the system for farm use with less monitoring.

Capturing cattle urine in latrines could help mitigate pollution, greenhouse gas emissions and the spread of diseases to humans, says Patricia Yang, a mechanical engineer at the National Tsing Hua University in Taiwan who was not involved in the study. "If we can manage animal waste as well as we manage human waste," she says, "then we can eliminate these diseases." —*Nikk Ogasa*

WOMBATS POO CUBES, and for a long time no one knew why. Puzzled by the seemingly sculpted scat—the animals deposit up to 100 cubes a day—Yang and her colleagues examined roadkill wombats and found their intestinal walls formed grooves, or corners, when contracting, producing the cubic geometry. The odd shape keeps the excrement from rolling away, which may help the creatures stake their territory.



PEE SPEAKS, at least for some fish. Curious about communication using nonvisual cues, researchers separated cichlids in a tank with a transparent barrier and injected the fish with dye to observe their urine. When the fish saw one another, they approached the barrier and urinated. And when urine was allowed through holes in the barrier, the fish behaved differently: the smaller fish acted more submissively toward the bigger ones.

HORSE MANURE is a favorite of pandas—the fluffy creatures have been observed slathering the waste on their bodies. Curious about this odd behavior, researchers conducted experiments and found that two compounds in fresh horse dung quieted a mammalian protein known to warn the body of cold, suggesting that the messy manure might help the pandas numb themselves when exposed to chilly weather.

Farlap/Alamy Stock Photo

Illustrations by Brown Bird Design

IN THE NEWS

Quick Hits

By Nikk Ogasa

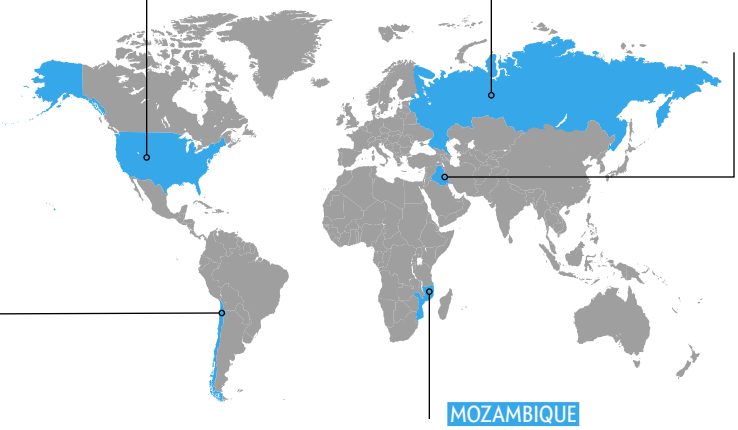
For more details, visit www.ScientificAmerican.com/jan2022/advances

U.S.

Biologists found that two male California Condor chicks were "virgin births," produced with no contribution from a second parent. This discovery suggests that the largest North American land birds can sometimes reproduce asexually, a strategy that could help the critically endangered species survive.

RUSSIA

A DNA analysis of hundreds of ancient horse bones offers evidence that modern domestic horses originated in southwestern Russia around 4,200 years ago. Although horses existed elsewhere, this genetic record indicates humans may have favored the Russian horses' strength and temperament.



CHILE

Patches of glassy rocks scattered over a broad swath of the Atacama Desert contain minerals similar to a comet sampled by NASA's Stardust Mission, new research finds. The rocks may have formed when a comet exploded over the desert and melted sand into glass.

IRAQ

The oldest-known drawing of a ghost has been discovered on a 3,500-year-old tablet from Babylon. The drawing depicts a bearded apparition being led forward by a woman, and a translation of an adjacent engraving reveals instructions for an exorcism ritual.

ANTARCTICA

Scientists analyzing Antarctic ice cores found large amounts of soot dating back 700 years. Wind-current simulations and historical records link the soot to when the Maori arrived to New Zealand and began burning dense forests to clear land.

MOZAMBIQUE

New work spots a genetic cause for the sharp uptick in female elephants born tuskless in Gorongosa National Park since the Mozambican Civil War began in 1977. This rapid evolution was likely driven by wartime tusked elephant poaching.

BIOLOGY

Beet Bait

A chemical from malaria parasites draws mosquitoes to a deadly dinner

Plant-based meat alternatives are making the rounds from food blogs to five-star restaurants—and soon they may appear on menus for some decidedly different diners. A new study published in *Communications Biology* shows how to trick mosquitoes into eating beet juice "blood" laced with poison.

Mosquito-borne diseases kill more than 700,000 people every year, with malaria alone claiming more than half of them, says Stockholm University infection biologist and study lead author S. Noushin Emami. One approach to controlling mosquito populations is mixing poison with a sugary bait. But other insects love sugar, too—and can fall victim to poison intended for their vampiric neighbors.

Solutions to global health issues must be simple to work in practice, says Lech Ignatowicz, CEO of a start-up called Molecular Attraction, which he and Emami founded to fight insect-borne diseases. The two researchers and their colleagues wanted to create mosquito bait that is affordable, scalable—and specific to blood-sucking insects. First the team needed a simple, blood-free base for the bait, as contaminant-free blood is difficult and expensive to source and store. The solution? Beet juice. Beets are plentiful in Sweden, Ignatowicz says, and their bright pink juice is visible inside mosquito guts, making it easy for researchers to see if the insects are actually consuming it. But getting mosquitoes to go plant-based required some persuasion.

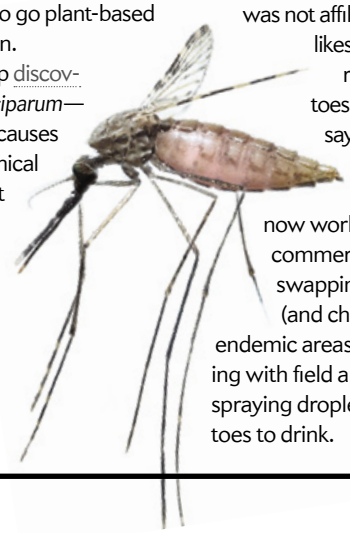
In 2017 Emami's group discovered that *Plasmodium falciparum*—one of the parasites that causes malaria—releases a chemical called HMBPP into a host animal's blood. This acts as a molecular bon appétit to mosquitoes, enticing them to chow down on *Plasmodium*-filled blood so the parasite can spread to a new host.

"HMBPP is the taste of a bloody, hot, juicy steak for the mosquitoes," Emami says. In the study, about five times as many mosquitoes drank the beet juice after the researchers added just a bit of HMBPP. Emami says the chemical helps to ensure that only these particular bloodsuckers would be attracted to the juice and consume the added pesticide. The team is also considering natural alternatives to the poisons tested, and the researchers ultimately aim to find something that harms only mosquitoes.

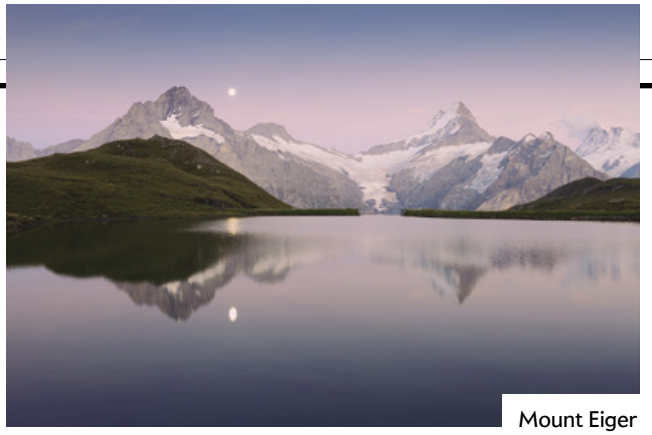
Arizona State University infectious disease biologist Kristina Gonzales-Wartz, who was not affiliated with the study, says she likes the idea of using HMBPP to restrict the toxin to mosquitoes. "It's very innovative," she says. "But how feasible is it on a bigger scale?"

The researchers are now working to adapt the bait for commercial use, which may involve swapping beets for more popular (and cheaper) plants in malaria-endemic areas. They are also experimenting with field applications—including spraying droplets onto foliage for mosquitoes to drink.

—*Annie Melchor*



Lech Ignatowicz



Mount Eiger

GEOLOGY

Glacial Whispers

Tech uses ultralow sounds to detect ice avalanches

When a Goodyear blimp–sized chunk of ice fell from a collapsing glacier on the Swiss Alps' Mount Eiger in 2017, part of the rumble it produced was too low for human ears to detect. But these vibrations held a key to calculating the ice avalanche's critical characteristics.

Low-frequency sound waves called infrasound that travel great distances through the atmosphere are already used to monitor active volcanoes from afar. Now some researchers in this field have switched focus from fire to ice: dangerous slabs snapping off glaciers. Previous work has analyzed infrasound from snow avalanches but never ice, says Boise State University geophysicist Jeffrey Johnson, who was not involved with the new study but collaborated with the lead author on previous work. "This was different," Johnson says. "[A signature of] a new material has been detected with infrasound."

Usually glaciers move far too slowly to generate an infrasound signal, which researchers pick up using detectors that track minute changes in air pressure. But a collapse—a sudden, rapid breaking of ice from the glacier's main body—is a prolific infrasound producer. Glacial collapses drive ice avalanches, which pose an increasing hazard to people in mountainous regions as rising temperatures weaken large fields of ice. A glacier "can become detached from the ground due to melting, [causing] bigger break-offs," says University of Florence geologist Emanuele Marchetti, lead author of the new study, published in *Geophysical Research Letters*. As the hazard grows, scientists seek new ways to monitor and detect such collapses.

Researchers often use radar to track ice avalanches, which is precise but expensive and can monitor only one specific location and neighboring avalanche paths. Infrasound, Marchetti says, is cheaper and can detect break-off events around a much broader area as well as multiple avalanches across a mountain. It is challenging, however, to separate a signal into its components (such as traffic noise, individual avalanches and nearby earthquakes) without additional measurements, says ETH Zürich glaciologist Małgorzata Chmiel, who was not involved with the new study. "The model used by Marchetti et al. is a first approximation for this," she says. By isolating the relevant signal, the model let the researchers monitor an ice avalanche's speed, trajectory and volume from afar using infrasound.

Marchetti and his colleagues are now working to improve their detectors to pick up more signals across at-risk regions in Europe, and they have set up collaborations around the continent to better understand signals that collapsing glaciers produce. They are also refining their mathematical analysis to tease out each ice cascade's physical details. —*Ellis Avallone*

Michal Balada/Getty Images

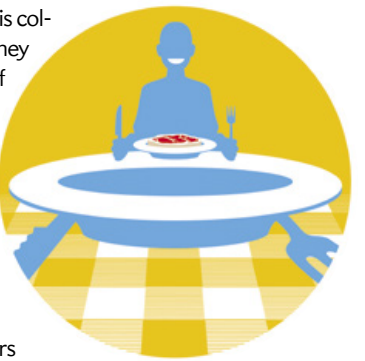
GENETICS

Hungry Hominins

When food is scarce, it pays to be small

About a million years ago a small mutation might have unlocked a big advantage for ancient humans. A recent study in *Science Advances* suggests that a variant of a critical stretch of DNA called the growth hormone receptor gene protected against starvation—in part by limiting individuals' body size during periods of resource scarcity. The variant was widespread among *Homo sapiens* and their relatives, although it suddenly plummeted in frequency beginning around 40,000 years ago, especially in East Asia and Eurasia. Many people still carry it today.

Previous research had linked the variant, called *GHRd3,* to characteristics such as smaller birth size and earlier sexual maturity, as well as other qualities that can benefit organisms when food is scarce, says the study's lead author Omer Gokcumen, an anthropologist at the University at Buffalo. Still, researchers wanted to know more precisely what role the mutation played in human evolution.



To dig deeper, Gokcumen and his colleagues turned to mice. Or rather they turned some mice into analogues of early humans. Using the genetic editing tool CRISPR-Cas9, the team deleted a section of mice's growth hormone receptor gene so it resembled the *GHRd3* variant. The modified mice were not especially different from ordinary ones when fed a regular diet. But when fed very little, the male carriers grew up to be smaller than their unmodified counterparts. Gokcumen's team also found that among a group of 176 modern human children who survived malnutrition, symptoms were less severe in boys and girls with *GHRd3.*

These findings could help explain why *GHRd3* has persisted for so long. Perhaps it paid to be small in times of scarcity, the researchers speculate—but in times of abundance large size won out. Changes in available resources could then have balanced the costs and benefits of different variants within a population. "It's a trade-off," Gokcumen says. "I would probably fare better than Arnold Schwarzenegger if we [each] had 1,000 calories a day."

The team's explanation is "plausible," says Megan Dennis, a geneticist at the University of California, Davis, who was not part of the study. She praises the functional experiments in mice but notes that the affected gene is involved in so many fundamental processes that it is difficult to pin down *GHRd3*'s most adaptive effects. "I was like, 'Wow, there's so much that could be happening here,' " Dennis says.

And the study researchers continue to wonder what could have caused this variant's decline around 40,000 years ago. Climate change, migration, and the advent of better hunting and fishing tools all could have had an impact. Or it could have been something else entirely, Gokcumen says: "That is a very strange time in human evolution." —*James Dinneen*

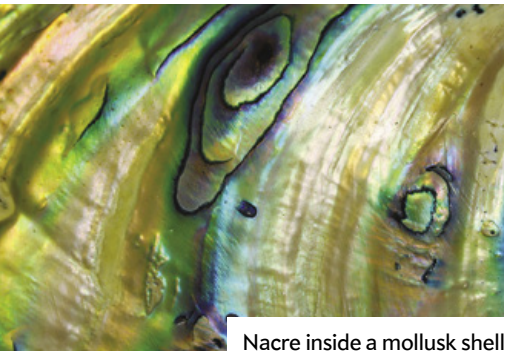
MATERIALS SCIENCE

Sea Goggles

Seashells inspire a new superstrong glass composite

Nacre, an iridescent material that lines some seashells, gains strength and toughness from its structure: brittle mineral chips glued into layers by squishy proteins. Now researchers have used the same principle to develop a superstrong glass composite that could one day make nearly unbreakable smartphone screens, windshields and other items that currently rely on various types of treated glass.

The new material combines rigid glass flakes, less than one hundredth of a millimeter thick, with flexible acrylic. "When we combine those two together, similar to nacre, we recover the best parts of both components," says Allen Ehrlicher, a McGill University bioengineer and co-author of a recent paper describing the composite, which was published in *Science*.



Nacre inside a mollusk shell

Helen Davies/Alamy Stock Photo

Both glass and acrylic are transparent on their own, but light travels through each of these materials at a different speed. As a result, previous attempts to combine them made a substance that was too opaque. So the researchers mixed small quantities of a hydrocarbon with the acrylic until it interacted with light more like glass does.

The result is not only transparent, Ehrlicher says, but also 400 percent stronger and 650 percent more damage-resistant than the material used in car windshields: resin sandwiched between two layers of glass. Plus, the new substance can be cut and drilled with standard tools. Ehrlicher compares the way the acrylic binds the glass flakes into a stacked structure to a brick wall with staggered layers: any crack snaking through the new material will follow the acrylic seams in a convoluted path, thus requiring more energy to fracture. "By forcing it to go through a long path, to break through a lot of this connective material—a lot of this 'mortar,' by analogy—we create a material that's very, very tough," he explains.

To construct these layers, the researchers spun their ingredients in a centrifuge. The simple technique means "you would be able to do this at scales much larger than what a lot of [other] synthetic nacre can be done at," says Cornell University materials scientist Lara Estroff, who was not involved in the research. Such ease of manufacturing could enable a variety of applications—eventually. Arun Varshneya, president of Saxon Glass Technologies, points out that the material is still less transparent than glass and more prone to surface scratches. Nevertheless, he says, "I'm actually quite enthused with this gallant effort in the right direction." Varshneya, who was also not involved in the research, lauds the composite's strength throughout the material, in contrast to the chemically strengthened glass used in items such as smartphone screens (whose hardening is limited to a thin surface layer).

Ehrlicher says he hopes to keep improving the new material's transparency and scratch resistance while retaining its remarkable toughness. "Inevitably it's been a trade-off between transparency and strength, or strength and rigidity, or work of fracture and rigidity," he says. "And what we've created here is the best sweet-spot balance of all of those." —*Sophie Bushwick*

PUBLIC HEALTH

Science in Images

By Bethany Brookshire

Hyenas' nighttime scavenging reduces disease transmission

Giggling, sneaky, carrion-scavenging—and good for public health? Hyenas around the Ethiopian city of Mekelle often dine on livestock carcasses. In the process, a new study suggests, they may prevent infections of anthrax and bovine tuberculosis in nearby humans and animals.

More than 300,000 people live in Mekelle, along with more than 100,000 head of livestock, according to the study authors. When residents toss dead chickens, donkeys or cattle into the city's dump, spotted hyenas come calling. "If you're walking around in Mekelle at night and you don't see a hyena, you're doing something wrong," says Stanford University graduate student Chinmay Sonawane. Wild game has become scarce in the area, and hyenas make up the difference with dead livestock. The resulting reduction in fetid waste "is something that people in Mekelle and people in Ethiopia broadly do appreciate," Sonawane says.

To investigate the possible public health benefits more closely, Sonawane and his colleagues observed hyenas chowing down in the local landfill over 40 nights to learn how much they eat. The researchers then estimated how many cases of anthrax and bovine tuberculosis could spread from contact with animal carcass waste in Mekelle and modeled disease rates with and without hungry hyenas cleaning up.

They found that a single hyena crunches up 983 kilograms of dead livestock a year. In 2019 Mekelle's roughly 210 hyenas gulped down about 4.2 percent of the available animal carcasses. By doing so, the model suggests, the scavengers prevented three anthrax and two bovine tuberculosis infections in people and 11 anthrax and 129 bovine tuberculosis infections in livestock. Figuring in disease treatment and livestock costs, the scientists calculated that hyenas saved humans more than $50,000 that year. Sonawane and his colleagues published their results in the *Journal of Applied Ecology*.

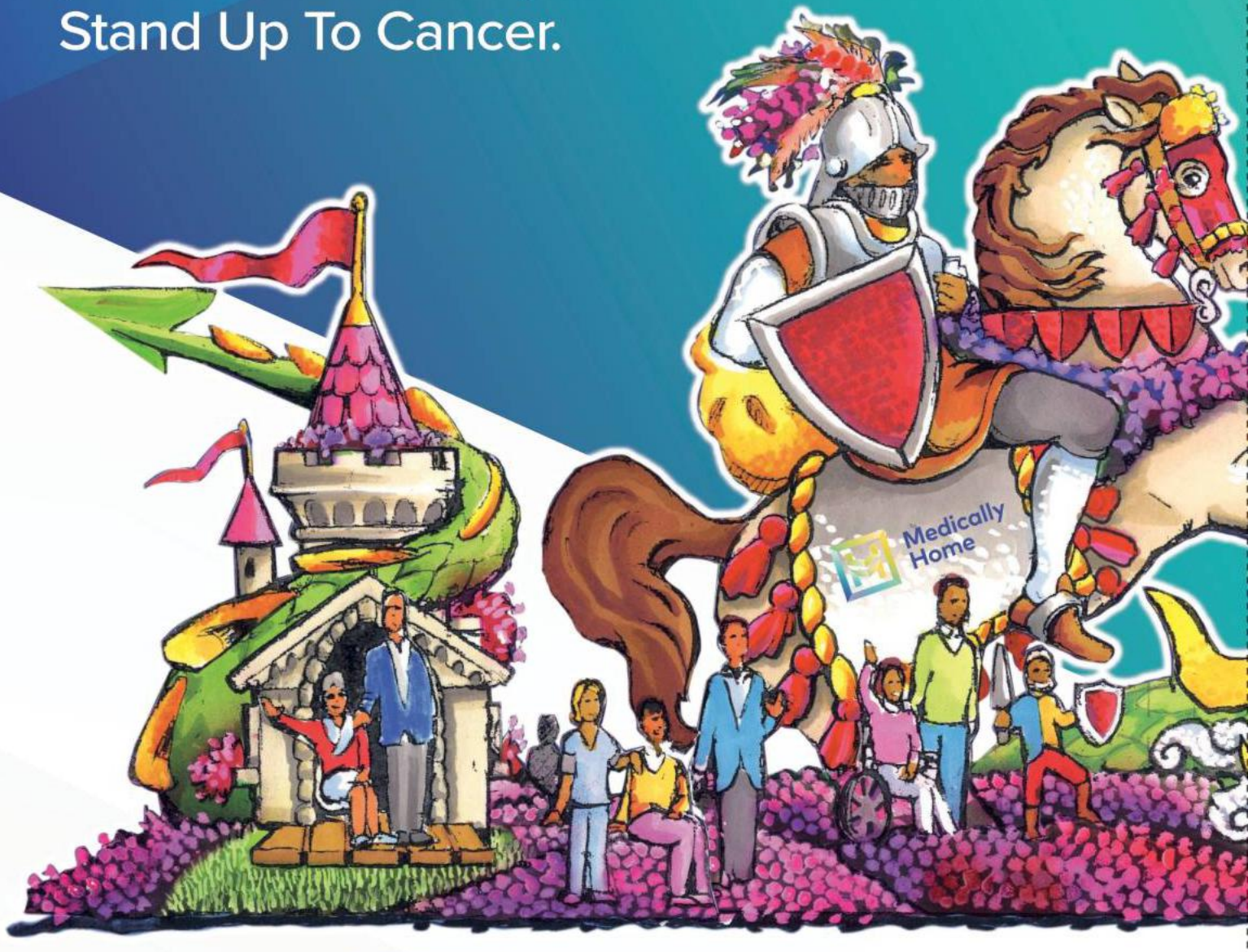
Despite its importance to the ecosystem, scavenging has been studied less than behaviors such as predation, says University of Washington wildlife ecologist Laura Prugh, who was not involved in the study. Prugh says she hopes studies like this one, which explore how scavengers directly benefit humans, "will help motivate people to conserve species that often don't get the same respect."

For more, visit ScientificAmerican.com/science-in-images

Art Wolfe

We honor all the researchers, scientists, and clinicians who made hospitalizing patients safely at home a reality.

Scientific American is a proud media partner of Medically Home and Stand Up To Cancer.



Medically Home®

medicallyhome.com

In the spirit of perseverance to achieve this impossible dream – a global movement on behalf of patients.

ROSE PARADE®
presented by
HONDA

See our "Home Is Where the Hospital Is" float at the Rose Parade® January 1, 2022

STAND UP TO CANCER®

It will take perseverance to achieve Stand Up To Cancer's mission of turning every cancer patient into a long-term survivor. ***Become a part of that mission by donating at StandUpToCancer.org/RoseParade.***

Faith Shearin's seven poetry collections include *Moving the Piano, Darwin's Daughter* and, most recently, *Lost Language* (Press 53, 2020). Her new young adult novel, *Lost River, 1918,* is due out this summer, to be followed next year by *Horse Latitudes,* a book of short stories.

DEATH CAP

I was troubled by how easy it was to mistake
one thing for another, as with snakes—

the Scarlet King resembling the Coral
with its arrangement of black

on yellow, or the harmless Hognose
which is often confused

with a Copperhead. Likewise, mushrooms—
however you might examine the warts

on the umbrella caps or the thin white gills
you could miss some telltale sign—

the partial veil around a stem, say, or
white spores, the Sprouting Amanita

pretending to be a Young Puffball
and then, days later

the lethal symptoms would begin: burning
thirst, blurred vision,

your heartbeat growing
dangerously slow.

We lived like this for more than a year—
unable to tell which

doorknobs were ordinary and which
harbored the virus, afraid to taste the

vivid winter air.

Paul Starosta

Claudia Wallis is an award-winning science journalist whose work has appeared in the *New York Times, Time, Fortune* and the *New Republic.* She was science editor at *Time* and managing editor of *Scientific American Mind.*

The Zoom Boom in Psychotherapy

Remote sessions can be as effective as in-person treatment

By Claudia Wallis

In the before times, clinical psychologist Leslie Becker-Phelps met with patients in a tidy private office in Basking Ridge, N.J., carefully observing their demeanor, body language and, with couples, interpersonal vibe. That changed with COVID's social-distancing exigencies. "My office is a 14-foot by 14-foot room," she explains, "and I am not going to do therapy with masks that cover something that is so important in therapy—the face." Today her sessions take place by videoconference or, sometimes, phone. "I've found that it works," she says. "I was surprised."

Becker-Phelps is hardly alone in switching up her practice during the pandemic. In a survey of 1,141 clinical psychologists released in October by the American Psychological Association (APA), 96 percent said they were providing remote or "telehealth" services to patients, and an equal portion judged them to be effective. As recently as 2019, only 21 percent of psychologists reported offering videoconferencing as an option, says Lynn Bufka, senior director for practice transformation and quality at the APA. Still, patients might wonder: Is meeting with a therapist on video really equivalent to an in-person session? What about the initial diagnostic process? Are some types of therapy better suited than others to remote delivery? For some of these questions, we have solid answers; for others, not quite yet.

Long before COVID, researchers began to look at how well remote psychotherapy works. Most studies focused on people with depression treated with cognitive-behavioral therapy (CBT). This approach, which aims to change negative patterns of thought and behavior, "lends itself well to research because it has a clear structure and process," Bufka notes. In CBT, patients work through a series of information modules and exercises. A 2018 meta-analysis of 20 studies involving more than 1,400 patients found that the therapy is equally effective for depression, as well as a range of anxiety disorders, whether delivered in person or online. "You can do it individually or in groups, by telephone or by Internet interventions, and the effects are not different," says clinical psychologist Pim Cuijpers of Vrije University in Amsterdam, a co-author of the meta-analysis and of many studies on remote therapies.

Some alternatives to CBT have also been studied, though in less depth. Cuijpers, along with his colleagues in the Netherlands and Australia, has found that interpersonal psychotherapy—another highly structured approach—is about as effective for depressive symptoms as CBT when delivered online, and a 2020 meta-analysis concluded that even psychodynamic therapy, which focuses more on the roots of problems than on outward behaviors, can be delivered effectively via technology. The same seems true of therapies designed to treat post-traumatic stress disorder, according to a 2017 review of 41 studies of teletherapy for veterans with PTSD.

Remote technology can work well for diagnosis, too. In many studies of teletherapy, however, the initial diagnostic screening was done in person. "There was a concern about capturing the severity of the individual's presentation," Bufka explains. But now insurers have loosened rules around remote diagnosis and treatment, and clinicians are using teletherapy for first assessments. "I was concerned about a loss of subtle and nonverbal communication—not catching things on a camera the way you might if you are sitting in the room," says psychiatrist Peter Halperin of the Cooley Dickinson Health Care system in Northampton, Mass. Instead he sees some advantages: "It is tough for somebody to go to a new building, see a new person, and in that first hour talk about highly charged emotional stuff. I found that people are more facile at doing it when they are talking to me from their homes."

There can, of course, be glitches. The APA survey found that the top challenges were technical and connectivity problems and patients finding a private space for sessions. "It's not unusual for people to do therapy from their car," Becker-Phelps says. Some of her patients miss in-person proximity, and she does, too. In a shared space, she can use her own physical presence, leaning forward with compassion when a patient is upset or to take control when couples get overheated in therapy.

Like telecommuting, teletherapy seems destined to stay. There are battles ahead about whether insurers will reimburse it at the same rates as in-person therapy, Bufka says, and clinicians will need to use platforms that meet federal privacy requirements, if they are not already doing so. But given the rising demand for mental health services in the COVID era, having more options for accessing care is not merely convenient; it is essential. SA

Illustration by Fatinha Ramos

WONDER OF THE ANCIENT WORLD

ARCHAEOLOGY

Scientists have revealed new details about the complex gearing of the Antikythera mechanism of ancient Greece

By Tony Freeth

OUTSIDE/INSIDE: The main drive wheel of the Antikythera mechanism, as seen in a photograph of its present state (*left*) and in an x-ray CT scan.

Tony Freeth is a member of the University College London Antikythera Research Team. A mathematician and an award-winning filmmaker, Freeth has conducted research on the Antikythera mechanism and promoted it through films and presentations since 2000.

IN 1900 DIVER ELIAS STADIATIS, CLAD IN A COPPER AND BRASS HELMET AND A HEAVY CANVAS SUIT, emerged from the sea shaking in fear and mumbling about a "heap of dead naked people." He was among a group of Greek divers from the Eastern Mediterranean island of Symi who were searching for natural sponges. They had sheltered from a violent storm near the tiny island of Antikythera, between Crete and mainland Greece. When the storm subsided, they dived for sponges and chanced on a shipwreck full of Greek treasures—the most significant wreck from the ancient world to have been found up to that point. The "dead naked people" were marble sculptures scattered on the seafloor, along with many other artifacts. Soon after, their discovery prompted the first major underwater archaeological dig in history.

One object recovered from the site, a lump the size of a large dictionary, initially escaped notice amid more exciting finds. Months later, however, at the National Archaeological Museum in Athens, the lump broke apart, revealing bronze precision gearwheels the size of coins. According to historical knowledge at the time, gears like these should not have appeared in ancient Greece, or anywhere else in the world, until many centuries after the shipwreck. The find generated huge controversy.

The lump is known as the Antikythera mechanism, an extraordinary object that has befuddled historians and scientists for more than 120 years. Over the decades the original mass split into 82 fragments, leaving a fiendishly difficult jigsaw puzzle for researchers to put back together. The device appears to be a geared astronomical calculation machine of immense complexity. Today we have a reasonable grasp of some of its workings, but there are still unsolved mysteries. We know it is at least as old as the shipwreck it was found in, which has been dated to between 60 and 70 B.C.E., but other evidence suggests it may have been made around 200 B.C.E.

In March 2021 my group at University College London, known as the UCL Antikythera Research Team, published a new analysis of the machine. The team includes me (a mathematician and filmmaker); Adam Wojcik (a materials scientist); Lindsay MacDonald (an imaging scientist); Myrto Georgakopoulou (an archaeometallurgist); and two graduate students, David Higgon (a horologist) and Aris Dacanalis (a physicist). Our paper posits a new explanation for the gearing on the front of the mechanism, where the evidence had previously been unresolved. We now have an even better appreciation for the sophistication of the device—an understanding that challenges many of our preconceptions about the technological capabilities of the ancient Greeks.

ANCIENT ASTRONOMY

WE KNOW THE GREEKS of that era were accomplished naked-eye astronomers. They viewed the night sky from a geocentric perspective—every night, as Earth turned on its axis, they saw the dome of stars rotating. The stars' relative positions remained unchanged, so the Greeks called them the "fixed stars." These early astronomers also saw bodies moving against the background of stars: the moon goes through a rotation against the stars every 27.3 days; the sun takes a year.

The other moving bodies are the planets, named "wanderers" by the Greeks because of their erratic motions. They were the deepest problem for astronomy at the time. Scientists wondered what they were and noticed that sometimes the wanderers move in the same direction as the sun—in "prograde" motion—then come to a stop and reverse direction to move in "retrograde." After a while they reach another stationary point and resume prograde motion again. These rotations are called the synodic cycles of the planets—their cycles relative to the sun. The seemingly strange reversals happen because, as we know now, the planets orbit the sun—not, as the ancient Greeks believed, Earth.

In modern terms, all the moving astronomical bodies have orbits close to the plane of Earth's motion around the sun—the so-called ecliptic—meaning that they all follow much the same path through the stars. Predicting the positions of the planets along the ecliptic was very difficult for early astronomers. This task, it turns out, was one of the primary functions of the Antikythera mechanism. Another function was to track the positions of the sun and moon, which also have variable motions against the stars.

Much of the mechanism's design relies on wisdom from earlier Middle Eastern scientists. Astronomy in particular went through a

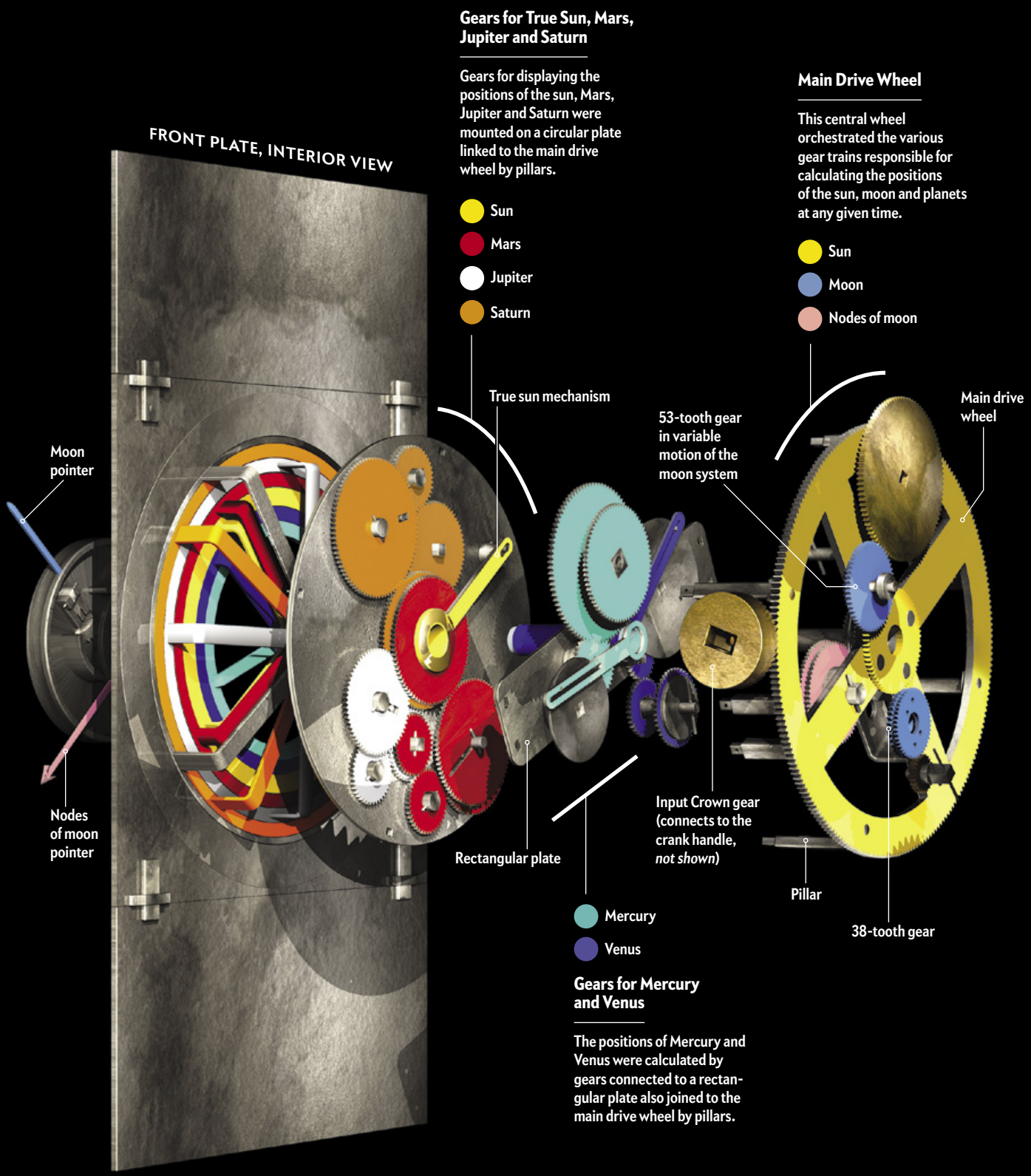
A Celestial Calculation Machine

Discovered more than a century ago in a shipwreck, the Antikythera mechanism is the most technologically complex object ever found from the ancient world. Likely dating back to between 205 and 60 B.C.E., the bronze device contains dozens of small gears with teeth about a millimeter long that were used to predict the positions of the sun, moon and planets at any chosen time. A recent study by the University College London Antikythera Research Team has proposed a new model of how the gearing on the front of the machine worked.

Front: Inside the device a "main drive wheel" turned all the gearing, which moved pointers and concentric rings displaying the positions of different celestial bodies. Small spheres showed the positions of the sun and moon and the phase of the moon. Colored beads marked the locations of the planets along the ecliptic, the plane of the solar system.

Back: The rear face contained two large dials, as well as some smaller ones. The large top dial was a calendar that represents the Metonic cycle, a 19-year period over which 235 moon phases recur. The large lower dial was the 223-month saros dial, which predicts the dates of solar and lunar eclipses.

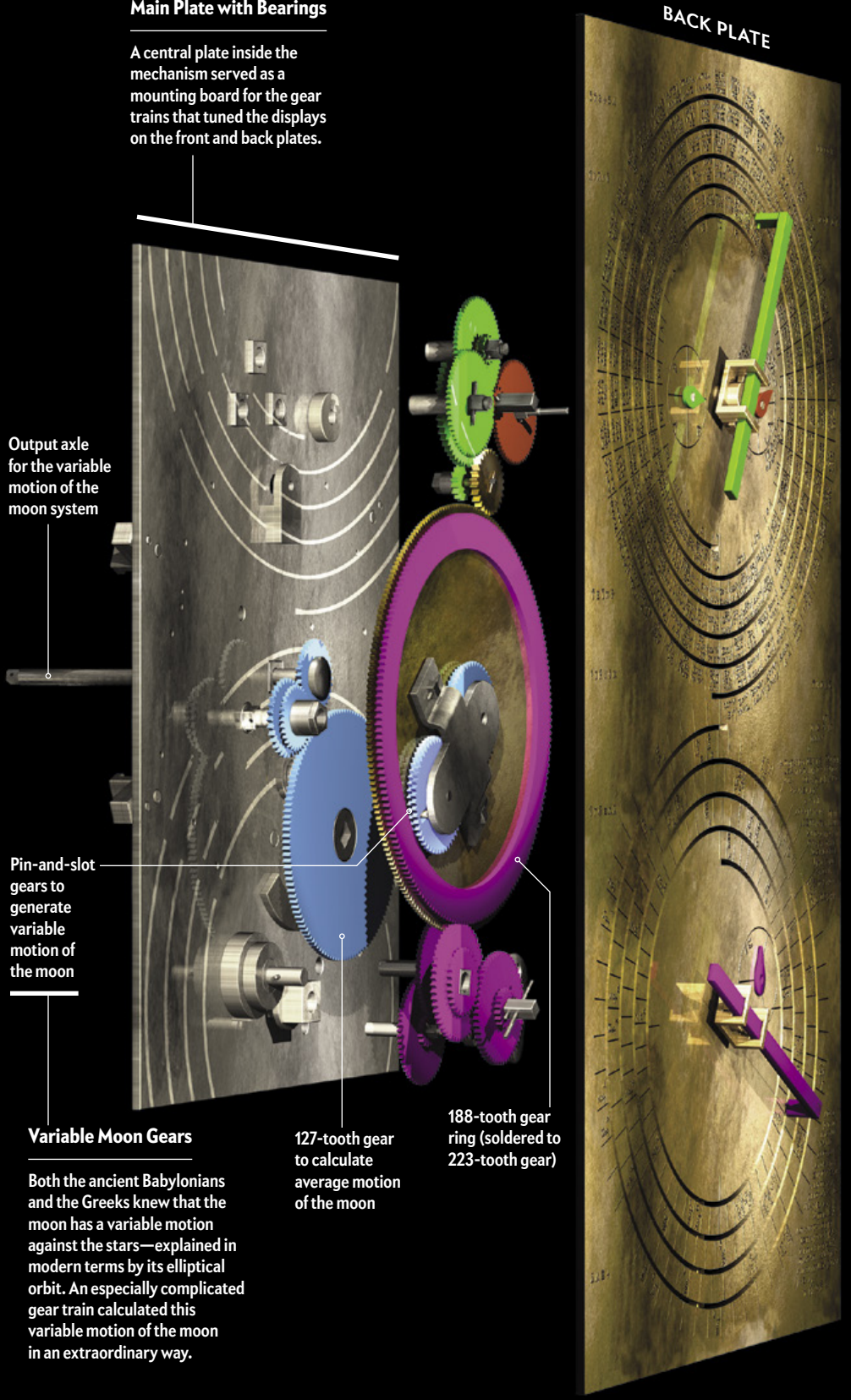
Graphic by Tony Freeth



Graphic by Tony Freeth and Jen Christiansen, Model by UCL Antikythera Research Team

INSIDE THE MACHINE

The new model of the Antikythera mechanism proposes a total of 69 gears, forming a shockingly complex astronomical calculation tool. Most of this complexity was hidden in the innards of the device, where trains of gears worked together on different calculations, and some gears served double duty for multiple purposes. From the outside, a user could turn a calendar dial to a desired point in the past, present or future, and the gears inside would move pointers and rings on the surface display to reveal celestial predictions.



transformation during the first millennium B.C.E. in Babylon and Uruk (both in modern-day Iraq). The Babylonians recorded the daily positions of the astronomical bodies on clay tablets, which revealed that the sun, moon and planets moved in repeating cycles—a fact that was critical for making predictions. The moon, for instance, goes through 254 cycles against the backdrop of the stars every 19 years—an example of a so-called period relation. The Antikythera mechanism's design uses several of the Babylonian period relations.

One of the central researchers in the early years of Antikythera research was German philologist Albert Rehm, the first person to understand the mechanism as a calculating machine. Between 1905 and 1906 he made crucial discoveries that he recorded in his unpublished research notes. He found, for instance, the number 19 inscribed on one of the surviving Antikythera fragments. This figure was a reference to the 19-year period relation of the moon known as the Metonic cycle, named after Greek astronomer Meton but discovered much earlier by the Babylonians. On the same fragment, Rehm found the numbers 76, a Greek refinement of the 19-year cycle, and 223, for the number of lunar months in a Babylonian eclipse-prediction cycle called the saros cycle. These repeating astronomical cycles were the driving force behind Babylonian predictive astronomy.

The Antikythera mechanism, with its precision gears bearing teeth about a millimeter long, is completely unlike anything else from the ancient world.

The second key figure in the history of Antikythera research was British physicist turned historian of science Derek J. de Solla Price. In 1974, after 20 years of research, he published an important paper, "Gears from the Greeks." It referred to remarkable quotations by Roman lawyer, orator and politician Cicero (106–43 B.C.E.). One of these described a machine made by mathematician and inventor Archimedes (circa 287–212 B.C.E.) "on which were delineated the motions of the sun and moon and of those five stars which are called wanderers … (the five planets) … Archimedes … had thought out a way to represent accurately by a single device for turning the globe those various and divergent movements with their different rates of speed." This machine sounds just like the Antikythera mechanism. The passage suggests that Archimedes, although he lived before we believe the device was built, might have founded the tradition that led to the Antikythera mechanism. It may well be that the Antikythera mechanism was based on a design by Archimedes.

FIENDISHLY COMPLEX

FOR DECADES RESEARCHERS were stuck trying to decipher the workings of the device by looking at the surface of its disintegrating fragments. In the early 1970s they finally got to peek inside. Price worked with Greek radiologist Charalambos Karakalos to obtain x-ray scans of the fragments. To their astonishment, the researchers found 30 distinct gears: 27 in the largest fragment and one each in three others. Karakalos, with his wife, Emily, was able to estimate the tooth counts of the gearwheels for the first time, a critical step in understanding what the mechanism calculated. The machine was looking more complicated than anyone had conceived.

The x-ray scans were two-dimensional, meaning that the structure of the gearing appeared flattened, and they revealed only partial pictures of most of the gears. Scientists could only infer the number of teeth on many of the gears. Despite these shortcomings, Price identified a gear train—a set of linked gears—that calculated the average position of the moon on any specific date by using its period relation of 254 sidereal rotations in 19 years. Driven by a prominent feature on the front of the mechanism called the main drive wheel, this gear train starts with a 38-tooth gear (two times 19, as a gear with just 19 teeth would be a bit too small). This 38-tooth gear drives (via some other gears) a 127-tooth gear (half of 254; the full number would require too large a gear).

It seems that the device could be used to predict the positions of the sun, moon and planets on any specific day in the past or future. The maker of the machine would have had to calibrate it with the known positions of these bodies. A user could then simply turn a crank to the desired time frame to see astronomical predictions. The mechanism displayed positions, for instance, on a "zodiac dial" on the front of the mechanism, where the ecliptic was divided into a dozen 30-degree sections representing the constellations of the zodiac. Based on the x-ray data, Price developed a complete model of all the gearing on the device.

Price's model was my introduction to the Antikythera mechanism. My first paper, in fact, "Challenging the Classic Research," was a comprehensive demolition of most of Price's proposed gearing structure for the machine. Nevertheless, Price correctly determined the relative positions of the major fragments and defined the overall architecture of the machine, with date and zodiac dials at the front and two large dial systems at the back. Price's achievements were a significant step in decoding the Antikythera mystery.

A third key figure in the history of Antikythera research is Michael Wright, a former curator of mechanical engineering at London's Science Museum. In collaboration with Australian professor of computer science Alan G. Bromley, Wright carried out a second x-ray study of the mechanism in 1990 using an early 3-D x-ray technique called linear tomography. Bromley died before this work bore fruit, but Wright was persistent, making important advances, for example, in identifying the crucial tooth counts of the gears and in understanding the upper dial on the back of the device.

In 2000 I proposed the third x-ray study, which was carried out in 2005 by a team of academics from England and Greece in collaboration with the National Archaeological Museum in Athens. X-Tek Systems (now owned by Nikon) developed a prototype x-ray machine to take high-resolution 3-D x-ray images using microfocus x-ray computed tomography (x-ray CT). Hewlett-Packard used a brilliant digital imaging technique called polynomial texture mapping for enhancing surface details.

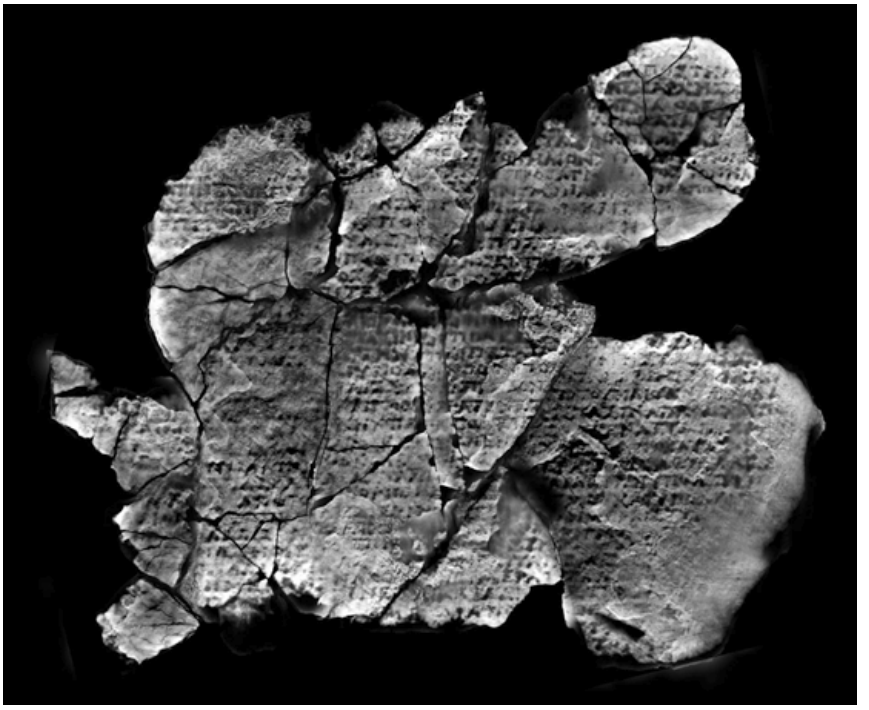
The new data surprised us. The first major breakthrough was my discovery that the mechanism predicted eclipses in addition to the motions of the astronomical bodies. This finding was connected to the inscription Rehm had found that mentioned the 223-month saros eclipse cycle. The new x-rays revealed a large, 223-tooth gear at the rear of the mechanism that turns a pointer around a dial that spirals out, making four turns in total that are divided into

223 sections, for 223 months. Named after the customary name of the Babylonian eclipse cycle, the saros dial predicts which months will feature eclipses, along with characteristics of each eclipse as described by inscriptions in the mechanism. The finding revealed an impressive new feature of the device, but it left a massive problem: a group of four gears lying within the circumference of the large gear that appeared to have no function.

It took months to understand these gears. When I did, the results were astonishing. These gears turned out to calculate the variable motion of the moon in a very beautiful way. In modern terms, the moon has variable motion because it has an elliptical orbit: when it is farther from Earth, it moves more slowly against the stars; when it is closer, it moves more quickly. The moon's orbit, however, is not fixed in space: the whole orbit rotates in a period of just under nine years. The ancient Greeks did not know about elliptical orbits, but they explained the moon's subtle motion by combining two circular motions in what is called an epicyclic theory.

I figured out how the mechanism calculated the epicyclic theory by building on a remarkable observation by Wright. He had studied two of the four mysterious gears at the back of the mechanism. He saw that one of them has a pin on its face that engages with a slot on the other gear. It might seem to be a useless arrangement because the gears will surely just turn together at the same rate. But Wright noticed that the gears turn on different axes separated by just over a millimeter, meaning that the system generates variable motion. All these details appear in the x-ray CT scan. The axes of the gears are not fixed—they are mounted epicyclically on the large 223-tooth gear.

Wright discarded the idea that these gears calculated the moon's variable motion because in his model, the 223-tooth gear turned much too fast for it to make sense. But in my model, the 223-tooth gear rotates very slowly to turn the pointer for the saros dial. Calculating the epicyclic theory of the moon with epicyclic pin-and-slot gears in this subtle and indirect way was an extraordinary conception by the ancient Greeks. This ingenuity reinforces the idea that the machine was designed by Archimedes. This research on the back dials and gearing completed our understanding of the back of the mechanism, reconciling all the evidence to date. My colleagues and I published our findings in 2006 in *Nature*. The other side of the device, however, was still very much a mystery.



HIDDEN MESSAGE: X-ray CT scans made in 2005 revealed previously unseen inscriptions on the Antikythera mechanism, including a list of planetary cycles on the front cover (*shown here*) and a "user's manual" on the back cover.

THE FRONT OF THE MECHANISM

THE MOST PROMINENT FEATURE of the front of the largest fragment is the main drive wheel, which was designed to rotate once a year. It is not a flat disc like most of the other gears; this one has four spokes and is covered in puzzling features. The spokes show evidence that they held bearings: there are circular holes in them for turning axles. The outer edge of the gear contains a ring of pillars—little fingers that stick up perpendicularly, with shoulders and pierced ends that were clearly intended to carry plates. Four short pillars held a rectangular plate, and four long pillars held a circular plate.

Following Price, Wright proposed that an extensive epicyclic system—the two-circles idea the Greeks used to explain the odd reversing motions of the planets—had been mounted on the main drive wheel. Wright even constructed an actual model gearing system in brass to show how it worked. In 2002 he published a groundbreaking planetarium model for the Antikythera mechanism that displayed all five planets known in the ancient world. (The discovery of Uranus and Neptune in the 18th and 19th centuries, respectively, required the advent of telescopes.) Wright showed that the epicyclic theories could be translated into epicyclic gear trains with pin-and-slot mechanisms to display the planets' variable motions.

When I first saw Wright's model, I was shocked by its mechanical complexity. It even featured eight coaxial outputs—tubes all centered on a single axis—that brought information to the front display of the device. Was it really plausible that the ancient Greeks could build such an advanced system? I now believe that Wright's conception of coaxial outputs must be correct, but his gearing system does not match the economy and ingenuity of the known gear trains. The challenge our UCL team faced was to reconcile Wright's coaxial outputs with what we knew about the rest of the device.

One crucial clue came from the 2005 x-ray CT study. In addition to showing the gears in three dimensions, these scans made an unexpected revelation—thousands of new text characters hidden inside the fragments and unread for more than 2,000 years. In his research notes from 1905 to 1906, Rehm proposed that the positions of the sun and planets were displayed in a concentric sys-

tem of rings. The mechanism originally had two covers—front and back—that protected the displays and included extensive inscriptions. The back-cover inscription, revealed in the 2005 scans, was a user manual for the device. In 2016 Alexander Jones, a professor of the history of astronomy at New York University, discovered definitive evidence for Rehm's idea within this inscription: a detailed description of how the sun and planets were displayed in rings, with marker beads to show their positions.

Any model for the workings of the mechanism should match this description—an explanation literally inscribed onto the back cover of the device describing how the sun and planets were displayed. Yet previous models had failed to incorporate this ring system because of a technical problem that we could not solve. Wright had discovered that the device used a semisilvered ball to show the phase of the moon, which it calculated mechanically by subtracting an input for the sun from an input for the moon. But such a process appeared to be incompatible with a ring system for displaying the planets because the outputs for Mercury and Venus prevented the moon-phase device from accessing the input from the sun gear system. In 2018 Higgon, one of the graduate students on our UCL team, came up with a surprisingly simple idea that neatly fixed this technical problem and explained a mysterious pierced block on one of the spokes of the main drive wheel. This block could transmit the "mean sun" rotation (as opposed to the variable "true sun" rotation) directly to the moon-phase device. This setup enabled a ring system for the front of the Antikythera mechanism that fully reflected the description in the back-cover inscription.

In trying to decipher the front of the device, it was imperative to identify the planetary cycles built into the mechanism because they define how the gear trains calculated planetary positions. Earlier research assumed that they would be based on the planetary period relations derived by the Babylonians. But in 2016 Jones made a discovery that forced us to discard that assumption.

The x-ray CT of the front-cover inscription shows it is divided into sections for each of the five planets. In the Venus section, Jones found the number 462; in the Saturn section, he found the number 442. These numbers were astonishing. No previous research had suggested that ancient astronomers knew them. In fact, they represent more accurate period relations than the ones found by the Babylonians. It seems that the makers of the Antikythera device discovered their own improved period relations for two of the planets: 289 synodic cycles in 462 years for Venus and 427 synodic cycles in 442 years for Saturn.

Jones never figured out how the ancient Greeks derived both these periods. We set out to try ourselves. Dacanalis, our other UCL graduate student, assembled a comprehensive list of the planetary period relations and their estimated errors from Babylonian astronomy. Could combinations of these earlier relations be the key to the more accurate Antikythera period relations? Eventually we found a process, developed by philosopher Parmenides of Elea (sixth to fifth century B.C.E.) and reported by Plato (fifth to fourth century B.C.E.), for combining known period relations to get better ones.

We proposed that any method the Antikythera creators used would have required three criteria: accuracy, factorizability and economy. The method must be accurate to match the known period relations for Venus and Saturn, and it must be factorizable so the planets could be calculated with gears small enough to fit into the mechanism. To make the system economical, different planets could share gears if their period relations shared prime factors, reducing the number of gears needed. Such economy is a key feature of the surviving gear trains. Based on these criteria, our team derived the periods 462 and 442 using the idea from Parmenides and employed the same methods to discover the missing periods for the other planets where the inscriptions were lost or damaged.

Armed with the period relations for the planets, we could now understand how to fit the gear trains for the planets into the tight spaces available. For Mercury and Venus, we theorized economical five-gear mechanisms with pin-and-slot devices, similar to Wright's mechanisms for these planets. We found strong supporting evidence for our reconstruction in one four-centimeter-diameter fragment. Inside this piece, the x-ray CT shows a disk attached to a 63-tooth gear, which turns in a D-shaped plate. The number 63 shares the prime factors 3 and 7 with 462 (the Venus period). A gear train using the 63-tooth gear could be designed to match a bearing on one of the spokes of the main drive wheel. A similar design for Mercury matches the features on the opposite spoke. These observations gave us great confidence that we were on the right track for Mercury and Venus.

For the other known planets—Mars, Jupiter and Saturn—our team conceived of very compact systems to fit the available space. These designs were a radical departure from Wright's systems for these planets. Working independently, Christián C. Carman of the National University of Quilmes in Argentina and I had shown that the subtle indirect gearing system for the variable motion of the moon could be adapted for these planets. Our UCL team proved that these gearing systems could be extended to incorporate the new period relations for the planets. This system allowed the Antikythera makers to mount several gears on the same plate and design them to precisely match the period relations.

These economical seven-gear trains could intricately interleave between the plates on the pillars of the main drive wheel so that their outputs conformed to the customary cosmological order of the celestial bodies—moon, Mercury, Venus, sun, Mars, Jupiter and Saturn—that determines the layout of the ring system. The dimensions of the available spaces between the plates were exactly right to accommodate these systems, with some spare capacity and some evidence still unexplained.

We added a mechanism for the variable motion of the sun and an epicyclic mechanism for calculating the "nodes" of the moon—the points at which the moon's orbit cuts through the plane of the ecliptic, making an eclipse possible. Eclipses happen only when the sun is close to one of these nodes during a full or new moon. Medieval and renaissance astronomers called a double-ended pointer for the nodes of the moon a "dragon hand." The epicyclic gearing for this dragon hand also exactly explained a prominent bearing on one of the spokes that had previously appeared to have no function. We had finally explained all the features on the main drive wheel; we published our findings in March 2021 in *Scientific Reports*.

A BEAUTIFUL CONCEPTION

WE NOW UNDERSTOOD HOW the front display matched the description in the back-cover user's manual, with the sun and planets shown by marker beads on concentric rings. The front cover also displayed the moon's phase, position and age (the number of days from a new moon), and the dragon hand that showed eclipse years and seasons.

With the concentric rings for the planets, we realized that we could now make sense of the front-cover inscription as well. This

FRAGMENTS: Over the years the original mass of the Antikythera mechanism has split into 82 pieces. Figuring out how they all fit together has been a challenging puzzle for researchers. The largest fragment (*top left*) holds the main drive wheel.

writing is a formulaic list of the synodic events of each planet (such as its conjunctions with the sun and its stationary points) and the intervals in days between them. On the back plate, the eclipse inscriptions are indexed to markings on the saros dial. On the front plate, inscriptions about the risings and settings of stars are indexed to the zodiac dial. Our insight was that the inscriptions on the front could refer to index letters on the planetary rings: if the sun pointer is at one of these letters, then the corresponding inscription entry describes the number of days to the next synodic event. Because the left-hand side of the inscription, where we would expect these index letters to be, is missing, we cannot prove the hypothesis—but it is a compelling explanation.

The device is unique among discoveries from its time. It singlehandedly rewrites our knowledge of the technology of the ancient Greeks. We knew they were highly capable—they built the Parthenon and the Lighthouse of Alexandria even earlier than the Antikythera mechanism. They had plumbing and used steam to operate equipment. But before the discovery of the Antikythera mechanism, ancient Greek gears were thought to be restricted to crude wheels in windmills and water mills. Aside from this discovery, the first precision-geared mechanism known is a relatively simple—yet impressive for the time—geared sundial and calendar of Byzantine origin dating to about C.E. 600. It was not until the 14th century that scientists created the first sophisticated astronomical clocks. The Antikythera mechanism, with its precision gears bearing teeth about a millimeter long, is completely unlike anything else from the ancient world.

Why did it take centuries for scientists to reinvent anything as sophisticated as the Antikythera device, and why haven't archaeologists uncovered more such mechanisms? We have strong reasons to believe this object can't have been the only model of its kind—there must have been precursors to its development. But bronze was a very valuable metal, and when an object like this stopped working, it probably would have been melted down for its materials. Shipwrecks may be the best prospects for finding more of them. As for why the technology was seemingly lost for so long before being redeveloped, who knows? There are many gaps in the historical record, and future discoveries may well surprise us.

With the Antikythera mechanism, we are clearly not at the end of our story. We believe our work is a significant advance, but there are still mysteries to be solved. The UCL Antikythera Research Team is not certain that our reconstruction is entirely correct because of the huge loss of evidence. It is very hard to match all of the surviving information. Regardless, we can now see more clearly than ever what a towering achievement this object represents. SA

FROM OUR ARCHIVES

Decoding an Ancient Computer. Tony Freeth; December 2009.

scientificamerican.com/magazine/sa

INSIDE AMERICA'S MILITIAS

SOCIOLOGY

In some members, longing for a fictional "simpler" national past can transform into violence and hatred

By Amy Cooter

Illustrations by Mark Smith

Amy Cooter is a senior lecturer in sociology at Vanderbilt University who has been studying militias as well as extremist groups for 16 years. Her analysis of neo-Nazis was published in *Sociological Inquiry* in 2006. She has testified before the U.S. Congress about her fieldwork in militia movements and how hate groups attempt to recruit military veterans.

"IS THIS FIELD DAY?" I ASKED THROUGH MY CAR WINDOW ON A CHILLY, RAINY APRIL MORNING IN central Michigan in 2008. A lone man dressed in head-to-toe camouflage, whose hand was casually resting on an AK-47 rifle strapped across his chest, nodded and stepped aside on the narrow road. I drove ahead to a parking area next to an old, red brick farmhouse and several acres of soybeans. About 50 people were gathering at a spot where the fields met a wooded bog. I was outside the village of Bancroft, at what was indeed the Michigan Militia's annual Field Day event. The group described it as a family and public outreach opportunity, held on private land that was owned by a World War II veteran.

Wood smoke drifted through the air from a campfire; some members were already loudly joking about the unpleasantness of the weathered, tarp-covered outhouse at the site, good-naturedly bemoaning the decision to not rent portable toilets as they had done the year before. A few of the men were already tearing open MREs—meals ready to eat that are packaged, high-calorie food typically issued to soldiers but also available at military surplus stores and on eBay.

Almost all the men were wearing some degree of camouflage and were laughing as they showed off new firearms, tactical vests or other equipment and told stories about past training events. The comparatively few women and children in attendance were more subdued and usually dressed in casual clothes rather than camo. Still, most of them participated in target shooting and other activities of the day.

This was the third militia event I had attended. I am a sociologist, and at that time I was a graduate student at the University of Michigan just beginning in-depth fieldwork and interview research about the militia movement in the U.S. I had approached members of this group a month earlier during a public meeting at a strip mall diner because I wanted to understand why people join civilian groups that prepare for armed combat, and I planned to examine whether militias propagate racism and violence. My fieldwork in Michigan, as well as in-depth interviews that included groups in other states, continued through 2013. Since then, I have maintained regular contact with militia members, especially in Michigan, and they update me with their activities and responses to political and social events. We regularly speak about their values and their motivations. I follow their online posts. Last summer I conducted a survey asking members what they thought about protests related to COVID social restrictions and George Floyd's murder in Minnesota.

I have learned that there is important variation across militia groups. They fall on a spectrum. At one end are units whose activities are largely limited to outings for "grown-up Boy Scouts," as several members described themselves at the Field Day event I went to years ago. At the other end are units that are openly angry, whose members plot violence against government officials and advocate overt white supremacy. Some of the latter stormed the U.S. Capitol on January 6, 2021. The more extremist militia bands tote guns in public, wear military garb and endorse various conspiracy fantasies. They have confronted racial justice activists and protested pandemic public health measures in many states. In Michigan, people in one militia splinter group were arrested in 2020 and charged with plotting to kidnap Governor Gretchen Whitmer in retaliation for a perceived failure to uphold individual liberties.

Across this spectrum, however, militia groups share certain similarities. Their members are almost exclusively white men, and they espouse values of nationalism as well as yearnings to restore "better times" from this country's past. I and other sociologists refer to them as nostalgic groups. Their values are often entwined with racist and sexist attitudes, in part because they deny or disregard the hostility directed at minority groups and women during that idealized history. A metaphor I like to use to explain the connection across these groups is that it is like having multiple trees on the same small plot of land. They are separate entities, but their roots grow in the same soil. Their branches intermingle when the wind blows just right, occasionally getting close enough so that you cannot tell where one tree stops and another begins.

That shared soil—this idealization of an imaginary past with greater freedom—creates a way for members and even some entire units to move across this spectrum. They can start off merely telling stories around a campfire but over time turn to conspiratorial thinking, open hostility or even violent action. I have observed an increase in extremism in recent years, with people who used to focus on camaraderie and preparedness at militia events now echoing claims that the insurrection at the Capitol was nothing more than a protest. Others repeatedly posted on social media about the need to personally "do something" about the supposedly stolen presidential election. Members making this shift were on edge in 2020, believing their core values of individualism and self-determination have been threatened by racial justice movements, the pandemic and efforts to control it and by what they claimed—falsely—was fraudulent voting.

Many of these people heard their fears reinforced through right-wing news media and Donald Trump's rhetoric about threats from immigrants and corrupt Democrats. The most apprehensive members possess stronger racist or xenophobic attitudes and are more prone to move toward the extreme end of the spectrum. They are susceptible to appeals from hate groups such as the Proud Boys or overt neo-Nazis, believing that despite differences they all share the overarching value of protecting what they see as America's foundation.

I GREW UP IN A CONSERVATIVE, rural, East Tennessee community where firearms for hunting, target practice and personal protection are part of the culture. As a child, I learned gun safety and basic marksmanship, witnessed my father shoot and kill a rabid coyote that was trying to eat my pet rabbit, and, when I was old enough to legally do so, obtained my concealed carry permit. My background gave me a greater familiarity with firearms and the people who use them than other social scientists who have studied militia groups exclusively via media reports or online message boards. Militia members invited me to private trainings and other events very early in my fieldwork and openly talked to me about their beliefs, values and motivations.

MILITIA MEMBERS were among those drawn to the Capitol insurrection on January 6, 2021.

Tayfun Coskun/Anadolu Agency via Getty Images

No one really knows how many civilian militia groups exist because they repeatedly form, splinter into separate units and dissolve, as members' interests wax and wane. Typical units have no more than 20 or so members who consistently attend events, but some have only two people, and others have more than 200. In addition to the heavy skew toward white males—at least 90 percent in most groups—most participants are in their late 20s or early 30s, although I have known of members as young as 18 and as old as 70. There are a few women who fully participate in militias, and because of their activity they tend to be well respected and rise to leadership roles. (Jessica Watkins, a leader of an Ohio militia who was arrested for her participation in the Capitol riot, is one example.) Still, most militia units have a culture suffused with casual misogyny.

People in militias believe it is their constitutional duty as good Americans to be heavily armed and prepared to defend themselves, their families and their

country against threats ranging from natural disasters to foreign invasion. They join to practice and share skills related to target shooting, land navigation and general emergency preparedness. Many members first learned these skills in the military. One 27-year-old man, who had a regular job as a customer service representative, told me that his militia participation was about "serving the public, wanting to do [his] part for the community." He proposed ideas for his group such as organizing fundraisers to help people who had lost their jobs. Members like him saw their militia involvement as simply another form of neighborly support and a means to connect to other people with similar values.

These people look to the American Revolution as their ideal historical moment and view the Founding Fathers as nearly impeccable paragons whose perceived individualism, fearlessness and rebellion should be emulated today. A longtime leader of the Southeast Michigan Volunteer Militia told me in numerous conversations that contemporary militia membership is purely about following the standard set by the Founding Fathers to uphold the Constitution—a refrain frequently repeated by other members at public militia gatherings I attended. He told me, "Look, as a people, we really need to get back to our roots, and we need to be a little better armed, and we need to understand that, you know, that's how you secure your society and that's how you keep it free is by having armed citizens." He went on to say he was "really inspired" by the courage of militia founders. He said those people were "labeled as radicals and extremists [when] all they were doing is quoting the Constitution."

Militia members often told me they long for a "simpler time," when they insist that individuals—especially men—took more responsibility for working and providing for their families, where the federal government was smaller and not a substitute for self-sufficiency the way they perceive it to be today.

In their vision of the past, members generally ignore the oppression of people from nonwhite backgrounds that is part of American history. Very few militia members I encountered were openly racist. Some units even made regular but unsuccessful attempts to recruit nonwhite members and included messages on their Web sites intended to convey inclusivity. This was the leading statement on the Southeast Michigan Volunteer Militia's site until they stopped maintaining it about five or six years ago: "Everyone is welcome, regardless of race, creed, color, religion or political affiliation, provided you do not wish to bring harm to our country or people. If you are a United States citizen (or have declared your intent to become such), who is capable of bearing arms, or supports the right to do so, then YOU ARE the MILITIA!"

In conversations, militia participants do not appear to be aware that racism is broader than the undisguised, legalized segregation of the past or the continued hatred from open white supremacists. Most have limited understanding of how systematic racism prevents equal economic attainment or equal access to quality health care or educational opportunities.

For example, one member, a 56-year-old white man, a lifelong Detroit resident who worked in IT, blamed what he described as the "downfall" of his city on "forced busing" that happened in the wake of the civil rights movement and was intended to help equalize school opportunity. Opposition to busing has a history of open racism, but this man was trying to make a different argument. He said he believed both Black and white families resented the busing policy, which required children to go to school far away from home and spend a lengthy time in transit. He said dislike of the policy made Black and white "good workers" abandon the city, leaving behind comparatively lazy workers and disengaged citizens of both racial groups.

He showed little comprehension of why his argument did not apply to Black families who cannot pick up and move elsewhere for a variety of reasons, including financial barriers such as lower home values, caused by long-standing discrimination in lending and real estate markets. The depressed prices prevent them from selling a house and then buying one in a better school district. Nor did this militia member understand that Black families might have embraced busing rather than resenting it: it was an opportunity to send their children to superior schools in a city that had historically neglected them.

Members of militias, in my analysis, show what sociologists call "modern racism," where they endorse ideas of cultural inferiority rather than biological deficiency. In one of the more conspicuous examples I encountered, an interviewee told me he was not "outright" racist and that he had good Black friends before going on to say that some Black people made him uncomfortable. "I guess when you see a group of them [young Black men] dressed up or somethin' and they're hippin' and hoppin' at a corner.… It's just that … I don't know, I guess it's just because I don't know them." His comment reflects stereotypical notions that treat groups of Black men as "otherized"—as different from his friendly group and as vaguely threatening, even though he did recognize his lack of personal connection to them might be a factor in his negative perceptions.

Whiteness and masculinity are central features—though often not clearly obvious ones—in the rearview nationalism of militia members' values. Their nostalgic stories hinge on archetypes of independent, brave men whose heroic efforts were responsible for establishing a nation as these groups wish it to be again. Those men are always white. Groups vary in the extent to which they understand and embrace the race- and gender-biased elements of this narrative.

Sociologist Ruth Braunstein of the University of Connecticut noted in a recent article examining the intersections of religion, race, and nationalism that nostalgic groups take advantage of a "cultural power of whiteness" and "thus write themselves into their American story as the patriotic heroes who will alter the course of the country's decline by urging a return to the conditions of the past."

Historian Robert Churchill of the University of Hartford has developed a two-part typology that distinguishes between "constitutionalist" and "millenarian" militias and that has been invaluable for understanding how this kind of aggressive and selective nostalgia enables people to move to more extreme and violent groups. Constitutionalist groups, Churchill says, believe it is their personal responsibility to uphold an originalist interpretation of the Constitution focused on a heavily limited government. They see themselves as law-abiding patriots whose presence limits the overreaching actions of central authorities.

I found this in my research as well. One constitutionalist group leader told me he believed that public demonstrations by militia units "remind the government that they serve the people and not the other way around"; he indicated that he believes militia units visibly exercising their Second Amendment rights to carry weapons keeps the U.S. government from moving toward tyranny.

Millenarian militias, in contrast, take an offensive stance against governments and are generally more open to violent action. Their focus during meetings is less on self-sufficiency and bonding while target shooting. They spend more time on conspiratorial speculations about ways the government must be interfering in their lives and fantasize about exacting retribution for those actions.

For example, one millenarian member told me that his reason for militia membership was "revenge." He was a Desert Storm veteran who believed that the war in Iraq had been conducted under false pretenses and that the U.S. government had experimented on him and his fellow soldiers. He claimed this experimentation led to others in his unit dying early from cancer and other diseases and having high rates of children with birth defects. He said he had chosen not to have children of his own because he feared that outcome. His fear and bitterness led him to believe the government might persecute him for talking about his experiences, and he emphasized that he welcomed the fight. Although precise motivations for hating the government varied, this general attitude of anticipating and even yearning for a violent confrontation was common in millenarian members I encountered. About a year and a half after I interviewed this man, several members of his militia, which called themselves the Hutaree, were arrested and charged with crimes related to an alleged plot to kill Michigan police officers.

IN BOTH MY AND CHURCHILL'S estimations, for most of the early 2000s militias in the U.S. were about 90 percent constitutionalist groups and 10 percent millenarian groups, and most posed little threat of violence. But that proportion has shifted toward extremism in the past decade, we both believe, as members feel increasingly fearful of changing social conditions in a variety of areas—immigration, the pandemic, protests against police shootings of Black people and the presidential election—fears which Trump directly stoked.

Churchill says it "seems the millenarian wing has come to the fore." Even though the exact millenarian percentage in the movement is difficult to judge, his observation resonates with what I have seen. Constitutionalist groups that previously ridiculed conspiracy fantasies have pivoted to saying things like they were "monitoring" or "researching" claims from the far-right conspiracy movement QAnon, even as they denied fully embracing them. They share posts that prophesized terrorist attacks that never came to be. They pass around fake news stories about people in the antifa (antifascist) movement traveling on buses to locations all over the country and setting fires to stoke general chaos. One of the most common forays into conspiracy fantasies that I saw militias across the country post to social media pages leading up to the 2020 election were images of Joe Biden being affectionate with his granddaughter or other children. These were presented as purported "proof" of QAnon theories about pedophilia in Democratic leadership.

In 2020 some militias became more willing to bump shoulders with fundamentally racist groups in an effort to maintain their vision of America.

During racial justice protests and the stress of the pandemic in 2020, some militias became more willing to figuratively and literally bump shoulders with fundamentally racist nostalgic groups in an effort to maintain their vision of America. They stood together in public. I watched militia members discuss online some shared interests with previously adversarial groups. A member of an Indiana unit advocated on his social media posts for "loyal Americans" to work together to "take back" a civil rights protest zone in Seattle that had declared autonomy from the city. He believed stories that anarchists were planning to take over other American cities if such zones were left unchallenged. Some members who responded to my

2020 survey felt COVID-related restrictions were unacceptable state control. A few had similar objections to state power when police broke up social justice demonstrations, but many believed such protests were really orchestrated by antifa and needed to be opposed.

Recently I have observed some constitutionalist members embracing such fear-driven ideas and rapidly drifting into the millenarian framework or even beyond, while sometimes taking other members with them. There was a disturbing example of this dangerous transition when some members of the large, public Michigan Liberty Militia splintered off to form a group called the Wolverine Watchmen. Then they recruited other people who had not previously been affiliated with the Liberty group. In spring 2020, according to court documents, the Watchmen plotted a coup of the Michigan governorship, angered by state restrictions on activities enacted to reduce the spread of COVID. Militia members said such orders were a red-line infringement on civil liberties. Details of the case are still emerging, but it appears that the Watchmen formed and radicalized after discovering that the Liberty Militia was not violent enough for its goals.

This case is similar to another that received much less national attention. Shortly before the 2016 election, three militia members were accused (and ultimately convicted) of plotting to bomb a Somali refugee community. Lawyers for the accused men suggested that they had been moved beyond merely complaining about immigrants into planning actions to harm them because then candidate Trump's anti-immigrant rhetoric legitimized their fears about threats to America from Muslim outsiders.

The January 6 insurrectionists also seem to embody a movement toward extremism. Participants believed they needed to "Stop the Steal" and do something to prevent their preferred candidate and their vision of the nation from slipping away. The incursion was a mass act of violence and a clear escalation from the disgruntled chatter about supposed election fraud that many had observed during the prior several months. What is more, this was radicalization that extended beyond the boundaries of militia or other nostalgia groups. Many insurrectionists at the Capitol were previously unaffiliated.

Although federal law-enforcement attention has had a cooling effect, other people inspired by events at the Capitol may now seek out the more violent nostalgic groups for future action. Churchill told me that "there is convergence of apocalypticism, coming from the [militia] movement, and from QAnon, and from Evangelical Christianity. What we really saw on January 6 was not just the [militia] movement but a whole broader phenomenon."

To those of us who have studied militias for a long time, that phenomenon unfortunately has the feel of the 1990s, where nostalgic groups were more on edge, "less rational, a lot more emotional," as a long-term militia leader—a government employee—told me. Groups were ready to fight the state, and they feared the state was about to attack them after law-enforcement sieges in Waco, Tex., and Ruby Ridge, Idaho. The charged environment fostered men like Timothy McVeigh, who killed 168 people in a devastating act of domestic terrorism in Oklahoma City in 1995.

THERE ARE VERY FEW positive ways to look on the most recent developments. Perhaps one is that our country in general seems to have a greater awareness of the need to take militias and other nostalgic groups seriously. The House Committee on Veterans Affairs asked me and other experts to testify in October 2021 about extremist groups recruiting military veterans to their ranks. Various nostalgic bands have openly sought to recruit veterans for decades in part because they represent a commitment to the nation that can attract other new recruits. Extremist factions may also desire to use veterans' military skill sets for violent activities. Congressional investigations into these scenarios are long overdue as is serious research into how veterans, especially those disenchanted with their service experiences, can be better supported and discouraged from radicalization.

Speculating on how militias may evolve in the future under increased scrutiny is difficult, in no small part because the units are still adapting to the aftermath of Trump's presidency. In contrast to what many members had predicted, they did not see President Biden enact martial law or start an immediate attack on Second Amendment rights. Millenarian militias and other groups on the extreme end of the nostalgic group spectrum nonetheless remain vigilant, and some are eager for violence. Members may be plotting deadly actions, but now they are on increasingly private and secure Internet platforms that are more difficult to monitor.

So the reality is that the danger has not abated. Quite the opposite: Militia emotions and activity could be easily exacerbated by another political leader who encourages exclusionary thinking and paranoia or by a foreign terrorist attack that nostalgic groups perceive as threatening to America's safety or culture.

Law enforcement must remain watchful for signs of radicalization in the movement, but as uncomfortable as it is, we as a society also must recognize that militias' violent potential is not limited to these groups. They are not fluke outliers. Members share ideological similarities with other white Americans who distrust the government and believe the country has declined because of increasing liberalism. Much work remains to repair the distrust and to protect innocent people from the violence that it breeds. SA

FROM OUR ARCHIVES

Extinguishing the Threat. Kevin Dutton and Dominic Abrams; *Scientific American Mind,* May 2016.

scientificamerican.com/magazine/sa

Dawn of the Din

EVOLUTION

For billions of years Earth was quiet. Then animals started making a ruckus

By Michael B. Habib

Illustration by Sam Falconer

Michael B. Habib is a paleontologist and biomechanist at the Natural History Museum of Los Angeles and the Greater Los Angeles Zoo Association. He studies the anatomy and motion of pterosaurs, birds and feathered dinosaurs.

WE TAKE IT FOR GRANTED THAT VIRTUALLY EVERY HABITAT ON EARTH IS ALIVE with the sounds of animals, from the haunting songs of whales in the oceans to the riotous symphony of birds, frogs and insects in forests to the hubbub of humans and our technological creations in cities the world over. Yet for most of our planet's history the only sounds were those of the wind, rain and waves.

In my work as a paleontologist, I seek to understand the lives of extinct animals—how they moved, what they ate, the sounds they might have made. I also serve as an animation and creature-design consultant for exhibits, television, movies and games. Among the most common topics I have been asked to tackle for these projects are those pertaining to animal sounds. Whether someone is reconstructing long-vanished pterosaurs for an academic study or designing a creature for a blockbuster film, sound is paramount in bringing both past and imaginary worlds to life.

Recent insights into the evolution of animal acoustics have led to a new understanding of how our modern-day soundscapes came to be. Fossils reveal when the major types of sound-production—and sound-detection—structures appeared in the forerunners of today's invertebrate and vertebrate creatures. And in some cases, clever modeling has allowed scientists to re-create the ancient sounds themselves. Many details remain to be worked out, but we can now begin to piece together the dawn of the din.

BREAKING THE SILENCE

THE FOSSIL RECORD INDICATES that life on Earth got its start 3.7 billion years ago. But those earliest organisms—including microbes and, much later, soft-bodied animals similar to today's jellies—were a quiet bunch. It was not until the evolutionary burst that occurred in the Cambrian period, between 541 million and 485.4 million years ago, that animals acquired some basic sound-making behaviors related to locomotion and predation. Yet even then the hush under water, where these creatures lived, was probably punctuated only by the skittering of arthropod feet across sand or the faint grinding of a cephalopod breaking a shell. Meanwhile the terrestrial realm remained essentially silent. More than 200 million years passed before the buzzing of insects started to fill the air, giving rise to an entirely new acoustic world.

The oldest-known putative insect dates to 408 million years ago and was probably soundless and deaf. Scientists do not know exactly when insects started to first make or hear sounds, but the fossil record provides a minimum date: a katydid from around 250 million years ago has the sound-producing anatomy characteristic of this group. The earliest-known fossils of cicada relatives also date to this time. These insects can generate exceptionally loud sounds by rapidly buckling and unbuckling drumlike structures on their bodies called tymbals. The sound-production structures are so well preserved in some insect fossils that researchers can reconstruct the songs the creatures sang in life. In 2011 a team led by Jun-Jie Gu, now at Sichuan Agricultural University in China, worked out that a specific ancient katydid emitted songs tuned to a frequency of 6.4 kilohertz, which is roughly an octave higher than Mariah Carey's highest recorded note.

For these earliest buzzing insects, the advantages of producing and hearing sound would have been numerous. They could communicate over distances, hear predators approach and perhaps even lure prey by mimicking the sounds of a target animal's potential mate. Sound offered a new means of attracting mates and in so doing gave rise to a new kind of biological battle: the evolution of the loudest.

Vertebrates probably began experimenting with sound in some limited form around the same time that insects started buzzing and chirping. Today's amphibians, reptiles and mammals all possess a larynx, or voice box, near the top of their airway. This fact suggests they inherited it from their last common ancestor, which would mean the larynx is nearly as old as land vertebrates themselves, going back 300 million years or so. It probably took millions of years for truly specialized or powerful vocalizations to evolve in these animals, however. Little is known about these early stages of vertebrate vocalization, not least because the larynx is made up of cartilage, which generally does not preserve well.

What we do know is that starting roughly 230 million years

ago, during the Mesozoic era, vertebrate animals evolved a wide range of vocal abilities. That is when the world became truly loud. For example, frogs, with their rich repertoire of calls and songs, first showed up in the Mesozoic. Mammals also debuted around this time, and their characteristic chirps, growls and hisses probably evolved early on. Although we do not have much direct evidence of the sound-production apparatus in early mammals, we do have an exciting fossil record of their ears. The mammalian ear is unique, with three tiny bones in the middle ear, two of which are derived from bones that make up the jaw in most other vertebrates. These special ears are quite good at hearing high-frequency sounds, which could have helped the mammals find buzzing insect prey. These mammals might also have been capable of producing high-frequency sounds, allowing individuals to communicate with one another in a frequency range that few other animals could detect.

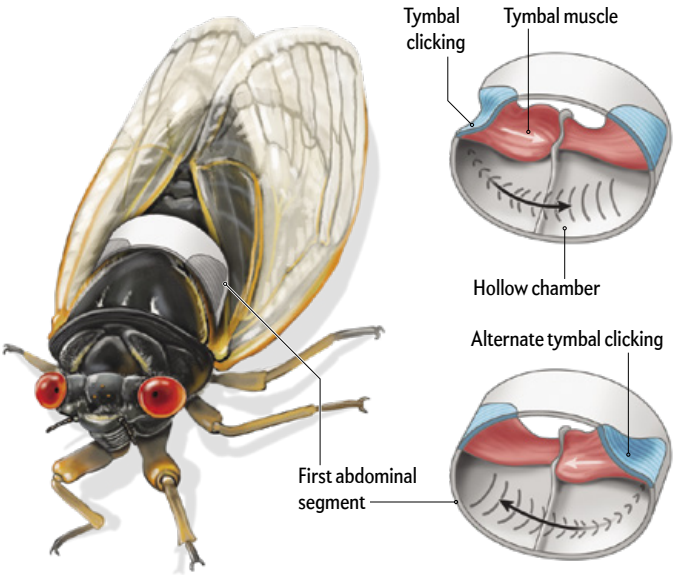
Among the most acoustically talented animals in the Mesozoic were the dinosaurs. In 1981 David Weishampel carried out one of the first reconstructions of a fossil animal's vocalization, working with the herbivorous, duck-billed dinosaur *Parasaurolophus*. This creature had a giant crest on its head that connected to its airway. Weishampel demonstrated that the crest made for an excellent resonating chamber. By taking into account the size and shape of the crest, he was able to estimate the sound repertoire of *Parasaurolophus* and reproduce it with a model he built. (To this day, Weishampel affectionately refers to that rig as his "honker.")

Increasingly sophisticated digital tools have made it possible to do this kind of in-depth analysis on many more specimens. Since 2008 Lawrence Witmer of Ohio University and his team have been using CT scans, along with fluid mechanics modeling, to assess sound production in various dinosaur species. They have discovered that the skulls of many dinosaurs contained complex chambers. Air flow through these spaces would have been correspondingly convoluted. The air flow helped to regulate body temperature, but it also might have enabled the animals to produce a wide array of sounds, including honks, bellows and trumpets.

Reconstruction of dinosaur vocalizations has long been a mainstay of the movie industry. The roars in films such as *Jurassic Park* are among the most famous portrayals of extinct-animal sounds. But Julia Clarke of the University of Texas at Austin and her colleagues found that the sounds of predatory dinosaurs such as *Tyrannosaurus rex* might have been more birdlike than mammallike. Reporting on Clarke's work, some journalists wrote the fearsome tyrannosaurs might have "honked" rather than "roared." But before you begin picturing *T. rex* as a giant goose, it is worth noting the researchers meant "honk" from a biomechanics standpoint—a sound produced largely through the nose rather than the mouth, starting with the vibration of structures deep in the chest. Scaled to tyrannosaur size, that honk becomes a bass-baritone mega war trumpet. The beast could have sounded off with the full force of the entire brass section of the Los Angeles Philharmonic before entering battle armed with six-foot-long bone-crushing jaws.

Tymbals

Insects such as cicadas and katydids sing their songs using drumlike structures on their bodies called tymbals. Rapid buckling and unbuckling of the tymbals produces loud sounds. The fossil record shows that these noise-generating structures evolved by 250 million years ago.



Some dinosaurs were probably quite a bit less vocal than often portrayed, however. In the original *Jurassic Park,* the long-necked brachiosaurs trumpet like elephants. In reality, they were probably nearly voiceless. At most they might have been able to hiss. In all tetrapods—the group that includes the first land vertebrates and their descendants—the primary vocalizations in the larynx are controlled predominantly by the recurrent laryngeal nerve. This nerve always has the same strange configuration: it runs all the way down the neck, loops around large blood vessels in the upper and middle chest, and then runs back up the neck to the larynx. As a result, the signals for voice have to travel about twice the length of the neck.

For short-necked animals, including humans, the resulting delay in signal speed is trivial. But for a giant, long-necked dinosaur, this delay would be comparatively enormous—so much so, in fact, that there would be no way to properly control the rapid movement of the vocal cords during complex vocalizations such as honking or trumpeting. The next time you watch *Jurassic Park,* imagine honking hadrosaurs, trumpeting tyrannosaurs and hissing brachiosaurs.

In all likelihood, many dinosaurs were impressive vocalists. But one group in particular evolved some of the most sophisticated vocalizations of any animal. Members of this group still live among us: the birds. The earliest-known birds were identified from fossil deposits that are about 150 million years old, although their unique vocal abilities may have evolved somewhat later.

Birds have a special vocal structure called a syrinx. Their larynx is reduced, and the syrinx provides nearly all of their vocal control. Whereas the larynx resides at the top of the main airway,

Graphics by Mesa Schumacher

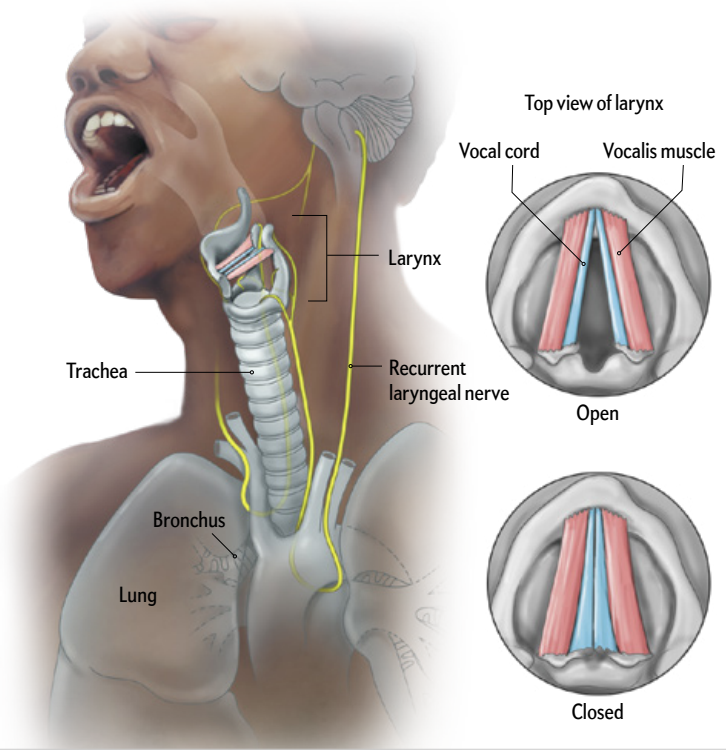
the syrinx sits at the bottom, where the trachea (aka the windpipe) branches out to the lungs. This anatomical arrangement offers several advantages. One of the most fundamental, described in 2019 by Tobias Riede of Midwestern University and his colleagues, is that it greatly improves the resonating efficiency. In other words, it produces more sound for the same energetic cost. Another advantage is that the syrinx can use the airstreams from the right and left lungs differently. Songbirds are particularly adept at this; the sounds from each side can be produced simultaneously or independently. In some cases, the two sides are specialized for different frequency ranges, enabling the bird to sing internal duets. The modern-day Hermit Thrush's beautiful song results from this capability.

Scientists do not yet have a firm grasp on the origins of the syrinx. The oldest avian syrinx discovered to date comes from a specimen of the extinct bird *Vegavis,* described in 2016 by Clarke and her colleagues. *Vegavis* lived during the latest part of the Cretaceous period, 66 million to 69 million years ago. But its syrinx was already fairly specialized, with its expanded resonating space and asymmetry associated with dual-sided sound production. A more primitive version of the organ could have originated earlier.

Interestingly, the other vertebrate fliers of the Mesozoic, the pterosaurs, did not have a syrinx. So contrary to what Hollywood might have us believe, pterosaurs did not sound like birds. They probably sounded more like other reptiles. They might have growled, hissed, clicked or even bill clacked, opening and closing their beaks to make a clattering sound. The bill clack from a giant pterosaur, one with a nine-foot-long skull, could have been deafening to a wide range of creatures at close range.

Larynx

Today's mammals, reptiles and amphibians all have a larynx, or voicebox, that they use to produce a wide variety of sounds. The larynx contains the vocal cords and is controlled mainly by the recurrent laryngeal nerve. Because the larynx is composed of cartilage, it tends to not be preserved in fossils. But its presence in all of the living terrestrial vertebrates suggests that it originated in their last common ancestor, perhaps 300 million years ago.



SEEING WITH SOUND

WITH THE ARRIVAL of the Cenozoic era, starting 66 million years ago, a whole new way of experiencing the world acoustically emerged: echolocation. Bats and whales appeared early in the Cenozoic, and both groups evolved this ability to see with sound. Echolocation requires quite a bit of sophisticated anatomy, though. To use echolocation, an animal has to produce a beam of sound, aim it in the desired direction, listen for the echoes, and then process those echoes to determine the distance, speed and general shape of whatever object the sounds bounce back from. It is a great trick for navigating and hunting in dark skies or murky waters.

Just like with light, the size of the smallest object that can be seen with echolocation is equal to half the wavelength of the emitted beam. Sound waves are much longer than light waves, however, so to get a decent picture of the environment or to see tiny insects, the emitter must produce very high-frequency sounds, which have shorter wavelengths than low-frequency sounds do. In bats, these calls, which are produced by the larynx and tongue, are typically far too high for us to hear. Human hearing maxes out at about 20,000 hertz, whereas bat calls range from about 10,000 to a staggering 200,000 hertz. We only ever hear the bats' lowest-frequency calls; they sound like high squeaks to us, but they are the equivalent of bass-baritone voices to them.

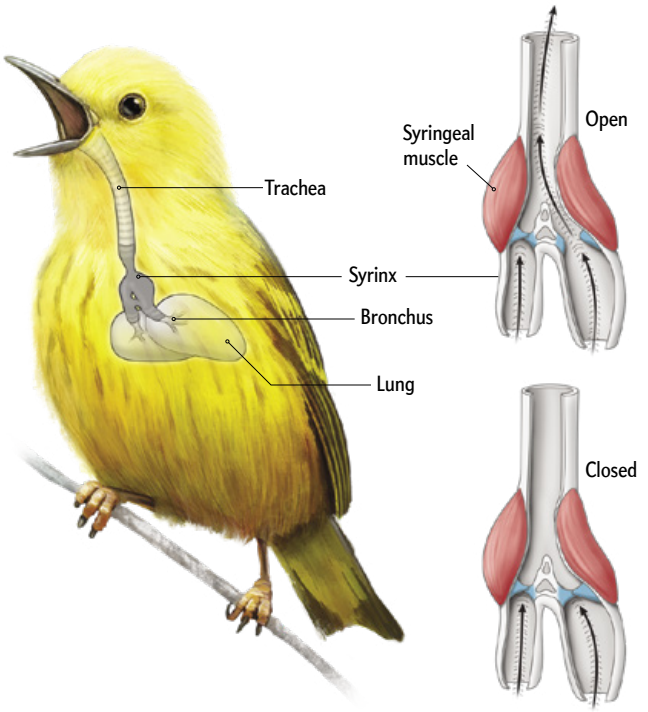
We know roughly when bats started echolocating because of characteristics of the ear anatomy in fossil bats. To hear the echoes of ultrasonic calls, bats need comparatively giant inner ears. The primary structure of hearing in the skull is called a cochlea. Both of your cochlea would fit on the face of a dime with room to spare. If your cochlea were the same relative size as a bat's, each would be about the size of a golf ball. The 50-million-year-old *Icaronycteris index* from western Wyoming is one of the earliest-known bats, and it already had skull characteristics associated with ultrasonic echolocation in living bats.

The evolution of echolocation in bats marked a major ecological revolution: vertebrates could now hunt insects on the wing in total darkness. After 275 million years, flying insects had nowhere to hide. Bats flourished as a result of this innovation. Today they make up roughly 25 percent of mammal species, and although some bats rely solely on vision to hunt, most of them echolocate.

As well as echolocation works in aerial environments, aquatic habitats are in some ways even more amenable to the use of reflected sound to de-

Syrinx

Birds evolved a vocal structure called the syrinx that they use to produce their sophisticated songs and calls. It sits at the bottom of the main airway, where the trachea branches out to the lungs, an arrangement that allows the animals to make more sound for the same energetic cost. It also enables them to use airstreams from the left and right lungs independently to produce different sounds. The oldest-known fossil birds are 150 million years old. Their specialized vocal anatomy may have evolved later.



termine where objects are in space. Water carries sound energy with far less signal loss per unit distance, giving aquatic echolocators a longer range than their aerial counterparts. High-frequency sounds always have reduced range compared with low-frequency sounds in the same environment, but in the water some dolphins can manage to make out objects with echolocation from as far as 650 feet away. The aerial bats, in contrast, cannot locate large objects more than 160 to 300 feet away; the range is much shorter for tiny insect prey.

Marine dolphins, such as the familiar bottlenose dolphin, can use echolocation to get a "first look" at long range in dark or cloudy water. River dolphins, such as those that live in the Amazon River, make even greater use of echolocation. The environment of these cetaceans is exceptionally murky. The river dolphins have smaller eyes and thus reduced visual acuity compared with other cetaceans, and they seem to rely heavily on echolocation to navigate and find food.

Marine mammals hold other sound records, too. If producing sound that travels as far as possible is the name of the game rather than trying to hear the echoes, then the best option is to use very low-frequency sounds. Big animals in aquatic environments have the natural advantage here. It is no surprise, then, that the champions of massive sonic range are the giant baleen whales. With larynxes up to two feet long and calls so low a human cannot hear them, some of these whales sing songs that can carry for hundreds, possibly thousands, of miles. Between the bats and the whales, the world is even noisier than we humans may realize.

THE LANGUAGE REVOLUTION

SOME 230 MILLION YEARS after the sounds of early mammals began to permeate the world, vocalization took on a new role with the evolution of human language. The anatomical prerequisites for language, including a larynx that can adjust rapidly and sophisticated integration of the larynx and tongue, seem to date back at least to the origin of our genus, *Homo*. This means human ancestors may have had some form of speech as early as 2.8 million years ago. Exactly when and in which *Homo* species language first originated remains a matter of debate, though. Language arose not only from the anatomy that enables speech but also from the capacity for symbolic thought. Most models suggest *Homo erectus,* which debuted around 1.8 million years ago, was the first human ancestor to use symbols. But fully formed human language, with its complex rules of grammar and syntax, might be unique to our own species, which would mean it originated within the past few hundred thousand years.

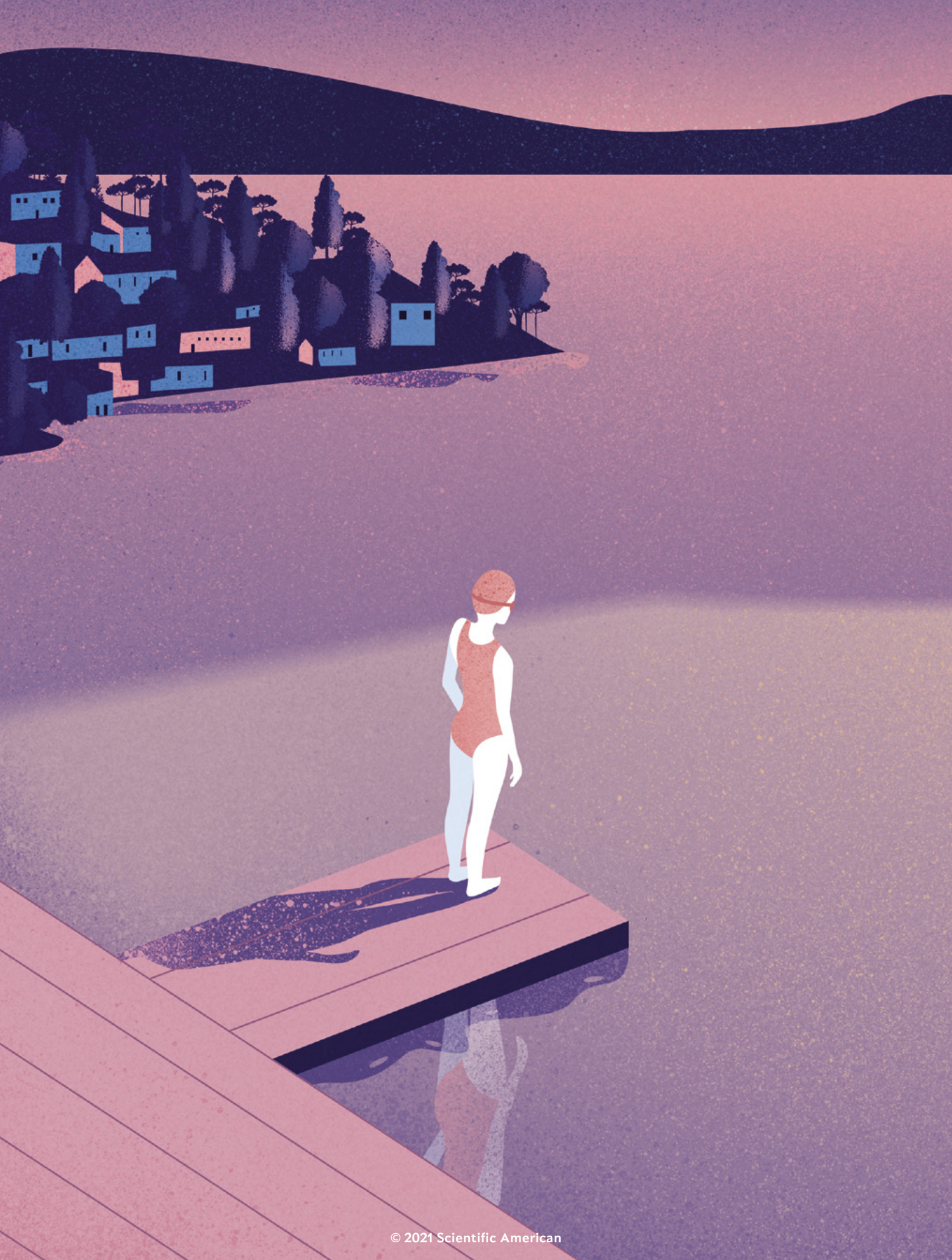
It is not just the possession of language that is so powerful: humans are unique in their abilities to teach, learn and record language. Although researchers have successfully taught some other primates to use sign language, none of these educated apes has ever taught this language to others of its species, even when given the opportunity. In one case, a chimpanzee at the Duke University primate facility who had been taught sign language was reunited with his troupe. He tried to use his new skill set to communicate with his fellow chimps. After a week of attempts, his keepers found him in a corner of the paddock, where he had isolated himself. When they asked him in sign language why he was not with the other chimps, he signed back, "Because they are insects."

Human language is one of the most impactful biological traits ever to have evolved. The formation of our social groups, societies and civilizations has been predicated on it. By coordinating our efforts through language, we have invented everything from agriculture to space shuttles—technologies that themselves contribute to contemporary soundscapes. Ours may not be the earliest animal sound, or the loudest, or the sweetest, but it is, in a sense, the one that most changed the world. SA

FROM OUR ARCHIVES

Flights of Fancy. Michael B. Habib and Terryl Whitlatch; April 2021.

scientificamerican.com/magazine/sa



PSYCHOLOGY

THE LONG SHADOW OF TRAUMA

Borderline personality disorder is one of the most stigmatized psychiatric diagnoses. Is it time to recast it as a trauma-related condition?

By Diana Kwon

Illustrations by Kelly Romanaldi

Diana Kwon is a freelance journalist who covers health and the life sciences. She is based in Berlin.

TWO WINTERS AGO, AFTER A SPELL OF BURNOUT LANDED HER IN THE HOSPITAL, ANN BEGAN HAVING disturbing dreams. Visions of her father turned into distressing flashbacks from her childhood—scenes of physical and psychological abuse.

A single mother of three daughters, Ann, whose name has been changed for privacy, grew up a town in eastern Germany, an hour's drive from the country's capital, Berlin. She spent her childhood surrounded by alcoholics, including her father and her grandfather. After school, she would often return to an empty house, and she found no comfort when her parents came home. Both her mother and father were violent, physically and emotionally. As a teenager, she was raped multiple times. She also lost a close friend, who, after becoming pregnant, was murdered by her own father.

Of all those horrible experiences, Ann says that the thing that hurts the most is how little her parents seemed to care about her. When she told her mother she had been raped, her mother responded by saying she was to blame for her own assault. When she was hit by a car while biking to work, her father unsympathetically said, "Get up, everything is fine," and sent her on her way. It was only after a colleague rushed to her in shock, asking why her head was covered in blood, that she realized how bad the accident had been. "That's the hardest thing for me," Ann tells me, as her voice starts to tremble and tears fill her eyes. "To have parents that don't see you as a person."

Based on her recollections, Ann was an angry, aggressive child who struggled to control her emotions and communicate effectively with others. As a teenager, she attempted suicide twice. During adulthood, Ann, now in her 40s, engaged in risky behavior such as driving too fast and has often felt the need to hurt herself, which she fulfilled by picking at her skin. The urge was so compulsive that some mornings she woke up with bloodied arms. Emotion regulation continues to be one of her biggest issues: when problems arise, she quickly becomes overwhelmed. "I need to talk to somebody immediately," she says. "Otherwise I'm afraid I will do something to myself."

I met Ann at the Central Institute for Mental Health (also known as the ZI, an acronym for its German name), which sprawls across several city blocks in the compact, gridlike center of Mannheim, a midsize city in the southwest of Germany. There Ann is receiving treatment for complex post-traumatic stress disorder (PTSD), a cluster of severe and persistent symptoms that follows exposure to prolonged trauma, and borderline personality disorder (BPD), a condition marked by intense, unstable emotions that adversely affects an individual's self-image and relationships and is often accompanied by self-harm and suicidal behavior.

BPD and complex PTSD share a number of features, such as difficulty regulating emotions and an altered sense of self. A key difference, however, is that complex PTSD explicitly frames an individual's condition as a response to trauma, whereas BPD does not. Many people fit the criteria for both disorders. But the degree to which trauma plays a role in BPD has been the subject of intense debate among psychiatrists and psychologists.

Studies show that anywhere between 30 and 80 percent of people with BPD meet the criteria for a trauma-based disorder or report past trauma-related experiences. Most clinicians who have studied or treated people with BPD agree that not everyone diagnosed with this condition has undergone trauma—at least as it is traditionally characterized. But a growing body of evidence suggests that what constitutes "trauma" is not obvious: even when adverse experiences do not fit the textbook definition of trauma, they can leave lasting marks on the brain and heighten the risk of developing mental ailments such as BPD.

These realizations are challenging the definition and treatment of BPD. Some clinicians and patients have called to rebrand BPD as complex PTSD, arguing that the overlap between these two conditions is significant enough to eliminate the former diagnosis. BPD has long been harshly stigmatized—even by mental health professionals, some of whom reject patients as manipulative, difficult, and resistant to treatment. Others say that although not all BPD is complex PTSD, the evidence of early stressors playing a role in its development is enough to warrant reassessment of its label.

"I think that borderline personality disorder does not fit in the concept of a personality disorder," Martin Bohus, a psychiatrist at the ZI, tells me. "It fits much better to stress-related dis-

orders because what we know from our clients is that there is no borderline disorder without severe, interpersonal early stress."

BLURRY BOUNDARIES

WHEN BOHUS WAS a clinical trainee in Germany, one of the first scenes he encountered on a psychiatric unit was a woman sitting on the floor, painting with blood from her self-inflicted injuries. When Bohus inquired about the patient, the senior psychiatrist on the unit simply said, "Oh, that's just a borderline patient. You cannot do anything. Just discharge her."

"But what if she commits suicide?" Bohus asked.

"They never kill themselves," the psychiatrist responded. "They just say they will." Bohus, following his mentor's advice, discharged the patient. Soon after, the woman took her own life.

This decades-old experience was the first of many that led Bohus, now an established psychiatrist in his mid-60s, to realize that something was wrong with the way that clinicians were treating people with BPD. "In those times, [the field] was completely dominated by this extremely conservative, and I would say hostile, paternalistic, patronizing attitude toward clients," Bohus says.

The term "borderline" was coined in the 1930s by German-American psychiatrist Adolph Stern, who used it to describe a condition that lay in the gray boundary between neurosis—mental ailments such as depression and anxiety that are not accompanied by hallucinations or delusions—and psychosis, in which people lose touch with what is real and what is not. These patients, he wrote, are "extremely difficult to handle effectively by any psychotherapeutic method."

For years "borderline" remained a nebulous concept. It did not become an official diagnosis until the 1970s, when John Gunderson, a psychiatrist at McLean Hospital in Massachusetts, carefully examined and characterized a group of patients he noticed had been misdiagnosed with schizophrenia. Gunderson defined six key features these people shared: intense emotions that were typically hostile or depressive in nature; a history of impulsive behavior; brief psychotic experiences; chaotic relationships; illogical or "loose" thinking as evident in, for example, bizarre responses in unstructured psychological tests; and an ability to uphold an outward appearance of normalcy.

Shortly after, in 1980, "borderline personality disorder" appeared in the third edition of the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM*), the main handbook used by psychiatrists and psychologists in North America and for research purposes worldwide. The diagnosis helped to spur investigations into the underpinnings of the condition and the development of treatments for patients. Long-term studies by Gunderson and his colleagues also revealed that despite the prevalent belief that borderline was a chronic, incurable condition, most patients do, eventually, recover.

How borderline relates to other personality disorders—which are broadly defined as enduring patterns of thinking and behaving that diverge from societal expectations and cause both individual and interpersonal problems—remains contested. When it initially appeared in the *DSM,* borderline was classified as one of several distinct personality disorders, each defined by specific features. Narcissistic personality disorder, for example, is characterized by grandiosity, self-centeredness and a lack of empathy.

BPD is more commonly diagnosed in women, but some studies suggest that the numbers of men and women with the disorder are roughly equal. The apparent gender difference may arise from women's greater willingness to seek mental health care, as well as from divergent presentations of the ailment that make men more likely to be diagnosed with narcissistic, antisocial or other personality disorders. These and other overlaps induced many clinicians and researchers to point to a dearth of evidence supporting distinct classes of disorders. They argued instead for a so-called dimensional model under which a single, broad personality disorder diagnosis would be characterized by symptom severity and the presence of certain traits in each patient.

Others experts spoke out vehemently against overhauling the existing system. Among them were Gunderson and Bohus, who argued that a large body of research on specific disorders—particularly BPD—had led to uniquely tailored treatments and that adopting a completely new model would upend this progress and harm patients. The 2019 version of the *International Classification of Diseases* (*ICD*), the diagnostic canon published by the World Health Organization, adopted a new dimensional model but retained a separate borderline label to assuage supporters of the diagnosis; the *DSM,* last revised in 2013, kept the categories and included an alternative diagnostic framework with a dimensional approach. (Both the *DSM* and *ICD* are used widely by mental health clinicians and researchers worldwide, but the latter is more commonly utilized to label conditions for insurance purposes.)

Even without meeting the textbook definition of trauma, adversity can mark the developing brain.

Disagreements abound. Some experts, such as Carla Sharp, director of the Developmental Psychopathology Lab at the University of Houston, propose that the traits of BPD capture dysfunctions common among all personality disorders. Others, such as Bohus, hold that BPD is unique—and that the disorder has a specific link to past traumatic experiences. How one's history contributes to other personality disorders is unclear. Most studies to date have featured people with BPD because they are more likely than those with other personality disorders to seek help. Julian Ford, a clinical psychologist at the University of Connecticut School of Medicine, notes that although he views trauma as a potential contributor to all personality disorders, studies into this question are lacking. "There is enough research to indicate that trauma can play a role in virtually any personality disorder," Ford says. "Exactly what the role is—I don't know that we have the research to determine that yet."

EMOTIONAL SKIN

BOHUS REMEMBERS the eye-opening time he spent during his early years as a psychiatrist at the Weill Cornell Hospital in White Plains, N.Y., where he saw two radically different methods of treating people with BPD. In one, patients were confined to a locked unit and heavily medicated. The climate around them was hostile and suspicious, and most remained for a year or longer. In another, the unit was open, and the atmosphere was warm and supportive. Patients were encouraged to help one another develop skills that would enable them to tolerate their distress, and most left with noticeable improvement a few months after admission.

The latter unit structured treatment around a method developed by American clinical psychologist Marsha Linehan, who was herself diagnosed with BPD. Shortly before graduating from high school, Linehan was admitted to a locked ward in the Institute of Living, a psychiatric hospital in Hartford, Conn. There Linehan slashed her limbs with sharp objects, burned herself with cigarettes and smashed her head into the hospital floors. Her doctors attempted a range of treatments, including drugs, electroconvulsive shocks, seclusion and cold therapy (where she was wrapped in freezing blankets and strapped onto a bed)—most of which, according to Linehan, probably hurt more than helped.

This experience, which in her memoir Linehan recounts as a "descent into hell," motivated her to dedicate her life to helping others like herself. Through this journey Linehan came to highlight emotion dysregulation as a driving force of the disorder, noting that people with BPD routinely experience a roller coaster of emotions. "Borderline individuals are the psychological equivalent of third-degree-burn patients," Linehan told *Time* magazine in 2009. "They simply have, so to speak, no emotional skin. Even the slightest touch or movement can create immense suffering." For someone with BPD, seemingly minor provocations can arouse feelings of extreme anger, shame or despair.

Using these insights, Linehan developed a new treatment, which she called dialectical-behavioral therapy, or DBT. It focuses on both accepting oneself and modifying harmful behaviors: the name "dialectical" describes the balance between acceptance and change. Clinical trials have shown that DBT successfully reduces some of the key features of borderline, such as self-injury and suicidal behavior and hospitalizations, as well as other symptoms.

Seeing DBT in action, Bohus realized this method was far superior to the other means of treating BPD that were available at the time. After returning to Germany, he established the country's first unit specialized in treating BPD with DBT. Since then, DBT clinics have become widespread in Europe and the U.S. and have been established in Latin America, Asia and the Middle East. Despite the benefits of DBT, however, over the years Bohus noticed its limitation when it came to dealing with an issue many of his patients experienced: trauma.

"CAPITAL T" TRAUMA

PTSD APPEARED as an official diagnosis in the *DSM* in 1980, the first mental illness defined by an external cause. It described a condition in which problems such as flashbacks, nightmares and anxiety occur in the wake of a terrifying event. Similar ailments, such as the "shell shock" described during World War I, had been reported for decades. But it was widespread awareness of the psychological needs of Vietnam War veterans that prompted this inclusion.

In the early 1990s, after scanning years of literature on trauma survivors, Judith Herman, a psychiatrist at Harvard University, proposed "complex PTSD" as a new diagnosis (distinct from PTSD) to account for a cluster of symptoms that resulted from long-term exposure to extreme stress. These problems, Herman noted, occurred when one person was under the control of another, such as in the context of prisons or labor camps or in certain families. They included difficulties with emotion regulation, unstable personal relationships, pathological changes in identity and self-image, and self-destructive behavior.

"The current diagnostic formulation of PTSD derives primarily from observations of survivors of relatively circumscribed traumatic events," Herman wrote in a 1992 paper. "This formulation fails to capture the protean sequelae of prolonged, repeated trauma." She also noted that the symptoms of people with complex PTSD were "too easily attributed to underlying character problems" and risked being misdiagnosed as a personality disorder.

Decades of debate ensued. One of the biggest sticking points is the significant overlap between this diagnosis and BPD. Lois Choi-Kain, a psychiatrist and director of McLean Hospital's Gunderson Personality Disorders Institute, remembers the intense arguments that raged during the early 2000s. "There was a huge divide and an almost rabid controversy about the distinction of BPD and PTSD or trauma-related disorders, as though they were mutually exclusive and as if only one could stand," Choi-Kain says. People generally fell into two camps, she explains: those who thought PTSD was being unfairly pathologized as a problem of personality and others who said that whereas many with BPD had trauma in their past, it did not explain the entire disorder.

A core question at the center of this debate has been: What qualifies as trauma? Although some people with BPD, such as Ann, have experienced severe traumatic experiences in their past and clearly fit the complex PTSD diagnosis, many with the condition do not. One is Rebbie Ratner, a 49-year-old woman who was diagnosed with BPD a decade ago and runs a YouTube channel, BorderlineNotes, to raise awareness about the condition. Ratner explains that she investigated the complex PTSD diagnosis during her lifelong journey of trying to figure out an explanation for the extreme emotional pain and a slew of problems she had struggled with, including many damaged relationships and a serious eating disorder. "It never fully sat with me," Ratner says. "There are some real difficult psychological things that happened in my family," she adds, but none were severe enough to meet the criteria for a trauma-related disorder. "I think I have parents who do love me."

In the fifth (and most recent) edition of the *DSM,* "trauma" includes events in which a person directly experiences or witnesses "exposure to actual or threatened death, serious injury, or sexual violence," learns that such events happened to a close family member or friend, or has repeated exposure to these events (for example, while working as a first responder or a police officer). But for many in the mental health community, what counts as trauma is not so clear-cut. The official definition can be thought of as describing "capital T" trauma, as opposed to the "little t" trauma of distressing experiences such as verbal abuse, neglect, bullying and poverty that are not considered severe enough to hit this diagnostic bar. "The definition of trauma is always extremely tricky," says Andreas Maercker, a clinical psychologist at the University of Zurich and one of the proponents of complex PTSD.

A large U.S. survey of potentially traumatic experiences, ranging from violence and neglect to growing up in an unstable home, revealed that almost two thirds of adults experienced at least one such event in early life. Neuroimaging studies of people who have dealt with such adversities find that some little t traumas can leave lasting marks on the brain, especially when such stresses are experienced during childhood or adolescence, when the brain is still developing. Some of these alterations are very specific. For example, people with a history of verbal abuse from their parents appear to have changes in the auditory cortex that correlate with verbal difficulties later in life. Broader impacts include reduction in the size of the hippocampus (a structure involved in memory and learning), heightened activity in the amygdala (a key center

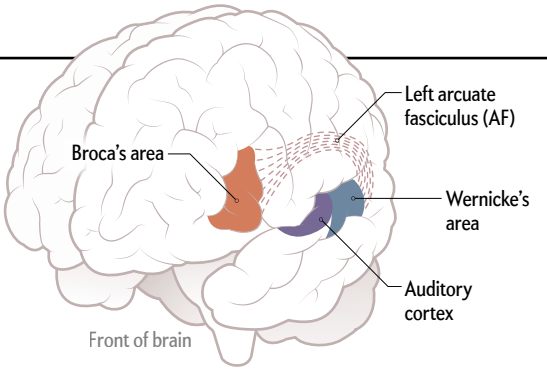
The Traumatized Brain

Childhood adversity leaves enduring marks on the brain. Some alterations, such as in the structure and function of the amygdala, hippocampus and other regions involved in processing memory and emotion, are common to all types of maltreatment. Other changes are more specific. Children subjected to chronic verbal abuse, for example, may have weakened connections between regions involved in understanding and producing speech. These changes most likely helped them survive incapacitating distress but later in life can lead to psychological problems. Many who have these abuse-induced brain markers do not experience psychiatric disorders, however. Growing up in otherwise supportive environments and thus escaping "traumatic invalidation" might have protected those people.

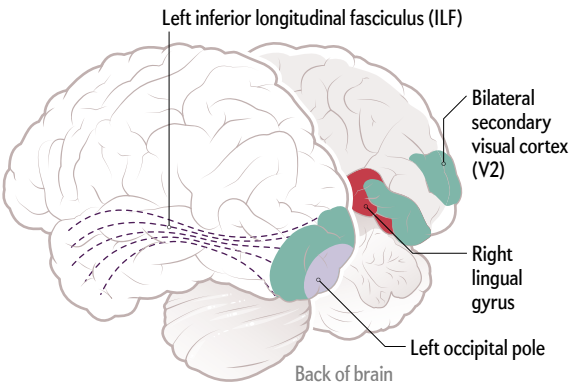
Areas Affected by Childhood Verbal Abuse

Left auditory cortex
An area of the superior temporal gyrus, it processes information contained in sound.

Left arcuate fasciculus (AF)
A bundle of nerve fibers connects Wernicke's area of the brain to Broca's area —two regions involved in producing and understanding speech and language.



Areas Affected by Witnessing Domestic Violence



Bilateral secondary visual cortex (V2)
Connected with visual memory as well as other components of vision.

Left occipital pole
Part of the primary visual cortex; any damage to this area can lead to defects in the field of vision.

Left inferior longitudinal fasciculus (ILF)
A long nerve pathway that connects vision-processing regions in the front and the back of the brain. These two areas are involved in the perception of faces.

Right lingual gyrus
Part of the primary visual cortex, linked with the ability to process vision, especially related to text.

Areas Affected by Childhood Sexual Abuse

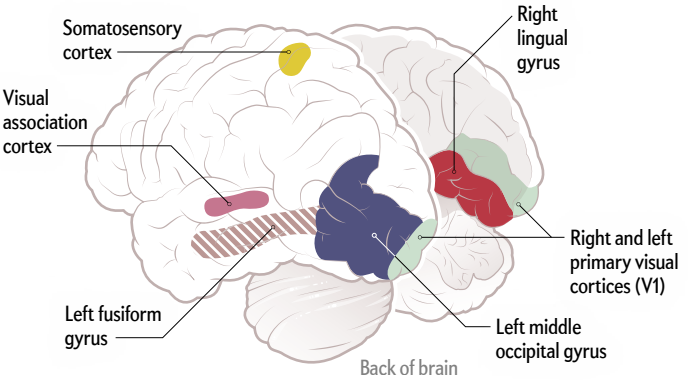
Right and left primary visual cortices (V1)
Respond to simple visual inputs such as orientation and direction.

Visual association cortices
Believed to help with recognition and discrimination of visual shapes and objects.

Left middle occipital gyrus
Helps with the perception of bodies and faces.

Left fusiform gyrus
Thought to underlie the ability to process facial expressions and therefore crucial for interacting appropriately in social situations.

Parts of somatosensory cortex
Sensory region representing the clitoris and surrounding genital area.



Source: "The Effects of Childhood Maltreatment on Brain Structure, Function and Connectivity," by Martin H. Teicher et al., in *Nature Reviews*, Vol. 17, October 2016 (*brain graphic reference*)

Graphic by Now Medical Studios

for emotion regulation), and distorted connections between these and other regions of the brain.

"The effects of emotional maltreatment and emotional neglect are really quite profound," says Martin H. Teicher, director of the Developmental Biopsychiatry Research Program at McLean Hospital. "They're completely on par in terms of brain effects with physical abuse or sexual abuse."

Assessments of people diagnosed with BPD have revealed a variety of environmental stressors that heighten the risk of developing the condition. These include big T trauma such as childhood sexual abuse and little t traumas, such as harsh parenting, neglect and bullying. Bohus, along with another psychiatrist at the ZI, Christian Schmahl, and their colleagues have found that patients with BPD and those with a history of trauma also share some common neurobiological alterations. These changes include structural and functional abnormalities in the limbic system, which is associated with emotion and includes the amygdala and hippocampus.

This overlap, Schmahl says, may indicate a signature of trauma or stress that underlies BPD. Clearly delineating a neural signature of BPD remains a challenge, but the findings so far have already inspired potential new treatments. Schmahl and his colleagues at the ZI are currently testing whether neurofeedback training of the amygdala—in which people are taught to control their brain activity in real time—can augment existing therapies.

"Traumatic events, whether it's childhood bullying or neglect from parents or caregivers, have long-term consequences for people—they impact your ability to trust others, regulate your emotional states, and how you learn to cope," says Shelley McMain, a clinical psychologist at the Center for Addiction and Mental Health in Toronto. "They have wide-ranging consequences in various life domains—and as a result, I think it becomes very important to consider the implications of childhood adverse experiences when you're treating people who are diagnosed with borderline personality disorder."

Some experts, such as Choi-Kain, hold that although stress and past trauma play a big role in the development of BPD, the disorder also has other components. For one, studies comparing identical and fraternal twins (who share nearly 100 percent and roughly 50 percent of their genes, respectively) and of families indicate that the disorder is strongly heritable, suggesting there may be a genetic component. Such biological dispositions may mean a child is born with a sensitive temperament that makes it more likely for them to experience difficult situations as upsetting, according to Sharp.

On top of that, Choi-Kain notes that the relation between trauma and BPD does not go in only one direction. The symptoms of borderline, such as emotional dysregulation and interpersonal sensitivity, can make an individual with the disorder more fragile in stressful situations and interfere with their ability to cope effectively and communicate comprehensively, she explains. "A person who is emotionally and interpersonally sensitive becomes impulsive and angry at others when they feel hurt or threatened and are at risk to be misunderstood and experience rejecting, retaliatory or controlling responses from others," she adds. "These vulnerabilities can explain why those with the disorder encounter social adversity repeatedly." For example, one 2014 study of more than 2,000 teen girls and their parents found that the severity of BPD symptoms predicted how harsh parenting behavior became in the following year.

For these reasons, Choi-Kain thinks that replacing BPD with complex PTSD could harm more than help. "A person may develop BPD because they were dealt a very difficult set of cards that are both biological and environmental," she tells me. "And to kind of cleave off the people with trauma—it's like saying the only legitimacy to this disorder is if you've been heavily traumatized."

TRAUMATIC INVALIDATION

ONE OF THE BIGGEST lingering mysteries is why adverse experiences in childhood lead to BPD or other disorders—such as complex PTSD, depression or substance use—in some people but not others. Looking for answers, Teicher's team conducted neuroimaging studies on people who remain without any psychiatric diagnosis despite maltreatment during early life. To their surprise, their brains looked very similar to those of people with a vast array of diagnoses—but with specific differences in certain regions, such as the amygdala. Teicher says these distinctions may help explain why some people are able to resist the psychological aftereffects of early problems.

What factors lead to resilience or vulnerability remains an

open question. Those who go on to develop BPD may have grown up in what Linehan calls a "traumatic invalidating environment," where a person feels devalued by those around them. Examples include a dearth of sympathy and care from parents in times of need, constant disapproval from family members, or bullying from peers. An accumulation of such encounters can lead to a variety of negative consequences, such as feeling alienated and being extra sensitive to rejection, Bohus says. "Most of our patients have really struggled to adapt to positive signals, all driven by this experience of repetitive traumatic invalidation," he says.

By studying dozens of women who were exposed to severe sexual assault in early life, Bohus and his colleagues found evidence that those who escaped the additional torment of invalidation are able to develop fulfilling partnerships and live without psychiatric problems. Crucially, Bohus says, they always had somebody they could talk to about their experience. "Of course, it's unpleasant; it's a disaster," he says. "But it's not so disastrous if you can share it."

Ann sees the constant invalidation she received from her parents as the root of her problems. "I can't really love myself, because my parents told me that I'm not lovable," she says. "I have to go against it every day. Every single day I wake up and say, I want to walk on a new path." Chronic invalidation on its own can also be considered a type of little t trauma—and may, without the presence of other painful or distressing events, lead to the development of BPD. Jana (name changed for privacy), a patient with BPD receiving treatment at the ZI, tells me that the lack of emotional validation she received as a child is what probably led to her condition. "I'm not quite sure my mother loved me or if she just felt obliged to love me—with my father, I know he loved me, but he wasn't able to show it," she tells me. "If your feelings are not validated by your parents … then you don't really learn how relationships work or how to use your emotions."

BREAKING THE CYCLE

THE RESIDENTIAL CLINIC for patients with BPD and complex PTSD in Mannheim is housed in one of the newest buildings at the ZI. The front facade is mostly glass, and the interior is clean and bright. Stephanie Mall, a young psychologist who works on the ward, gives me a tour of the floor where their adult patients reside. The doors, on which each patient has hung their name, are all closed, and the atmosphere is unexpectedly still. "Is it usually that quiet?" I later ask. "No, it's not always that quiet," Mall responds with a laugh. It was the afternoon, when most patients either go out or take a nap. Mornings are often filled with individual and group therapy sessions, so many of them are exhausted by midday, she explains.

As we sit eating lunch in a park a block away from the ZI, Mall describes a patient who came to the clinic after a suicide attempt that had landed her in the intensive care unit of a hospital. She had been diagnosed with BPD, and she was very ill—barely talking, extremely depressed and constantly cutting wounds into her arm so deeply they required stitches. "We discovered together that she had PTSD," Mall tells me. The woman had experienced intense violence, both sexual and nonsexual. It was only after receiving both DBT and trauma-specific therapy that the patient showed signs of positive recovery. "She doesn't hurt herself anymore," Mall says. "She is not suicidal at all. She wants to live." Before they met, "everybody just said she's manipulative, she's combative, just opposing all the time—and nobody asked why."

A handful of clinical research groups around the world are now working on integrating a focus on trauma into interventions for BPD. At the ZI, Bohus's team has established a new treatment that combines dialectical-behavioral therapy with trauma-focused therapy (which involves exposing the patient to stimuli that trigger trauma-related memories in a safe environment), which they have dubbed DBT-PTSD. One of the core aims of this treatment is to help people connect their past traumatic experiences to their present condition—and in doing so, to identify the related cues that trigger adverse thoughts and behaviors. "You need to repeatedly reactivate these cues and teach the brain that these cues are no longer relevant," Bohus explains. On its own, DBT is good at teaching people the skills to describe and regulate their emotional systems to control their behaviors. It rarely revises those cues, however.

Bohus and his colleagues recently carried out a multicenter, randomized controlled trial across three outpatient clinics in Germany to examine the efficacy of this treatment in women with childhood abuse–associated PTSD and who fit several of the criteria for BPD. Their study, which was published in July 2020 in *JAMA Psychiatry,* showed that this treatment significantly improved symptoms of PTSD and BPD—and to a greater degree than a well-established trauma-focused treatment known as cognitive-processing therapy.

The team is now modifying this treatment for people with BPD—but no big T trauma in their past—to deal specifically with the traumatic invalidation. The researchers are calling this new method "structured exposure DBT," or SE-DBT. A pilot trial, which will take place at two clinics in Germany and one in Canada, will begin in January. "I really see the focus on trauma processing in psychotherapy for BPD as really revolutionary and probably overdue," says McMain, who will be leading the Canadian trial at the Center for Addiction and Mental Health. "The hope is that this will accelerate recovery and accelerate change."

After spending several months at the ZI's residential clinic for BPD and complex PTSD, Ann is now continuing her therapy as an outpatient. She is still processing her past traumas, but her ability to control her emotions has significantly improved.

Even with these newly available therapies, many people with the combined BPD and complex PTSD diagnosis still struggle to find psychotherapists who will provide such treatments—which can often take months, if not years—at an affordable cost. For Peggy Wang, an American woman who has been diagnosed with both BPD and complex PTSD, the biggest question is not which of these is a better diagnosis for her; it is how she can access the treatment that will enable her to improve. Wang struggles with a multitude of problems—including substance use, job instability and problems forging healthy relationships—which she attributes to the emotional and physical abuse she endured at the hands of her parents. Wang tells me that she spent 10 years going from therapist to therapist in New York and California. When she finally found the right one, she could not pay for more than a few sessions.

"The labeling is not the issue," Wang says. "It's finding the solution for all of this." SA

FROM OUR ARCHIVES

A Disorder of Mind and Brain. Diana Kwon; November 2020.

scientificamerican.com/magazine/sa

FOOD

PROTECTING ALASKA'S HARVEST

Indigenous communities along the coast are developing scientific networks to test shellfish for toxins arising from harmful algal blooms

By Karen Pinchin

Photographs by Kiliii Yuyan

MUSSELS cling to rocks along the intertidal zone in Seldovia, Alaska.

ON A COOL MORNING IN AUGUST, STEPHEN Payton stood at the edge of a dock in Seldovia, Alaska, dragging a fine, conical net at the end of a pole through the rippling ocean water. Screaming crows and gulls wheeled above us in the damp air, as the long-limbed 30-year-old watched his ghostly net wend its way underneath the surface. A small plastic bottle at the net's narrow end captured and concentrated particles from the water. When Payton pulled the contraption up, he detached the bottle, added drops of iodine preservative to the wet muddle inside, labeled the sample and handed it to me. We climbed into his big white truck and drove a mile to Seldovia's gravel airstrip, where I scrambled onboard a cramped, six-seater propeller plane. Organisms within the bottle could deteriorate within hours, so time was of the essence.

Fifteen minutes later the pilot touched us down in Homer, on the opposite side of Kachemak Bay. Jasmine Mauer, a federally funded researcher who works across the street from the little airport, ushered me into her office and sat down at her bench. She squeezed a few drops of harbor water from the bottle onto a glass slide and slid it under her microscope. I peered over Mauer's shoulder as she searched, quadrant by quadrant, for the telltale shapes of tiny, toxic algae. After a few minutes she rolled her chair back; today, at least, the water was safe.

Payton, whose Aleut ancestors fished Alaskan waters for centuries, is the environmental assistant for the Seldovia Village Tribe. His town, on the southern portion of the Kenai Peninsula, is accessible only by boat or plane. On weekends he loves taking his three young kids fishing and clamming to provide them with healthy food, part of a subsistence lifestyle practiced by the Alutiiq and Unangax̂ people for ages. But he is haunted by the lurking danger he searches for every week: toxic algae. "The more I learn about it, the more it makes it a little scarier to go out and collect clams," Payton says.

Many Indigenous clammers have long avoided harvesting in summer's warmer waters, when harmful algal blooms (HABs) are more likely to occur, potentially creating toxins that get ingested by and accumulate in local fish and shellfish. Yet residents still trudge out in boots at low tide year-round, looking to scoop up bivalves from the exposed mud by spotting bubbles that rise from little breathing holes in the muck. "I know a lot of people who harvest in the summertime," Payton says. "I would never do that."

Harmful algal blooms, however, are occurring more frequently in Alaska's northern coastal regions, across more months of the year, making harvesting at any time a risk. Recent research found that blooms in the Arctic Ocean increased by more than 50 percent between 1998 and 2018. The frequency and intensity of dangerous blooms are likely

Karen Pinchin is a journalist based in Halifax, Nova Scotia. She is writing her first book, on the history, mysteries and future of bluefin tuna.

SCIENTISTS from the Alutiiq Pride Marine Institute—Annette Jarosz, Maile Branson and Jeff Hetrick—dig for clams near Seward as part of an ambitious, regional project to test shellfish for harmful algal toxins.

to rise even further as northern latitudes warm.

The biggest threat, Payton says, is the tiny *Alexandrium catenella,* a round dinoflagellate with thread-like "arms" it uses to swim. When it reproduces during an algal bloom, the brownish particle barely tints the water, but it produces a tasteless, odorless toxin known as paralytic shellfish poison (PSP) that is 1,000 times more toxic than cyanide. In humans, PSP causes tingling in the lips and tongue, numbness and loss of control in the arms and legs, and eventually paralysis in the chest and abdomen. Without a medical ventilator, death can occur in as little as half an hour.

In Seldovia, residents still talk about a woman on Macdonald Spit who, only a few years ago, nearly died and still suffers memory loss from eating a "hot clam." Luckily, her husband recognized the symptoms and rushed her to a clinic with a ventilator in Homer. Last year a Vietnamese fish plant worker in Unalaska died during an emergency flight to Anchorage after eating a handful of blue mussels and a marine snail at an Independence Day party.

Yet these poisonings do not deter thousands of Indigenous and non-Indigenous people from digging up and eating innumerable clams every year, any one of them potentially toxic. Around 34 million pounds of wild foods are harvested annually in Alaska's subsistence regions—about 276 pounds per person. In remote communities, marine mammals, fish, birds and shellfish make up around three quarters of harvested food.

The intertidal harvest also sustains vital knowl-

STEPHEN PAYTON, environmental assistant for the Seldovia Village Tribe, collects samples of bay water (*left*). Michael Opheim, his uncle and head of environmental work, joins two of Payton's sons to find clams for dinner (*right*).

edge and cultural lessons. "When the tide is out, the table is set" is a traditional saying that speaks to the shore's bounty: clams, mussels, sea urchins, Dungeness crabs, sea cucumbers, hard-shelled chitons, octopi and snails. Researchers suspect some or all of the animals may contain toxins. In Alaska's Kenai Peninsula region, two thirds of residents who collect clams live in low- to medium-income households.

In other coastal U.S. states, researchers regularly monitor shores for signs of harmful blooms. In Washington State, autonomous floating sensors survey 31 sites and communicate data to researchers and Indigenous tribes. Across California, a HAB monitoring-and-alert program combines coastal sampling by the state's department of public health with toxin data collected by university-affiliated researchers. In Maine, trained volunteers collect widespread water samples that are analyzed by the state's department of marine resources. Florida's fish and wildlife commission does weekly sampling and runs a Web site and hotline with up-to-date HAB warnings. Along the U.S. West Coast, subsistence harvesters brought home more than 221 million servings of seafood between 1990 and 2014, according to one study. Many people rely on the state-supported testing programs to certify that their harvests are safe.

Widespread testing does not exist in Alaska, even though HABs are rising along the coastline because of climate change. Alaska is the only coastal state whose government has declared it impossible to monitor for toxins in subsistence shellfish, such as the clams eaten by Payton's kids. The government says the coastal territory is just too big to cover. That makes

Alaska "the only state in the country where people still die from harmful algal blooms," says Steve Kibler, a North Carolina–based harmful algae researcher and an oceanographer at the National Oceanic and Atmospheric Administration.

In response, Indigenous communities reliant on shellfish, including Seldovia, are trying to fill this safety gap. They are gathering data, expanding local expertise and forming nascent monitoring networks that include toxin specialists from far away, while investing in testing methods built on coastal knowledge as well as cutting-edge science. They are overcoming geographical hurdles and logistical challenges to collect and move samples over thousands of miles. And they are passionately making a case for increased sovereignty over their traditional resources. Their efforts are improving safety as the danger is growing, providing lessons on how communities can persist against a seemingly insurmountable environmental threat.

NO SAFE BEACHES

PHYTOPLANKTON, commonly referred to as algae, are a keystone food source for countless marine creatures, from clams to baleen whales. The single-celled organisms have evolved into a riotous array of species, colors and shapes. Given the right combination of light, heat and micronutrients—from natural sources such as glaciers as well as agricultural and sewage runoff—algae can grow out of control, or "bloom." Some intense blooms tint the ocean in swirling blues, mahoganies or "red tides" visible from space—psychedelic watercolors of microscopic life on a macroscale. When

PAYTON'S FAMILY creates trenches and seeds baby clams to increase the number of mature shellfish available to subsistence harvesters and to help balance the intertidal ecosystem.

conditions no longer suit, the algae produce seeds, or cysts, that sink to the seafloor and lie dormant until conditions allow them to germinate.

Only around 250 of the 5,000 or so known algae species produce toxins or create suffocating mats of biomass, qualities that distinguish a "harmful" algal bloom from an innocuous one. Nearly 10,000 HAB events have been recorded over the past three decades, spiking in some regions of the world and dropping in others. Marine toxins from these blooms have poisoned thousands of people and killed hundreds worldwide since the 1980s, with the most deaths in the Philippines.

Along Russia's Kamchatka coastline, on the other side of the Bering Sea from Alaska, a 2020 bloom wiped out an estimated 95 percent of marine species, including fish, octopi, starfish and sea urchins. It was cited as the cause for vomiting, fever and corneal burns in more than a dozen surfers. In the U.S., damage to fisheries and tourism by harmful algae has caused nearly $1 billion in economic losses, according to NOAA, including a recent red tide of *Karenia brevis* phytoplankton along Florida's Gulf Coast that killed thousands of fish and left dozens of rotting manatees on its shores.

The threat can persist even after a bloom has subsided. An October 2021 study announced the discovery of the world's largest, most concentrated bed of *A. catenella* cysts—on the ocean floor in the Chukchi Sea region. Kept dormant by the historically chilly waters, these cysts remained asleep for up to a century, accumulating as Pacific Ocean currents carried algae northward toward the Arctic. As Pacific and

Arctic waters have warmed, though, so, too, has the Chukchi Sea's floor, parts of which are now reaching temperatures that can dramatically speed up cyst germination. "Many more of these cysts are going to germinate" and will threaten Pacific Arctic coastlines, including Alaska's, says Donald M. Anderson, a senior scientist at the Woods Hole Oceanographic Institution who led the work and has studied HABs for more than 40 years.

Potentially lethal algae are steadily drifting northward along Alaska's largely unmonitored coastline, with only a handful of unsung sentinels like Payton standing in its way. Although media reports about HABs usually focus on problems in U.S. West, East and Gulf Coast regions, the state with the worst algal blooms, NOAA's Kibler says, is Alaska.

The state government's explanation for being unable to test shellfish for local consumption is one of scale: Alaska's coastline is longer than all of the other U.S. state coastlines combined. During my flights above Seldovia I was struck by the stunning array of gray-brown inlets, fjords and bays that form an erratic, filigreed coastline meandering endlessly along vast seas. Even scientists and residents who advocate for statewide testing often concede that programs that work for other states simply are not feasible here. Floating ocean sensors would struggle to cover enough territory. Transporting chilled samples from remote communities to centralized laboratories is complex, slow and unreliable. And toxicity levels in bivalves can vary wildly, even between shellfish harvested a few feet apart on the same beach. Com-

DOMINIC HONDOLERO, a Tlingit scientist at the NOAA Kasitsna Bay Lab, skims water for tiny organisms (*left*). At the lab he inspects tanks that contain sand lance and Pacific cod to be analyzed for poisons created in toxic algal blooms (*right*).

plicating matters is that different species retain toxic chemicals for extremely varied periods. Butter clams, which grow large and tasty, can hold on to toxins for years. Blue mussels can go from deadly to safe and back within a week.

Alaska's legislature has long subsidized testing for the state's lucrative commercial oyster and geoduck clam industries, but it does not fund shellfish testing for subsistence harvesters, which costs around $125 per sample. Turnaround for state testing takes one to two weeks—tolerable for an aquaculture farm that can safely store shellfish, but a delay that is untenable for individuals. Left in tidal waters for that long, clean shellfish can ingest new toxins, and harvested clams piled up in buckets will spoil. The Alaskan government's position has long been that there simply is no safe subsistence shellfish.

D.I.Y. TESTING

THE STATE'S POSITION is unacceptable, says Karen Pletnikoff, community environmental and safety manager for the Aleutian Pribilof Islands Association, which is dedicated to promoting the self-sufficiency and independence of the Unangaŝ people. Clamming, she says, is a socioeconomic and dietary necessity. Losing those foods would be especially painful, Pletnikoff says, "because unlike so many other resources that are lost to us, these are still right in front of us. You can see the little holes when the tide goes out, you know that the [shellfish] are there, and they're delicious, but they have every likelihood to be deadly."

The state's position is not good enough for Seldovians, either, who have devoted time and resources "trying to make sure that what we had as children is here for our children and our grandchildren," says Michael Opheim, Payton's uncle. As head of environmental work for the Seldovia Village Tribe, he is also Payton's boss.

Opheim, wearing a leather vest and patterned shirt, stood to my right on a sandy tidal beach that has been one of his family's traditional digging spots, gazing at the distant mountains. He grew up in Seldovia in the 1970s and chuckled when he told me about how he used to fight with his sister to be the first to eat the fleshy "buttons," or abductor muscles, of butter clams, as quickly as their dad shucked them. The family unearthed bivalves by the bucketful, reaching the most plentiful beaches with their motorized

metal dinghy. Today Opheim is dogged by a constant worry that one poisoned clam could kill a family member or friend.

A few years ago Opheim joined the Alaska Harmful Algal Bloom network, formed in 2017 by researchers, tribal experts and government staffers who were frustrated with the lack of clarity about the HAB threat. His tribe approved funds to establish their town as a monitoring hub, from which he and Payton would collect samples and data and send them to any researcher willing to collaborate.

One of those compatriots is Bruce Wright, a marine researcher and former state science adviser who works for the Knik Tribe, about a 45-minute drive from Anchorage, Alaska's largest city. More than three decades ago Wright started testing shellfish with the Alaska Department of Fish and Game. Huge die-offs of seabirds and a small forage fish known as the sand lance had caught his interest around that time, and in 2005 funding finally allowed him to expand testing to the broader ecosystem. Today the non-Indigenous researcher frequently offers to run tests at the state lab for remote communities, using Knik funding to cover the costs, with the tribe's blessing. "People are going to eat this stuff," he says. "I'm looking for ways they can utilize those foods."

I met Wright inside the white hallways of Anchorage's Department of Environmental Conservation. We walked into a state-funded lab escorted by its director, Patryce McKinney; it is the only facility in Alaska that is federally approved to test shellfish for human consumption, which it does for the oyster and geoduck industries. Wright greeted a technician who had just injected three mice with a cooked slurry of oyster flesh and was waiting to see if they would die. Some days, after such injections, the mice die within seconds. This time they lived.

Opheim and the Seldovians have enlisted other veteran scientists, too. During one of the network's monthly calls, toxic algae expert Kathi Lefebvre, a NOAA research biologist in Seattle, explained her multiyear study into how toxins move through the Arctic food web. As soon as the call ended, Opheim, hungry for data, e-mailed Lefebvre, eagerly offering to send her samples that might give his tribe some insights.

Lefebvre was curious to test for toxins in fish and suggested Opheim catch a few dozen herring; recent herring die-offs had defied explanation. Opheim called his nephew, Payton, who went out with his kids and netted some of the silvery filter-feeding fish under a subsistence license. Payton slid the fish into plastic zip-top bags, froze them solid in his packed freezer and shipped them to Lefebvre, via a complex process involving several different planes and couriers between airlines, which Opheim later described in an e-mail as a "logistical bugger." Those herring still sit in Lefebvre's lab freezer because COVID has shut down her workplace. When it reopens, she plans to mash the herring, centrifuge the mush to get liquid and test for toxins.

Lefebvre entered the harmful algae scene in 1998 as a graduate student. She cleverly linked the mysterious seizures and deaths of hundreds of California sea lions with the harmful diatom *Pseudo-nitzschia* and its by-product, domoic acid. The acid, known as amnesic shellfish poison (ASP), causes memory loss, brain damage and, in severe cases, death. Like PSP toxins found in Alaska's shellfish, the poison is tasteless and odorless, and the diatoms are not neutralized by cooking. Although the Seldovians have already found the diatom in their waters, they have not detected any large blooms with it—yet. Lefebvre worries about warming waters in the north. "The environment is changing so drastically that the traditional knowledge [Indigenous people] have been using for 5,000 years [can't] prepare them for this kind of rapid change," she says. Pletnikoff agrees, with the caveat that Indigenous knowledge can grow and adapt.

Alaska's HAB network is an inspiring model, Lefebvre says—a group of globally connected experts with whom individuals in remote communities can personally engage. Residents can then transmute what they are learning into new, tribal teachings, informed

A FROZEN kittiwake gull, mussels and herring from Seldovia are prepared for shipping to labs in Anchorage and Seattle (*left*). Abalone, a traditional intertidal staple, are raised at the Alutiiq Marine Pride Institute for research on subsistence foods (*top right*). The institute also grows different algae to feed shellfish being reared there (*bottom right*).

by climate change, including ways to protect themselves and other vulnerable shellfish harvesters. Researchers such as Lefebvre are motivated, she says, by a sense that, even from afar, they have a role to play in protecting people living in Alaska's remote reaches.

Indigenous-led programs linked to the quasi-official HAB network are emerging across the state. In 2016 the southerly Sitka Tribe of Alaska established its own shellfish toxin testing program, opting for an enzyme-based test called ELISA that is used in various biological assays. Over about five years the program tested 1,700 shellfish samples and found that mussels, cockles and clams were increasingly exceeding safe limits. The tribe has issued periodic advisories against consuming local shellfish.

In Kodiak, an island southwest of Seldovia, the Kodiak Area Native Association started a free "harvest and hold" shellfish testing program for subsistence harvesters in 2020. It covers the cost of shipping samples to the Sitka program and pays for testing, and it works with harvesters to discuss the findings and provide resources on the risks of HAB toxins.

In 2021 the Alutiiq Pride Marine Institute in southerly Seward, which represents seven Indigenous tribes, bought its own ELISA machine to start an ambitious testing program for PSP and ASP. Eventually lab staff hope to test both water and clam flesh for toxins on a weekly basis, creating the largest, most geographically widespread monitoring in the state. The staff has also built a data-collection portal on the institute's Web site, where people in communities around the state can submit sampling data via a simple online form.

Despite all this work, a satisfying solution remains elusive. Wright says testing of shellfish by the Sitka Tribe and Alutiiq Pride is a good start, but he worries about the reliability. ELISA is not FDA-approved for shellfish intended for human consumption, because toxins produced by shellfish are often a grab bag of hundreds of different chemicals mixed together, some undetectable to the ELISA machine. U.S. researchers have tried for years to develop a portable rapid test for PSP, but the complexity of its toxins has stymied those attempts. That is why the mouse test is still widely used.

Wright says that only a mouse assay or a pricey molecular analysis tool operated by the state can definitively confirm that shellfish are truly safe to eat. These two tests are unlikely to be used in tribal-run labs anytime soon because animal testing is strictly regulated, and the molecular test requires costly equipment and specially trained technicians.

Jeff Hetrick, director of Alutiiq Pride, thinks the problem is just lack of money and lack of will on the part of the state, not technical complexity. "We had a man walking on the moon. We're going to Mars," he told me, sitting behind his desk in Seward and shaking his head. "And we're still injecting mice with toxin?"

IF THE SCIENTIFIC networks being built by native people in Alaska can provide rapid toxin testing, residents can feel confident that their plentiful harvests are safe to consume.

SELF-DETERMINATION

UNDETERRED, THE AD-HOC NETWORKS CONTINUE. Near the end of August, soon after I left Seldovia by plane, Opheim received a cell-phone call about a dying kittiwake gull along the shore. By the time he drove to the spot, the bird was already struggling to breathe. Opheim gently moved the gull to a local kennel where it soon died. He froze the bird and quickly e-mailed Wright: Could he test the gull for toxic algae? Yes, Wright responded.

But how to get the bird to Wright, 120 miles away? A month later Kiliii Yuyan, the photographer assigned to this story, found himself roped into transporting a gull carcass and blue mussels from Seldovia to Anchorage because he was going to ferry and drive there anyway. The frozen bird, which Opheim laid out on a tray before packing it on ice inside a battered foam cooler, was soft and cool to the touch, Yuyan says, so pristine it looked as if it had just died. Yuyan reached Wright a day later, near a creek where Wright was fishing for salmon as samples. He handed the goods to Wright, who took the bird, the mussels and the guts of a Coho salmon to the state lab for testing.

If the ingenuity shown by shellfish harvesters, tribal leaders and accommodating scientists provides some hope for managing toxins along Alaska's endless shores, perhaps the threat can be handled anywhere in the world, Opheim says. What subsistence harvesters really need is more data—data they trust, own and manage, which will help tribes control the future of their food supply. "Indigenous people have been stewards of the land, sea and air for many generations," Opheim says. "We're just trying to make sure that our community members are safe." With more state and federal funding for equipment and staff, he would like to set up the tribe's own lab, which would allow it to analyze samples on its own shores.

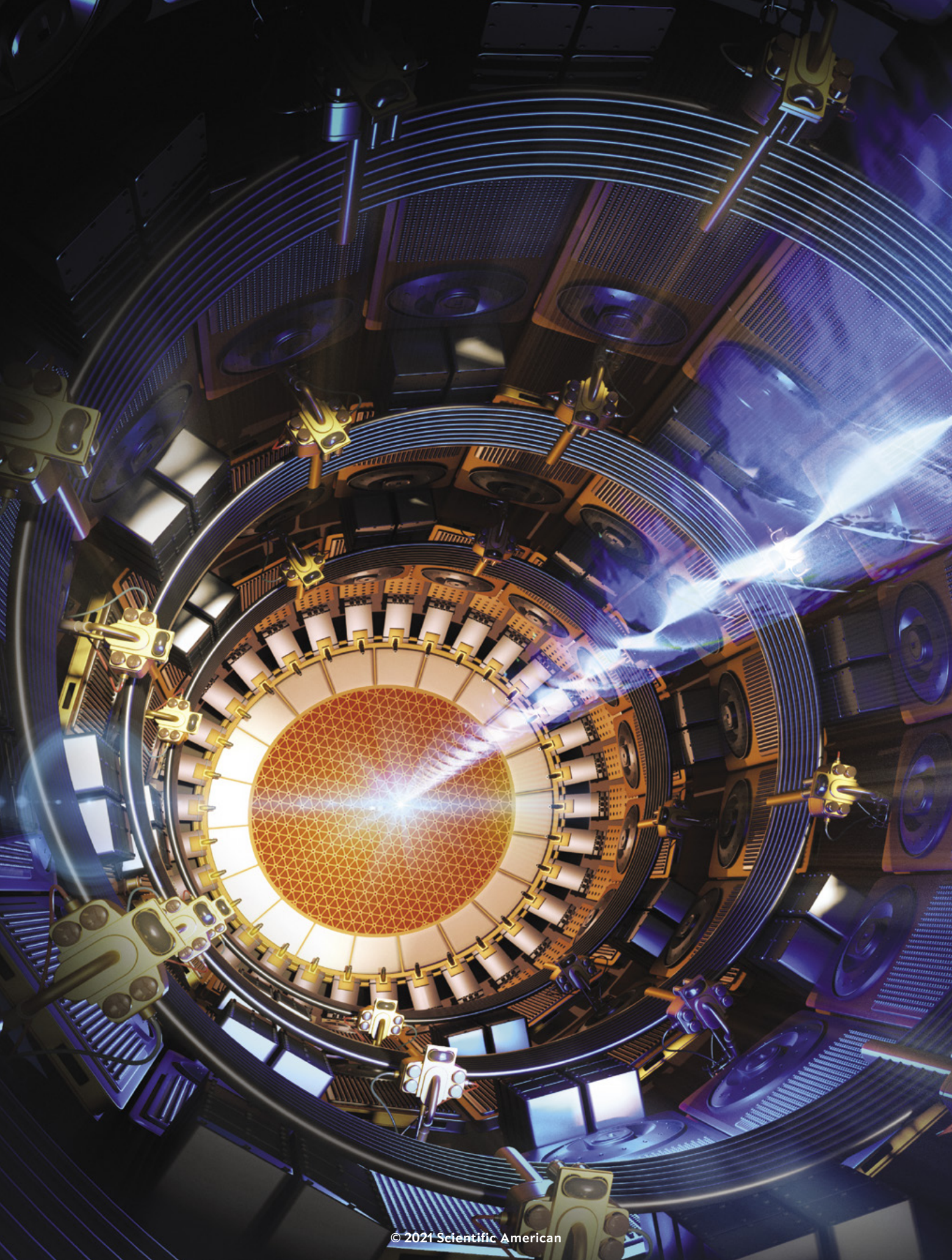
As autumn's dark, short days descended on Alaska's serrated landscape, Wright's lab results came back to Seldovia. The gull and mussels tested low for toxic algae, but the salmon liver was hot. At that same time, Wright received an e-mail from a deputy director of Russia's Academy of Sciences. For the past two decades she and her colleagues had only ever found a few hundred toxic algae per liter of ocean water near Vladivostok, but recently they had detected a staggering 200,000 *A. catenella* cells. Algae along that part of the country were growing massively, she wrote. Was Wright open to collaborating? Of course, he wrote back. There are lots of people paying attention now. SA

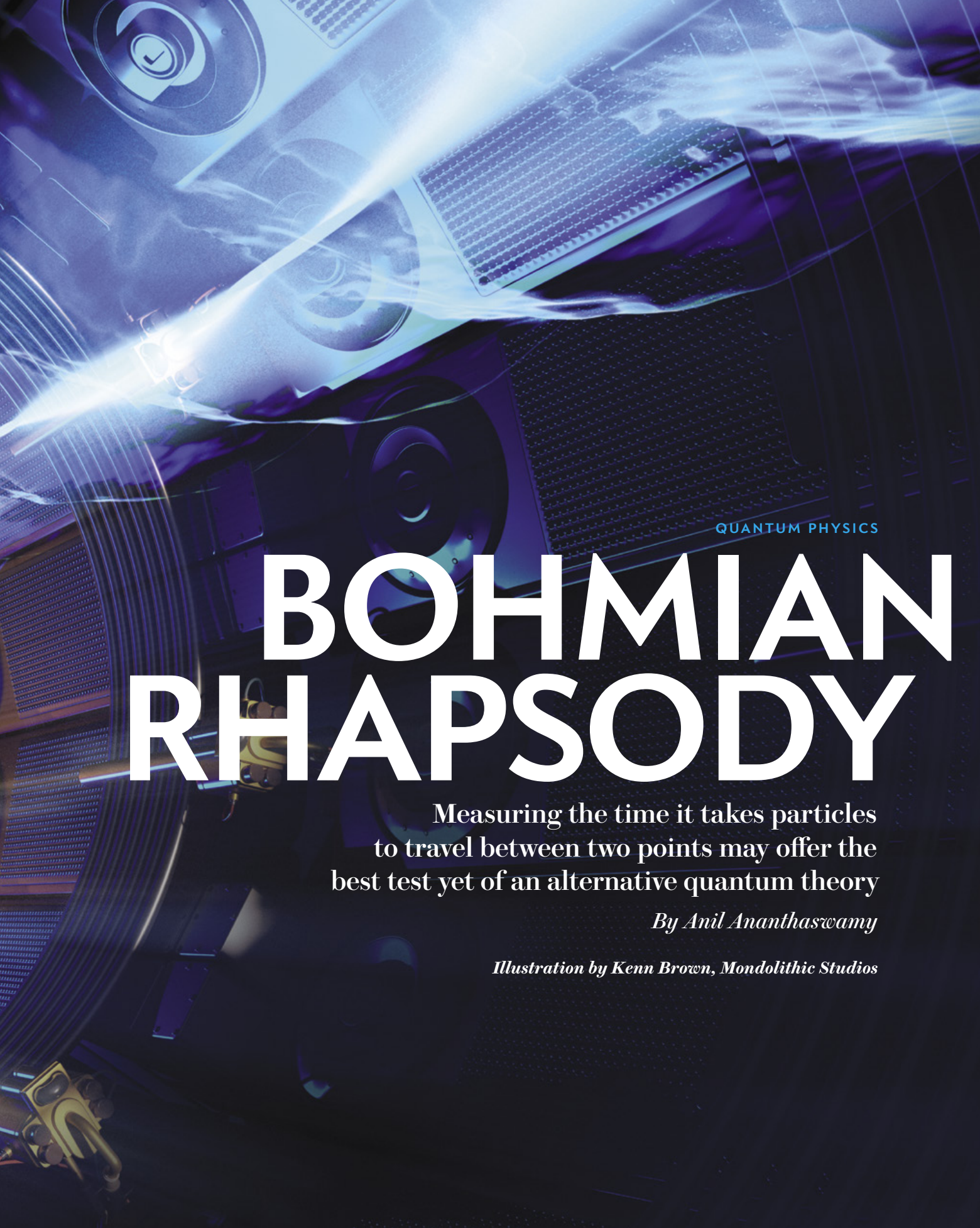
This story was supported by a grant from the Society of Environmental Journalists' Fund for Environmental Journalism.

FROM OUR ARCHIVES

Red Tides. Donald M. Anderson; August 1994.

scientificamerican.com/magazine/sa





QUANTUM PHYSICS

BOHMIAN RHAPSODY

Measuring the time it takes particles to travel between two points may offer the best test yet of an alternative quantum theory

By Anil Ananthaswamy

Illustration by Kenn Brown, Mondolithic Studios

Anil Ananthaswamy is author of *The Edge of Physics, The Man Who Wasn't There* and, most recently, *Through Two Doors at Once: The Elegant Experiment That Captures the Enigma of Our Quantum Reality.*

A DECEPTIVELY SIMPLE EXPERIMENT THAT INVOLVES MAKING PRECISE measurements of the time it takes for a particle to go from point A to point B could cause a breakthrough in quantum physics. The findings could focus attention on an alternative to standard quantum theory called Bohmian mechanics, which posits an underworld of unseen waves that guide particles from place to place.

A new study, by a team at the Ludwig Maximilian University of Munich (L.M.U.) in Germany, makes precise predictions for such an experiment using Bohmian mechanics, a theory formulated by theoretical physicist David Bohm in the 1950s and augmented by modern-day theorists. Standard quantum theory fails in this regard, and physicists have to resort to assumptions and approximations to calculate particle transit times. "If people knew that a theory that they love so much—standard quantum mechanics—cannot make [precise] predictions in such a simple case, that should at least make them wonder," says theorist and L.M.U. team member Serj Aristarhov.

It is no secret that the quantum world is weird. Consider a setup in which an electron gun fires the subatomic particles at a screen, as in the classic "double-slit experiment" [*see box on opposite page*]. You cannot predict exactly where any given electron will land to form, say, a fluorescent dot. But you can predict with precision the spatial distribution, or pattern, of dots that takes shape over time as the electrons land one by one. Some locations will have more electrons; others will have fewer. But this weirdness hides something even stranger. All else being equal, each electron will reach the detector at a slightly different time, its so-called arrival time. Just like the positions, the arrival times will have a distribution: some arrival times will be more common, and others will be less so. Textbook quantum physics has no mechanism for precisely predicting this temporal distribution. "Normal quantum theory is concerned only with 'where'; they ignore the 'when,'" says team member and theorist Siddhant Das. "That's one way to diagnose that there's something fishy."

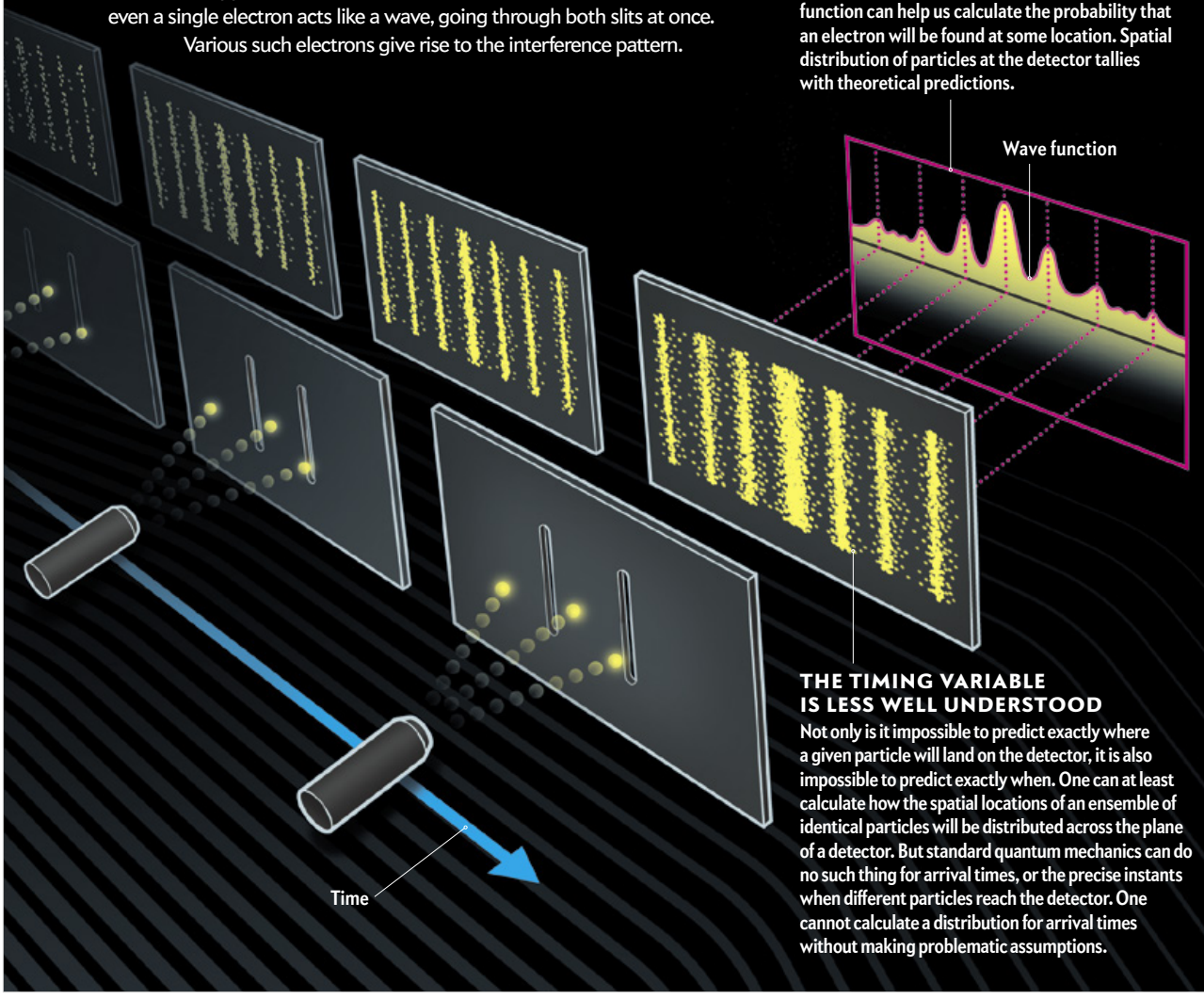
There is a deep reason for this curious shortcoming. In standard quantum theory, a physical property that can be measured is called an observable. The position of a particle, for example, is an observable. Each and every observable is associated with a corresponding mathematical entity called an operator. But the standard theory has no such operator for observing time. In 1933 Austrian theoretical physicist Wolfgang Pauli showed that quantum theory could not accommodate a time operator, at least not in the standard way of thinking about it. "We conclude therefore that the introduction of a time operator … must be abandoned fundamentally," he wrote.

Yet measuring particle arrival times, or their "time of flight," is an important part of experimental physics. Detectors at CERN's Large Hadron Collider, for example, and instruments called mass spectrometers use such measurements to calculate the masses and momenta of particles, ions and molecules. There is, however, a serious wrinkle: although these calculations concern quantum systems, they cannot be made using unadulterated quantum mechanics. Instead they require assumptions. In one method, for example, experimenters assume that once the particle leaves its source, it behaves classically, meaning it follows Newton's equations of motion.

The result is a hybrid approach—one that is part quantum, part classical. It starts with the quantum perspective, in which each particle is represented by a mathematical abstraction called a wave function. Identically prepared particles will have identical wave functions when they are released from their source. But measuring the momentum of each particle (or, for that matter, its position) at the instant of release will yield different values each time. Taken together, these values follow a distribution that is precisely predicted by the initial wave function. Starting from this ensemble of values for identically prepared particles and assuming that a particle follows a classical trajectory once it is emitted, the result is a distribution of arrival times at the detector that depends on the initial momentum distribution.

Tricky Trips via Spacetime

The double-slit experiment involves firing particles such as electrons at an opaque screen with two openings, or slits. Electrons that pass through the slits strike a detector on the other side, creating fluorescent dots. Intuitively, one would expect the dots to align with the two slits. But that is not what occurs. Instead an interference pattern gradually emerges. More dots land in regions of constructive interference and fewer or none in regions of destructive interference. This happens even if electrons are sent one at a time. Somehow even a single electron acts like a wave, going through both slits at once. Various such electrons give rise to the interference pattern.



PARTICLE POSITION PROBABILITY CURVES ARE PRETTY WELL KNOWN

What goes through the two slits is a particle's wave function, a mathematical abstraction that represents a particle's quantum state. Imagine a wave splitting into two waves, each propagating away from the slits and then eventually interfering with the other. The two components of the wave function either augment or cancel each other at the detector. The peaks and troughs of the combined wave function can help us calculate the probability that an electron will be found at some location. Spatial distribution of particles at the detector tallies with theoretical predictions.

THE TIMING VARIABLE IS LESS WELL UNDERSTOOD

Not only is it impossible to predict exactly where a given particle will land on the detector, it is also impossible to predict exactly when. One can at least calculate how the spatial locations of an ensemble of identical particles will be distributed across the plane of a detector. But standard quantum mechanics can do no such thing for arrival times, or the precise instants when different particles reach the detector. One cannot calculate a distribution for arrival times without making problematic assumptions.

Standard theory is also often used for another quantum-mechanical method for calculating arrival times. As a particle flies toward a detector, its wave function evolves according to the Schrödinger equation, which describes a particle's changing state over time. Consider the one-dimensional case of a detector that is a certain horizontal distance from an emission source. The Schrödinger equation determines the wave function of the particle—and hence the probability of detecting that particle at that location—assuming that the particle crosses the location only once. (There is, of course, no clear way to substantiate this assumption in standard quantum mechanics.) Using such assumptions, physicists can calculate the probability that the particle will arrive at the detector at a given time (t) or earlier. "From the perspective of standard quantum mechanics, it sounds perfectly fine," Aristarhov says. "And you expect to have a nice answer from that."

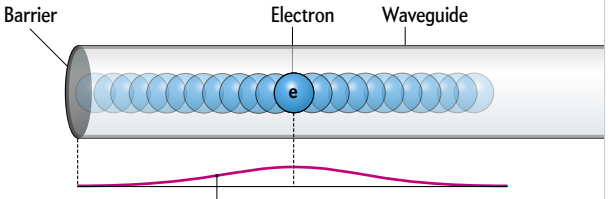
There is a hitch, however. To go from the probability that the arrival time is less than or equal to t to the probability that it is exactly equal to t involves calculating a quantity that physicists call the quantum flux, or quantum probability current—a measure of how the probability of finding the particle at the detector location changes with time. This works well, except that at

Graphic by Nick Bockelman

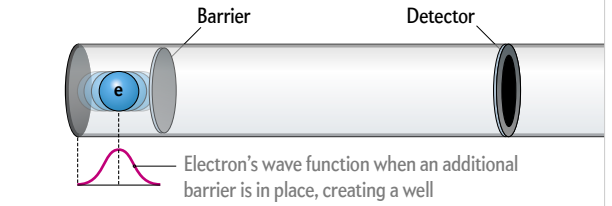
Measuring Arrival Times

Not all interpretations of quantum mechanics produce identical predictions for particle arrival times. Precisely measuring the exact moment that each of many different particles reaches a detector is no easy feat, but a bold new experiment should allow these predictions to be tested.

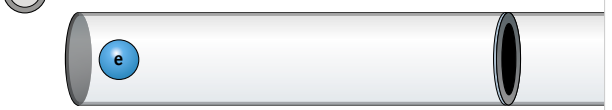
A particle is represented by a mathematical abstraction called the wave function. It can be used to calculate, say, the probability of finding the particle at a given location.



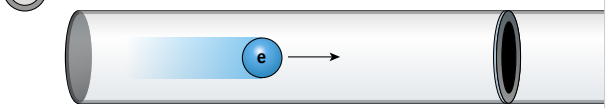
In this experiment, an electron in its ground, or lowest energy, state is held in place by an electric potential well.



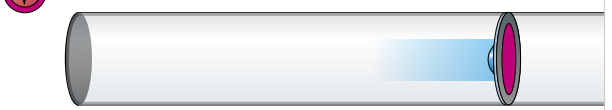
A timer starts when one barrier is removed.



The electron moves toward the detector.



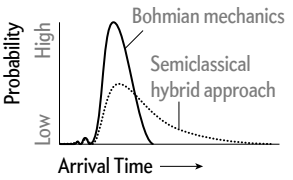
Time is recorded when the electron reaches the detector.



The experiment undergoes many repetitions, creating a distribution of arrival times.

This distribution depends on the direction of the spin vector of the particle's wave function. When the spin vector is perpendicular to the axis of the cylinder, the predictions of the arrival time distribution can be starkly different for different theories.

Arrival Time Distribution Predictions



times the quantum flux can be negative. Even though it is hard to find wave functions for which the quantity becomes appreciably negative, nothing "prohibits this quantity from being negative," Aristarhov says. "And this is a disaster." A negative quantum flux leads to negative probabilities, and probabilities can never be less than zero.

Using the Schrödinger evolution to calculate the distribution of arrival times works only when the quantum flux is positive—a case that, in the real world, only definitively exists when the detector is in the "far field," or at a considerable distance from the source, and the particle is moving freely in the absence of potentials. When experimentalists measure such far-field arrival times, both the hybrid and quantum-flux approaches make similar predictions that tally well with experimental findings. But they do not make clear predictions for "near field" cases, where the detector is very close to the source.

BOHMIAN PREDICTIONS

IN 2018 DAS and Aristarhov, along with their then Ph.D. adviser Detlef Dürr, an expert on Bohmian mechanics at L.M.U., who died in 2021, began working with colleagues on Bohmian-based predictions of arrival times. Bohm's theory holds that each particle is guided by its wave function. Unlike standard quantum mechanics, in which a particle is considered to have no precise position or momentum prior to a measurement—and hence no trajectory—particles in Bohmian mechanics are real and have squiggly trajectories described by precise equations of motion (albeit ones that differ from Newton's equations of motion).

Among the researchers' first findings was that far-field measurements would fail to distinguish between the predictions of Bohmian mechanics and those of the hybrid or quantum-flux approaches. This is because over large distances Bohmian trajectories become straight lines, so the hybrid semiclassical approximation holds. Also, for straight far-field trajectories, the quantum flux is always positive, and its value is predicted exactly by Bohmian mechanics. "If you put a detector far enough [away] and you do Bohmian analysis, you see that it coincides with the hybrid approach and the quantum-flux approach," Aristarhov says.

The key, then, is to do near-field measurements—but those have long been considered impossible. "The near-field regime is very volatile," Das says. "It's very sensitive to the initial wave-function shape you have created." Also, "if you come very close to the region of initial preparation, the particle will just be detected instantaneously. You cannot resolve [the arrival times] and see the differences between this prediction and that prediction."

To avoid this problem, Das and Dürr proposed an experimental setup that would allow particles to be detected far away from the source while still generating unique results that could distinguish the predictions of Bohmian mechanics from those of the more standard methods.

Conceptually, the team's proposed setup is simple. Imagine a waveguide—a cylindrical pathway that confines the motion of a particle (an optical fiber is such a waveguide for photons of light, for example). On one end of the waveguide, prepare a particle—ideally an electron or some particle of matter—in its lowest energy, or ground, state and trap it in a bowl-shaped electric potential well. This well is actually the composite of two adjacent potential barriers that collectively create the parabolic

Graphic by Jen Christiansen

shape. If one of the barriers is switched off, the particle will still be blocked by the other that remains in place, but it is free to escape from the well into the waveguide.

Das pursued the painstaking task of fleshing out the experiment's parameters, performing calculations and simulations to determine the theoretical distribution of arrival times at a detector placed far away from a source along a waveguide's axis. After a few years of work, he had obtained clear results for two different types of initial wave functions associated with particles such as electrons. Each wave function can be characterized by something called its spin vector. Imagine an arrow associated with the wave function that can be pointing in any direction. The team looked at two cases: one in which the arrow points along the axis of the waveguide and another in which it is perpendicular to that axis.

The team showed that when the wave function's spin vector is aligned along the waveguide's axis, the distribution of arrival times predicted by the quantum-flux method is identical to that predicted by Bohmian mechanics. But these distributions differ significantly from those calculated for the hybrid approach. When the spin vector is perpendicular, the distinctions become even starker. With help from their L.M.U. colleague Markus Nöth, the researchers showed that all the Bohmian trajectories will strike the detector at or before this cutoff time. "This was very unexpected," Das says.

Again, the Bohmian prediction differs significantly from the predictions of the semiclassical hybrid theory, which do not exhibit such a sharp arrival-time cutoff. And crucially, in this scenario, the quantum flux is negative, meaning that calculating arrival times using Schrödinger evolution becomes impossible. The standard quantum theorists "put their hands up when [the quantum flux] becomes negative," Das says. But Bohmian mechanics continues to make predictions. "There's a clear distinction between [it] and everything else," Aristarhov says.

EXPERIMENTALISTS ENTER THE FRAY

QUANTUM THEORIST Charis Anastopoulos of the University of Patras in Greece, an expert on arrival times, who was not involved with this work, is both impressed and circumspect. "The setup they are proposing seems plausible," he says. And because each approach to calculating the distribution of arrival times involves a different way of thinking about quantum reality, a clear experimental finding could jolt the foundations of quantum mechanics. "It will vindicate particular ways of thinking," Anastopoulos says. "So in this way, it will have some impact.... If it [agrees with] Bohmian mechanics, which is a very distinctive prediction, this would be a great impact, of course."

At least one experimentalist is gearing up to make the team's proposal a reality. Before Dürr's death, Ferdinand Schmidt-Kaler of the Johannes Gutenberg University Mainz in Germany had been in discussions with him about testing arrival times. Schmidt-Kaler is an expert on a type of ion trap in which electric fields are used to confine a single calcium ion. An array of lasers is used to cool the ion to its quantum ground state, where the momentum and position uncertainties of the ion are at their minimum. The trap is a three-dimensional bowl-shaped region created by the combination of two electric potentials; the ion sits at the bottom of this "harmonic" potential. Switching off one of the potentials creates conditions similar to what is required by the theoretical proposal: a barrier on one side and a sloping electric potential on the other side. The ion moves down that slope, accelerates and gains velocity. "You can have a detector outside the trap and measure the arrival time," Schmidt-Kaler says. "That is what made it so attractive."

For now his group has done experiments in which the researchers eject the ion out of its trap and detect it outside. They showed that the time of flight is dependent on a particle's initial wave function. The results were published in 2021 in the *New Journal of Physics*. Schmidt-Kaler and his colleagues have also performed not yet published tests of the ion exiting the trap only to be reflected back in by an "electric mirror" and recaptured—a process the setup achieves with 98 percent efficiency, he says. "We are underway," Schmidt-Kaler says. "Of course, it is not tuned to optimize this measurement of the time-of-flight distribution, but it could be."

That is easier said than done. The detector outside the ion trap will likely be a sheet of laser light, and the team will have to measure the ion's interaction with the light sheet to nanosecond precision. The experimentalists will also need to switch off one half of the harmonic potential with similar temporal precision—another serious challenge. These and other pitfalls abound on the path between theoretical prediction and experimental realization.

A clear experimental finding for the distribution of arrival times could jolt the foundations of quantum mechanics.

Still, Schmidt-Kaler is excited about the prospect of using time-of-flight measurements to test the foundations of quantum mechanics. "This has the attraction of being completely different from other [kinds of] tests. It really is something new," he says. "This will go through many iterations. We will see the first results, I hope, in the next year. That's my clear expectation." Meanwhile Aristarhov and Das are reaching out to others, too. "We really hope that the experimentalists around the world notice our work," Aristarhov says. "We will join forces to do the experiments."

In a yet to be published paper co-authored by Dürr before he died, the closing words could almost be an epitaph: "It should be clear by now that the chapter on time measurements in quantum physics can only be written if genuine quantum-mechanical time-of-flight data become available." Which theory will the experimental data pick out as correct—if any? As Dürr wrote, "It's a very exciting question." SA

FROM OUR ARCHIVES

Bohm's Alternative to Quantum Mechanics. David Z Albert; May 1994.

scientificamerican.com/magazine/sa

FICTION

Planet Plague

A virus escapes from melting ice

Review by Robin MacArthur

Sometimes a novel comes along that feels so prescient—so startlingly aligned with the happenings of the real world—it seems plausible that the author was attuned not just to scientific foreshadowing but to some divinatory reading of the stars.

I felt this reading Sequoia Nagamatsu's *How High We Go in the Dark,* a dystopian narrative set in the near future about an ancient virus that is uncovered by a scientist named Clara while she is researching melting permafrost in the Arctic. Tragically, Clara and her peers, while working tirelessly to slow the climate crisis, unwittingly spark the kind of global suffering they were hoping to avoid.

This Arctic plague soon causes widespread panic, death and grief, and Nagamatsu imagines the ways sorrow, technology and art might align in such a fathomable future. In a series of interconnected stories told from multiple points of view, we encounter a euthanasia theme park for dying children, a surreal version of the afterlife, a talking pig, a black hole implanted in the brain of a scientist, a funerary skyscraper, a dysfunctional repair shop for robotic dogs, and an interstellar spaceship. Woven throughout are flickers of starlight, myth and humanity's age-old connection with the natural world. Humming beneath the fantastical, scientific and mystical imaginings of this book are quiet and tender stories of love, family and belonging.

How High We Go in the Dark
by Sequoia Nagamatsu.
William Morrow, 2022 ($27.99)

Although the glitter of Nagamatsu's imaginative renderings was what first caught my attention, it was these personal stories that lingered. Set in the future amid a pandemic far worse than our own, this polyphonic novel reflects our human desire to find meaning within tragedy. To feel our innate interconnection with all things, to care for one another—strangers, even—during times of immense loss, to learn how to say goodbye, to make things of beauty, and, most essentially, to inhabit and tend a livable planet for all.

IN BRIEF

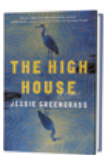
Dark and Magical Places: The Neuroscience of Navigation

by Christopher Kemp.
W. W. Norton, 2022 ($26.95)

Navigation is the one of the most complex cognitive tasks humans engage in daily. In this fascinating dive into the brain, neurobiology researcher Christopher Kemp explores how we orient where we're going, why we lose our way, and what scientists know about how we do both these things. Kemp's explanations of concepts such as grid cells are clear and engaging, but the book shines brightest in his entertaining descriptions of his own chronic lost-ness, as well as in surprisingly moving stories about people who have wandered perilously off route. Some make it home, but others don't. *—Tess Joosse*

The High House

by Jessie Greengrass.
Scribner, 2022 ($27)



In Jessie Greengrass's lush novel, set in a flood-ravaged Florida, a climate activist named Francesca has prepared a shelter but dies in a hurricane before she can reach it. Following her survival plan, Francesca's young son and stepdaughter flee to the "high house," where they are met by Grandy—a resourceful steward of sorts for the emptying vacation town—and his granddaughter. This unlikely quartet holes up, struggling to adjust to new circumstances. As the water rises, threatening to reach even them, Greengrass explores what it is like to grow up amid an escalating catastrophe and what remains after so much is swept away. *—Ian Battaglia*

This Boy We Made: A Memoir of Motherhood, Genetics, and Facing the Unknown

by Taylor Harris. Catapult, 2022 ($26)

Taylor Harris's gripping memoir is about medicine in the same way it is about race: completely and not at all. When her second child, Tophs, starts experiencing inexplicable symptoms, even the most seasoned specialists are baffled. At each turn in their medical journey, Harris and her husband demand to exist and to be taken seriously in a system that would rather ignore them. With tender, evocative prose, the author executes a daunting undertaking: to floodlight the intersection of two "burdens—Black and undiagnosed—in a world that is comfortable with neither." The result is alternately heartwarming and enraging. *—Maddie Bender*

Illustration by London Ladd

Science Class Is Now in Session

Join your instructor, Editor in Chief Laura Helmuth, for ***Examining the Big Questions of Time***

6-hour video course includes 12 lessons that wrestle with the deeper meaning of time

Based on our bestselling collector's edition, *A Matter of Time*

Contributions from physicists, philosophers, cosmologists and neurologists

Special Holiday Offer

Scientific American subscribers: **Save 90%!**

DVD: ~~$199.95~~ $19.95

Instant Video: ~~$169.95~~ $14.95

Go to:

www.TheGreatCourses.com/SciAm2

Offer valid until December 28, 2021

Brought to you by

SCIENTIFIC AMERICAN + THE GREAT COURSES

Eat to Save the Planet

Cutting back on red meat will help our climate, and anyone can do it

By Naomi Oreskes

When I give public lectures about the climate crisis, the most common question people pose is: "Are you an optimist or a pessimist?" My answer is yes. California has achieved dramatic emissions reductions in a thriving economy, which makes me hopeful, yet in general the fossil-fuel industry is determined not to change. The second most common question is: "What can I, personally, do?"

That's a tough one. The major drivers of climate change are collective enterprises such as power grids, industry, large-scale agriculture and transportation systems. About half of all greenhouse gas emissions comes from electricity generation and industrial fossil-fuel use. Substantial emissions reductions in these settings most likely will not come from personal actions; they will come from laws and policies such as carbon-pricing systems, revised building codes and supports for green investment.

Some people have argued that calls for individual action actually distract us from corporate responsibility. That could explain why the fossil-fuel industry is enamored of such entreaties. Oil giant BP popularized and promoted the idea of a carbon footprint, deflecting attention to its customers who, it suggests, should take personal responsibility by lowering their carbon footprints. One study found that focusing on individual activity actually undermines support for more effective policy initiatives such as a carbon tax.

Naomi Oreskes is a professor of the history of science at Harvard University. She is author of *Why Trust Science?* (Princeton University Press, 2019) and co-author of *Discerning Experts* (University of Chicago, 2019).

Another problem with personal behavior is that people do not like to be told what to do. As former congressperson Bob Inglis of South Carolina (a conservative) said in the documentary *Merchants of Doubt,* people think, "You're saying that I shouldn't have this house in a suburb? I shouldn't be driving this car?"

Yet individual acts can grow into influential group activity. It is easy to feel helpless in the face of the strength of the fossil-fuel behemoth or to think that calling your congressperson is a meaningless gesture, especially when you learn about the billions of dollars the industry and its allies have spent trying to block Congress from acting. But one effective act, and one that can be amplified, is to eat less red meat.

Cutting meat consumption is a powerful and personal thing most Americans can do to tackle the climate crisis, and they can do it immediately. About 40 percent of greenhouse gases come from agriculture, deforestation and other land-use changes. Meat—particularly beef—drives climate change in two ways: first, through cows' emission of methane, a potent greenhouse gas, and second, by destroying forests as they are converted to grazing land. Despite the economic slowdown caused by the COVID pandemic, atmospheric greenhouse gas levels continued to rise in 2020, in large part because of an emissions increase in the Amazon as rain forests were changed into land for cattle to satisfy the global demand for beef. By eating less beef, we can start to decrease that demand.

You do not have to become a vegan to do this. According to one recent study, if every person in the U.S. cut their meat consumption by 25 percent, it would reduce annual greenhouse gas emissions by 1 percent. That might not sound like a lot, but it would help protect the rain forest, so the positive effects—including reduced water and fertilizer use, improved biodiversity and safeguarded rights of Indigenous peoples—would be amplified.

Perhaps most important, social action is contagious—in a good way. If lots of us begin to eat less meat and if we talk about it constructively, we will likely influence others. Pretty soon the 1 percent reduction becomes 2 percent or more. Reduced demand for meat could motivate my local supermarket to carry better produce, making it easier for me and my neighbors to prepare a few more satisfying meat-free meals. Ultimately changes in demand will influence industry. Forty years ago few mainstream supermarkets carried organic products; now nearly all do. Consumer demand did that.

Cutting back on red meat also has the added benefit of being good for your health. So while I wouldn't advise governments to order people to stop eating hamburgers, if anyone asks, "What can I do?," a simple and accurate answer is: "Eat less meat. It's in your control, and you can begin right now. It benefits both you and the planet." SA

JOIN THE CONVERSATION ONLINE
Visit *Scientific American* on Facebook and Twitter or send a letter to the editor: editors@sciam.com

Illustration by Evangeline Gallagher

50, 100 & 150 YEARS AGO

INNOVATION AND DISCOVERY AS CHRONICLED IN *SCIENTIFIC AMERICAN*

Compiled by Mark Fischetti

JANUARY

1972 Molten Moonglow

"Thermocouples placed in two holes drilled on the surface of the moon by the astronauts of *Apollo 15* show that heat is flowing outward at about three times the rate that had been expected. The source of the heat is presumed to be the decay of radioactive elements and confirms the high level of radioactivity previously measured in samples of lunar soil. The puzzling aspect of the measurements is that if the entire moon were as radioactive as the surface soil, the entire body, in the words of one investigator, 'would be just a molten puddle.'"

Car Radar Navigation

"A motorist groping through a heavy fog may well wonder if radar would help. Although it is unlikely that radar for private automobiles will be available in the near future, many of the technical problems have been solved in an ingenious system developed by Mullard Research Laboratories for airport vehicles. The image presented by the system is a direct representation of the scene ahead of the driver, projected on a television picture tube in the cab of the vehicle."

1922 Postwar Garbage Crisis

"The present-day system of garbage reduction is founded on the thought that some of the contents are valuable. Destroy this value, and the whole system falls. That is what has happened. The principal material salvageable from garbage is grease. Prior to the war this grease found a ready market among soap and candle makers. But since the signing of the armistice this country has been flooded with millions of pounds of oils from [Asia], and tallow from South America, produced so cheaply that competition is impossible. All of the privately owned garbage reduction plants which have not already shut down will soon have to do so, and the municipal plants must follow."

1972

1922

1872

Abundance of Asbestos

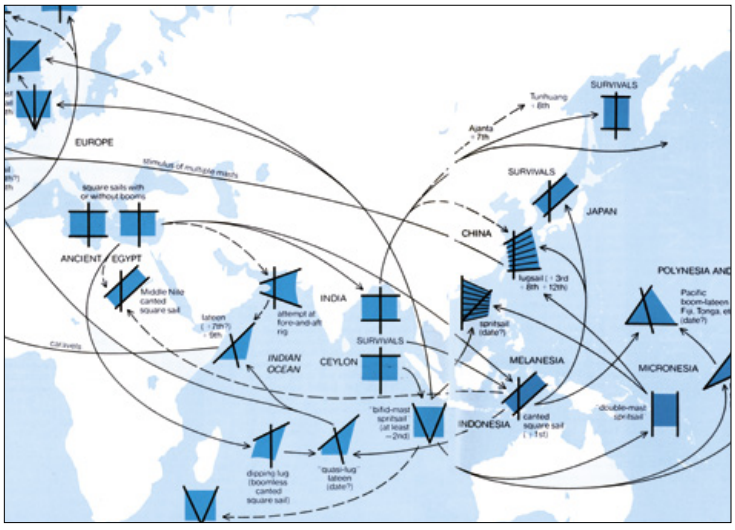
"A recent discovery was made of asbestos-bearing rock being of considerable value. The deposit is located in the serpentine rocks of the Canadian Pacific Railway north of Arrowhead. The *Montreal Daily Star* recently announced that a large manufacturing plant for making asbestos products is about to be constructed in Quebec. About 80 percent of the asbestos produced in Canada has heretofore been exported to the United States."

1872 Booster Shots for Smallpox

"Of all the fearful diseases that scourge the human race, [smallpox] is justly feared most. The disfigurating scars it leaves, upon many of those who escape death, are a lifelong sequel to a disgusting and painful sickness. Statistics show that about one half of those who have had the vaccine disease as a result of vaccination are liable to a form of smallpox called varioloid, approaching more or less in violence to malignant types of the disease. To insure safety, it is necessary that revaccination be practiced. There is no fact better established in medical science than that persistent revaccination will practically exterminate smallpox. Had we a law compelling vaccination and revaccination, we should soon cease to hear of the ravages of a scourge so dreadful. As it is, it is quite doubtful such a law could be enforced if enacted."

Press Temples, Pull Teeth

"Dr. A. C. Castle (*Dental Cosmos*) observes that he has for thirty years benumbed the temporal nerves, for painless extraction of teeth from their sockets, never having used chloroform, ether or nitrous oxide gas. One of two modes may be adopted. By application of ice to the temples, which is somewhat distressing, the sensation of cold striking deeply. The other is done by an assistant, with each of his middle fingers pressing with persistent firmness into the hollow behind the ridge of the temporal bone, which forms the [side wall of the eye socket]. Pressure for one minute is all that is necessary. The practice leaves no unpleasant sensation to annoy the patient. It is an instinctive method often adopted by people themselves, who press their temples with their fingers to relieve themselves temporarily of headache."



1972: "Types of sails are superimposed on a map of the Old World. The heavy lines are masts, sprits, gaffs and so on. The arrows show the possible genetic derivations, with the broken arrows indicating speculative relations."

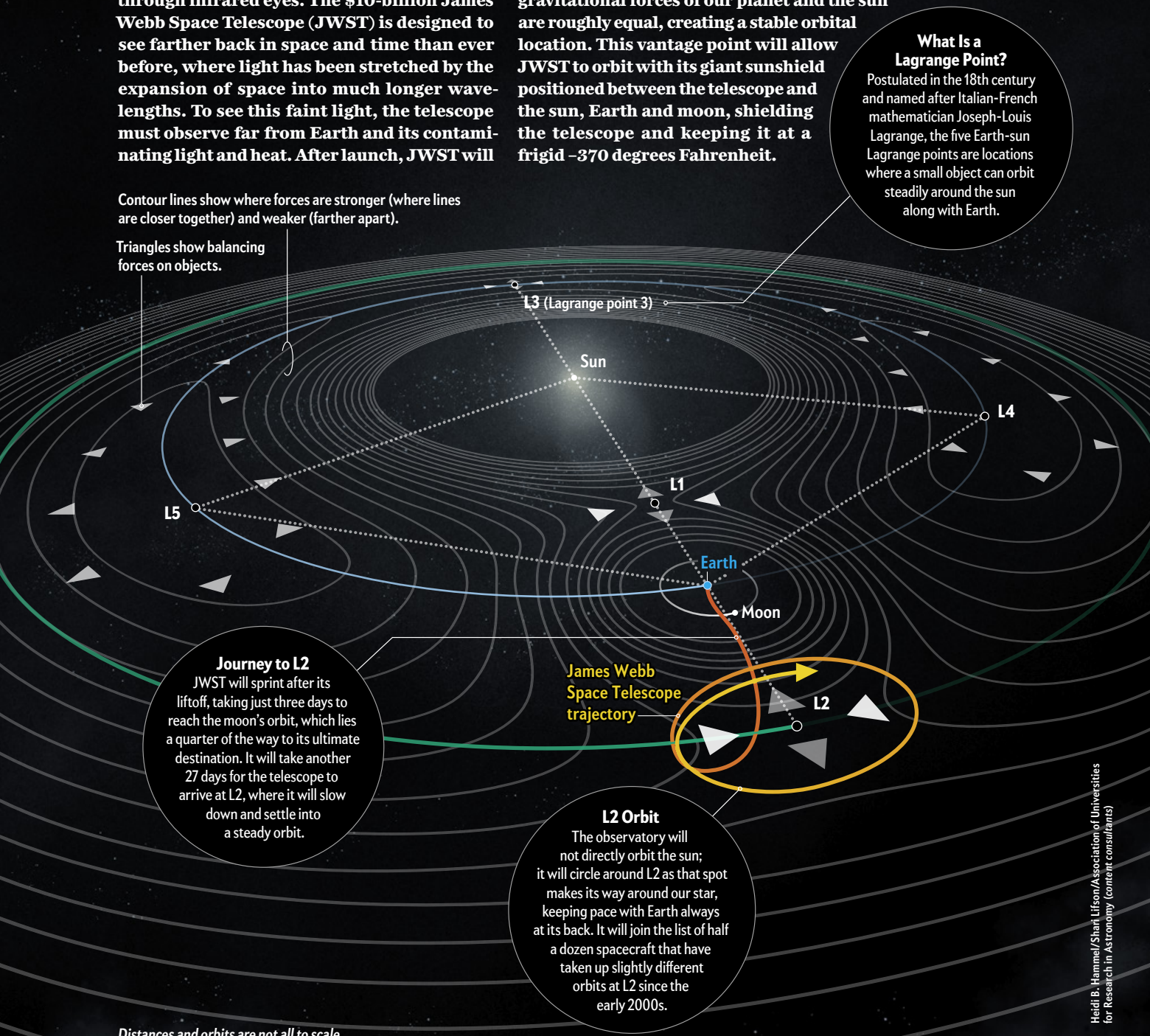
Scientific American, Vol. 226, No. 1; January 1972

Text by Clara Moskowitz | Graphic by Matthew Twombly

A Telescope's Long Journey

NASA's new observatory will travel to a spot where it can block light from Earth and the sun

The most ambitious space telescope built to date is about to start peering at the universe through infrared eyes. The $10-billion James Webb Space Telescope (JWST) is designed to see farther back in space and time than ever before, where light has been stretched by the expansion of space into much longer wavelengths. To see this faint light, the telescope must observe far from Earth and its contaminating light and heat. After launch, JWST will travel 1.5 million kilometers to Earth's second "Lagrange point" (L2), a spot in space where the gravitational forces of our planet and the sun are roughly equal, creating a stable orbital location. This vantage point will allow JWST to orbit with its giant sunshield positioned between the telescope and the sun, Earth and moon, shielding the telescope and keeping it at a frigid –370 degrees Fahrenheit.



What Is a Lagrange Point?
Postulated in the 18th century and named after Italian-French mathematician Joseph-Louis Lagrange, the five Earth-sun Lagrange points are locations where a small object can orbit steadily around the sun along with Earth.

Journey to L2
JWST will sprint after its liftoff, taking just three days to reach the moon's orbit, which lies a quarter of the way to its ultimate destination. It will take another 27 days for the telescope to arrive at L2, where it will slow down and settle into a steady orbit.

L2 Orbit
The observatory will not directly orbit the sun; it will circle around L2 as that spot makes its way around our star, keeping pace with Earth always at its back. It will join the list of half a dozen spacecraft that have taken up slightly different orbits at L2 since the early 2000s.

Distances and orbits are not all to scale.

Heidi B. Hammel/Shari Lifson/Association of Universities for Research in Astronomy (*content consultants*)

Scientific American Unlimited

Perfect for science fans, gain access to all of our publications, apps & the full website experience.

Digital archive access back to 1845 including articles by Einstein, Curie and other timeless luminaries in more than 7,000 issues!

12 print and digital issues of *Scientific American* per year

More than 150 eBooks and Collector's Editions

Access to *Scientific American Mind*, *Space & Physics* and *Health & Medicine*

More than 200 articles per month, including news and commentary, on ScientificAmerican.com

sciam.com/unlimited

An engineering revolution is underway in soft machines and robots to assist people in new ways through next-generation systems.

In Softbotics, our vision is to create a step change in moving robotics from industrial large scale to smaller human scale and thereby entering households, workplaces, hospitals and aspects of the environment to provide new solutions.

One day people around the globe will be touched by the enhanced performance these technologies will offer.

Learn more about partnering with us: softbotics.org.

Carnegie Mellon University
College of Engineering