

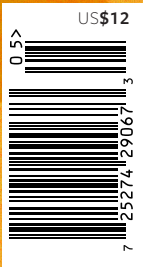
NAUTILUS



ISSUE 50

Science Connected

NAUTILUS





CORMAC MCCARTHY

Novelist, SFI Trustee and Life Fellow,
colleague, friend, and inspiration
1933-2023



SANTA FE
INSTITUTE

Cormac McCarthy at his typewriter in the Santa Fe Institute library. (image: SFI)

Contents

Editor's Note

- 5 *Here's to You*
BY KEVIN BERGER

Preludes

- 11 *Inebriated animals; when ancient architecture beats modern; watery moons; how climate change alters diseases; and an annotated iceberg*

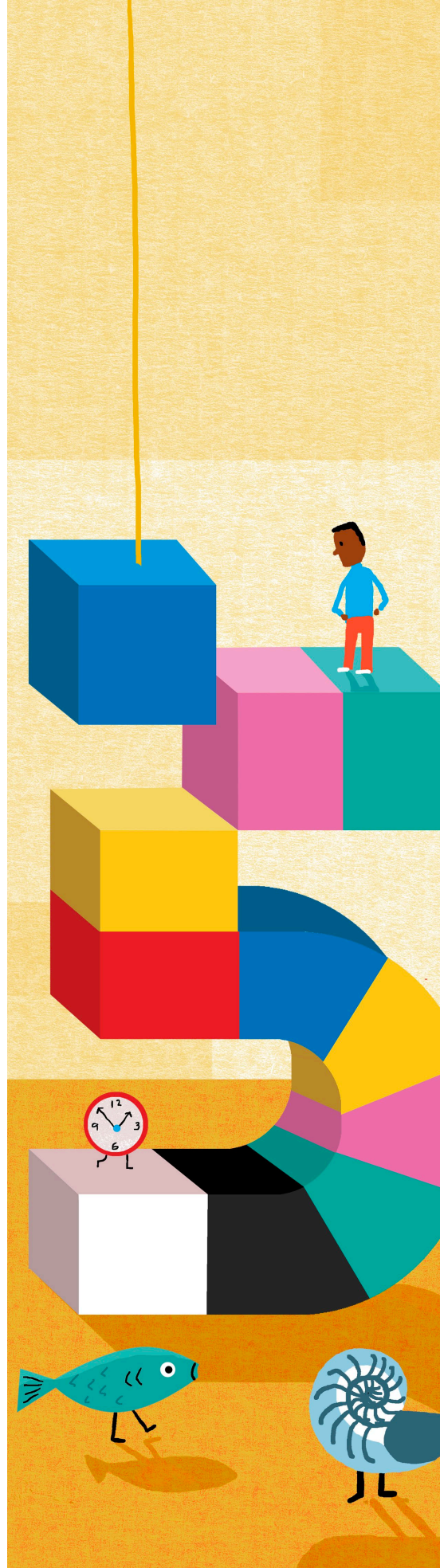
Cover Story

- 24 50 Facts So Romantic
One fact from each Nautilus print edition adds up to one amazing universe
BY NAUTILUS EDITORS

The Last Word

- 132 Yo-Yo Ma & Fabiola Gianotti
The renowned cellist and director-general of CERN, the largest particle physics lab in the world, discuss art, science, and truth

Cover Art by James Yang
Celebrating the 50th *Nautilus* print edition





the blue paradox

an immersive experience
on the ocean plastic crisis



museum of
science+industry
chicago

Presented by

scJohnson
A family company
at work for a better world

In partnership with

CONSERVATION
INTERNATIONAL 

Learn more at blueparadox.com



Features

- ARTS
- 22 **Cormac McCarthy Took Us Beneath the Surface**
Inside the celebrated novelist's first and only nonfiction essay
BY KEVIN BERGER
- ZOOLOGY
- 34 **The Perilous Life of the Solitary Pangolin**
Poached to the edge of extinction, the bashful animals are getting by with a little help from their friends in Africa
BY CHARLES DIGGES
- ARTS
- 44 **The New Renaissance**
Today's scientists and artists are reunited in a single creative culture
BY KRISTEN FRENCH
- TECHNOLOGY
- 60 **Why Conscious AI Is a Bad, Bad Idea**
Our minds haven't evolved to deal with machines we believe have consciousness
BY ANIL SETH
- HISTORY
- 68 **The 19th-Century Trippers Who Probed the Mind**
In the age of self-experiment, scientists took mind-altering drugs to test the limits of subjectivity
BY MIKE JAY
- PSYCHOLOGY
- 74 **Why Scientists Need to Get High**
Psychoactive drugs have long been hailed as miracle cures. But you can only understand the paths they blaze through the mind if you've traveled them.
BY STEVE PAULSON
- GEOSCIENCE
- 82 **The Secret Messages in Ancient Storms**
Paleotempestology promises to uncover patterns of historical hurricanes—to better predict destructive weather of the future
BY KATARINA ZIMMER
- ASTRONOMY
- 88 **Searching for Life Under a Methane Rain**
What future missions to Saturn's moon Titan will reveal about the universe
BY PAUL M. SUTTER
- GEOSCIENCE
- 92 **The Amazon River in the Sky**
A crucial link that sustains the Amazon rainforest is at risk of running dry
BY DANIEL HENRYK RASOLT
- PHILOSOPHY
- 100 **A Conversation with Animal Rights Pioneer Peter Singer**
"Animal Liberation" is nearly 50 years old. What have we learned?
BY BRANDON KEIM
- MICROBIOLOGY
- 110 **The Longevity Skeptic**
This biochemist calls BS on extending human lifespan. Is he right?
BY MATT FUCHS



NAUTILUS

EDITORIAL

NautilusNext CEO
Nicholas White

Publisher & Editorial Director
John Steele

Editor
Kevin Berger

Managing Editor
Liz Greene

Deputy Editor
Katherine Harmon Courage

Associate Editors
Kristen French
Brian Gallagher

Copy Editor
Teresa Cirolia

Production Designer
Tasnuva Elahi

Contributing Editors
Brandon Keim
George Musser
Lina Zeldovich

BOARD OF ADVISORS

David Agus *Professor of Medicine and Engineering, University of Southern California*

Bob Bazell *Adjunct Professor of Molecular, Cellular, and Developmental Biology, Yale University*

Christina Beck *Head of Science & Corporate Communications, The Max Planck Society*

Sean Carroll *Senior Research Associate, Department of Physics, California Institute of Technology*

Jennifer Dunne *Professor and V.P. for Science, Santa Fe Institute*

Josh Empson *Managing Director, Providence Equity Partners*

Bran Ferren *Co-Chairman, Applied Minds, Inc.*

Stuart Firestein *Chairman of the Department of Biological Sciences, Columbia University*

Heinz Falk *Professor Emeritus of Organic Chemistry, Johannes Kepler Universität Linz, Austria*

Jessica Flack *Professor and Director, Collective Computation Group, Santa Fe Institute*

Peter Galison *Pellegrino University Professor in History of Science and Physics, Harvard University*

Thomas Campbell Jackson *Venture Partner, Easton Capital Investment Group*

Beth Jacobs *Managing Partner, Excellentia Global Partners*

David Kaiser *Germeshausen Professor of the History of Science, MIT*

Lisa Kaltenegger *Associate Professor of Astronomy, Cornell University and Director of the Carl Sagan Institute*

David Krakauer *President, Santa Fe Institute*

Ben Lamm *Founder and CEO of HyperGiant*

Barnaby Marsh *Senior Advisor to the President, John Templeton Foundation*

Walter Murch *Film Editor, Director, Writer, and Sound Designer*

Gayil Nalls *Artist, Philosopher, and Writer*

Elisa New *Powell M. Cabot Professor of American Literature, Harvard University*

Gerry Ohrstrom *Private Investor and Producer; Former Chairman of G.L. Ohrstrom & Co. and the Ohrstrom Foundation*

Jerry Sabloff *External Professor and Past President, Santa Fe Institute*

Paula Sabloff *External Professor, Santa Fe Institute*

Caleb Scharf *Director of Astrobiology, Columbia University*

David Evans Shaw *Activist, Impact Investor, and Managing Partner of Black Point Group*

Ian Tattersall *Curator Emeritus, American Museum of Natural History*

Geoffrey West *Distinguished Professor and Past President, Santa Fe Institute*

Carlie Wiener *Director of Communications & Engagement Strategy, Schmidt Ocean Institute*

CONTACT

360 W 36th Street, 7S
New York, NY 10018

info@nautil.us

SUBSCRIPTIONS

Visit nautil.us/join

Published by:



NAUTILUS *Next*

Copyright © 2023. All rights reserved.

Here's to You

BY KEVIN BERGER

HAPPY ANNIVERSARY! *Nautilus* has been exploring the seas of science for 10 years. You're holding our 50th print issue, our showcase that complements our website. In this omnipresent digital world, isn't print great?

A decade ago, *Nautilus* founder John Steele had an idea: a science magazine that dove into big philosophical questions. Sparked by John's energy, we launched *Nautilus* from a midtown Manhattan dock in 2013. Our periscope had been aimed at other science magazines, institutions looking rusty to us. Our mission was clear. Let's inject vitality into a science magazine. Let's bring the incredible work being done in labs and the field with original writers and illustrators. Let's send them into the world to cover science like an artist, interpreting subjects with individual voices and perspectives. Let's spotlight how science reverberates in cultures and shapes societies and ourselves. Most of all, let's show the world that science is an ongoing story. We'll be the ones to tell it.

Inaugural editor-in-chief Michael Segal envisioned *Nautilus* like no other magazine. Each month we'd present a theme, a big idea, like Uncertainty or Time, and present it like the title of a book. Each week we'd publish a new chapter, featuring articles on the theme from myriad fields of science. When you got to the end of the book, you could reflect on connections—among the different fields of science, among science and culture, among you and the environment. To counteract the sense that the world is fragmented, we created *Nautilus* to show it is connected.

When I look back and remember our crew building *Nautilus*, and reflect on the territory we've now covered, I feel pretty darn proud. The surprising vantage points of our stories, and the daring verve in our prose, have won *Nautilus* top magazine and science media awards. But I see the waters we've covered as paths to new shores. While our website design and story presentation have evolved, our mission to delight and edify brims with the energy we had when we first set sail. We remain as independent as ever, determined to tell the ongoing story of science in our own fearless way.

On our 10th anniversary, 50 print issues strong, we raise a glass to you, our readers. Your support is the fuel of *Nautilus*. Cheers! We're so glad you're with us.



MAIDEN VOYAGE Issue 1 of the *Nautilus* print journal.

SCHMIDT



OCEAN
INSTITUTE

BOLDLY EXPLORE

OUR UNKNOWN OCEAN



Learn more:
strategicframework.schmidtocan.org

A SYMBOL OF HOPE

Gorongosa National Park in Mozambique is a landscape of wild, natural beauty. We restore wildlife, protect endangered species, and with over 102,000 large animals thriving in the Park, we're making a positive impact. We recognize the link between thriving communities and a healthy ecosystem by creating jobs and investing in local education and healthcare.

Join us as we empower Mozambique's next generation to lead Gorongosa Park. Be a part of this conservation success story at Gorongosa.org.



JOIN THE OCEAN KNOWLEDGE REVOLUTION



**2021
2030** United Nations Decade
of Ocean Science
for Sustainable Development

The UN Ocean Decade
is calling for
innovative
knowledge-based
solutions and ideas
to create
the Ocean We Want.

Scan for
more
information



Submissions open until
31 August 2023.

Or visit oceandecade.org

CHANGE IS CLOSER THAN YOU THINK

WILDHOPE

Coming Soon To **WildHope.TV**

hhmi | **Tangled Bank Studios**

tangledbankstudios.org





*"Sails of Change supports #30x30,
a global call to protect 30% of our planet by 2030.
To do so, we must Inspire, Unite, Change.*

- Dona Bertarelli, Founder of Sails of Change



Preludes

ZOOLOGY

Do Animals Get Drunk?

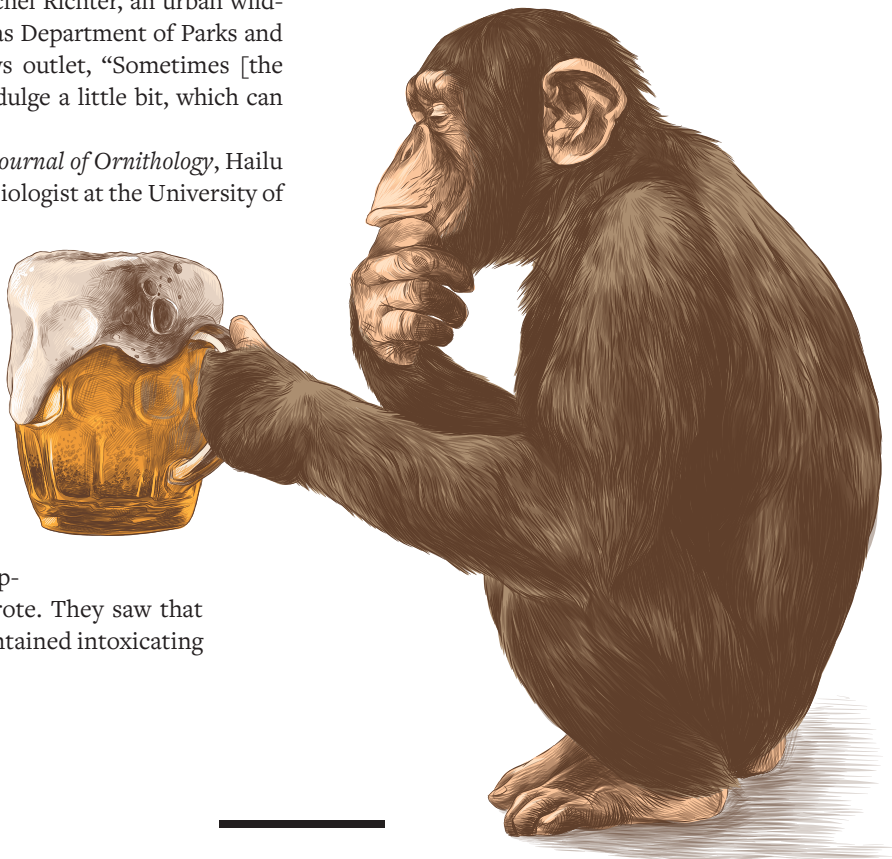
NOT LONG AGO, residents of Gilbert, a small town in Minnesota, began calling the cops on a peculiar neighborhood nuisance. Cedar waxwings, wonderfully colored little birds, were “flying into windows, cars, and acting confused,” local law enforcement reported. The disturbance made headlines in places like *NPR*: “Minnesota Residents Call Police On Rowdy Drunk Birds.”

What was going on? Apparently, an unseasonable frost had caused the berries the waxwings feed on to ferment earlier than usual, and as a result, the police stated, some were getting a “little more ‘tipsy’ than normal.” The waxwings were at it again a few years later, in Texas, prompting the *Houston Chronicle* to run the headline, “Cedar waxwings are the drunken revelers of the bird world.” Rachel Richter, an urban wildlife biologist with the Texas Department of Parks and Wildlife, told a local news outlet, “Sometimes [the waxwings] tend to overindulge a little bit, which can get them intoxicated.”

In a 2012 paper in the *Journal of Ornithology*, Hailu Kinde, a veterinary microbiologist at the University of California, Davis, and his colleagues, conducted necropsies on several flocks of waxwings that were found dead after flying into windows, fences, and other obstacles. Their examinations “revealed that all birds had engorged themselves with over-ripe berries of the Brazilian Pepper Tree,” the authors wrote. They saw that the birds’ livers, which contained intoxicating

levels of ethanol, had ruptured. “The cause of death in these birds,” Kinde and his colleagues wrote, “was trauma that resulted from colliding with hard objects when flying under the influence of ethanol.” One could make the argument that fruit trees near highways are responsible for a lot of animal-related car accidents.

Piotr Tryjanowski, an ecologist at the Poznan University of Life Sciences, doesn’t find stories like this surprising. Several species of migratory birds like waxwings, he points out, often consume fermented fruit, as ethanol-laden berries are not only sweeter but also provide the bird with more of an energy boost than their fresher counterparts. Such spirited berries make



an encouraging cocktail for a bird hesitating to embark on a daunting migration. These fortified tonics would have similar effects on humans, too: “If you’re going on a hike, it helps to have chocolate in your rucksack and not just nuts, because while fat provides long term energy, sugar provides energy faster and, when combined with alcohol, it works even faster,” Tryjanowski told me over a Zoom call. “This is especially true for birds, since their higher body temperature makes them get drunk faster, but sober up faster, too.”

It’s not just birds who seemingly enjoy hitting the bottle, so to speak. Hamsters lap up Everclear enthusiastically. Monkeys consume ethanol-laden fruit regularly, although their stomachs usually fill before reaching inebriating levels. In 1974, a reported 150 elephants broke into a brewery in West Bengal, India, and the 6,000 pound hulks went on a rampage that killed people. There are so many deer, seemingly plastered and generally “running amok.” And a moose was found drunk, stuck in a tree. There’s also the pet elk of the eccentric 16th-century Dutch astronomer Tycho Brahe to consider, as the elk met an unfortunate end falling down a flight of stairs in the nobleman’s castle after a night of binge drinking with his owner. Beyond the cautionary tale of animal endangerment, there is a glaring question: Are these animals really getting wasted, and if so, why?

In a 2011 paper, researchers observed that rodents, primates, and flies will drink enough to reach high blood-alcohol concentrations, noting that, “they often display observable signs of intoxication.” Still, the variations in anatomy and digestive enzymes and apparatuses make it difficult to discern exactly what’s going on when these creatures are consuming ethanol.

More recently, researchers analyzed the genomes of 85 mammals to see how widespread the ability to metabolize ethanol might be. They reviewed chimpanzees, pen-tailed treeshrews, elk, elephants, and a variety of birds and bats. The amount of ethanol consumed along with the observable behavioral differences across mammals were wildly variable. Pen-tailed treeshrews, for example, consume enough ethanol to intoxicate

A reported 150 elephants broke into a brewery in West Bengal, India.

a human, yet show no signs of intoxication. On the other hand, elks in Sweden exhibit signs of intoxication after simply feeding on a few rotting apples in autumn. Elephants actually turn out to be lightweights because they lack a crucial enzyme that metabolizes ethanol quickly. If dwarf hamsters

were as big as elephants, the furry rodents would drink them under the table, since they apparently have no trouble imbibing alcohol.

Even different species of the same order of creature, like bats, have considerably varying abilities to tolerate ethanol. Egyptian fruit bats have a hard time flying and echolocating after consuming a fruit with more than 1 percent ethanol, while Phyllostomid bats show no signs of intoxication even with blood alcohol concentrations that would make humans legally intoxicated. “What is clear,” the authors conclude, “is that the potential alcohol digestome varies widely among mammals to functional effect, and it is almost certainly erroneous to make inferences about one species based on another with divergent physiologies and ecologies.”

STILL, THERE IS THE QUESTION of why animals would get drunk in the first place. The rapidly available sugar might provide quick energy, but the overall evolutionary benefit to animals getting a little boozy is not at all clear. Tryjanowski says that “all the data in observations of animals drinking shows that” they are more likely to injure themselves, become more cavalier around predators, and that they are more likely to choose sub-optimal mates. An intoxicated animal seemingly rejects everything about adaptation: The creature literally becomes worse at living in its environment.

But just because the evolutionary reasons for animal tipping aren’t clear doesn’t mean they don’t exist. “There may be social and not just nutritional reasons for alcohol consumption,” says Robert Dudley, author of *The Drunken Monkey: Why We Drink and Abuse Alcohol*. “A study in *Science* about 10 years ago found that male fruit flies that have been recently rejected by a female are more likely to move to an area of the fruit with a higher ethanol concentration.” Are these tiny flies imbibing to soften the blow of sexual rejection?

A biologist at the University of California, Berkeley, Dudley spent a long time studying primates in Panama. He reports seeing intoxicated and emboldened spider monkeys going “bipedal and charging the comedor, opening the refrigerator, grabbing a loaf of bread, and storming out.” In *The Drunken Monkey*, Dudley also reiterates Darwin’s claim that one could attract African baboons with strong beer, and how Darwin once wrote his friend W.M. Moorsom about a monkey held captive in a pub by the owner who became a complete alcoholic (the monkey, although perhaps the pub owner, too).

Dudley’s so-called “drunk monkey” hypothesis states that, since fermentation not only amplifies the scent of the fruit but also signals the presence of digestible sugars, our evolutionary ancestors initially became fascinated with ethanol-laden fruit for nutritional reasons, and subsequently developed an attraction to its psychoactive effects. As a recent paper co-authored by Dudley states, “contemporary patterns of alcohol consumption ... may derive from these ancestral associations between ethanol and nutritional reward,” while

the “psychoactive and hedonic effects of ethanol may result in increased consumption rates.”

But regardless of why our animal ancestors started drinking, the consumption of alcohol might have been evolutionarily advantageous. “As every bar and restaurant proves every night, alcohol is an amazing aperitif,” Dudley says. “But it doesn’t just stimulate feeding, it also kills off microbes, thereby increasing health and reducing mortality.”

It may very well be the case that other animals started drinking for similar, nutritive reasons, only to develop a more social and hedonic attraction to ethanol later on. And perhaps there are tangentially adaptive reasons for animals drinking. While they may venture into new territories with lurking predators, they might also discover new habitats and food sources. And while they might choose sub-optimal mates under the influence, some species might have been too picky to begin with. “We’ve all thought about these possibilities,” Dudley confesses. “But who knows?”

—Marco Altamirano

HISTORY

The Ancient Architecture That Defies Earthquakes

THE POWERFUL 7.8 magnitude earthquake that struck Turkey and Syria on February 6 killed almost 50,000 people, most of whom died under rubble.

The tragedy falls in a decades-long history of out-sized death and destruction from recent earthquakes: The 1999 İzmit earthquake near Istanbul killed at least 17,000 people; the 2001 Gujarat earthquake in India killed upward of 20,000; and the 2005 Kashmir earthquake in Pakistan killed more than 87,000 and left some 3.5 million people unhoused. The immediate cause of the human tragedies was not the shaking ground itself, but the buildings people were in, most of which were constructed of reinforced cement concrete, a relatively quick and cheap building method.

Earthquakes don’t have to be so deadly, say scholars who study this issue. Many traditional buildings have

The gravitational force of the structure itself holds the stones in place.

stood the test of time in regions that have endured high seismic activity for centuries.

In Japan, people had long built earthquake-resistant structures mostly from wood. But a different tradition shows that even stone buildings can withstand vigorous shaking—if they are built with clever physics and architectural adaptations, honed over the centuries.

In the mountainous region of Himachal Pradesh in India, near where the Indian Plate is colliding with

the Eurasian Plate, many structures built in the *kath kuni* style have survived at least a century of earthquakes. In this traditional building method, the name, which translates to “wood corner,” in part explains the method: Wood is laced with layers of stone, resulting in improbably sturdy multi-story buildings.

It is one of several ancient techniques that trace fault lines across Asia. The foundations for the timber lacing system of architecture may have originally been laid in Istanbul around the fifth century. Stone masonry and wood-beam construction can still be seen in Nepal as well as in the traditions of Kashmiri *Taq* and *Dhajji Dewari* and Pakistani *Bhatar*. Even Turkey has a long tradition of similar construction methods. Despite their ancient origins, this model of construction has mostly fared better over centuries than much of the contemporary building across the continent’s many active seismic zones.

Built along the natural contours of the hills, *kath kuni* buildings typically get their signature corners from giant deodar cedars, which grow upward of 150 feet tall and 9 feet across in the Himalayas. These wooden beams layer between dry stones, which create walls. A single wooden “nail” joins the beams where they come together.

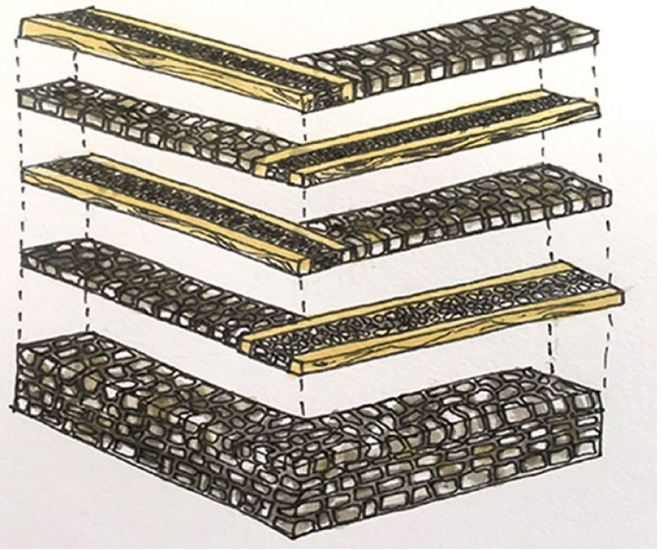
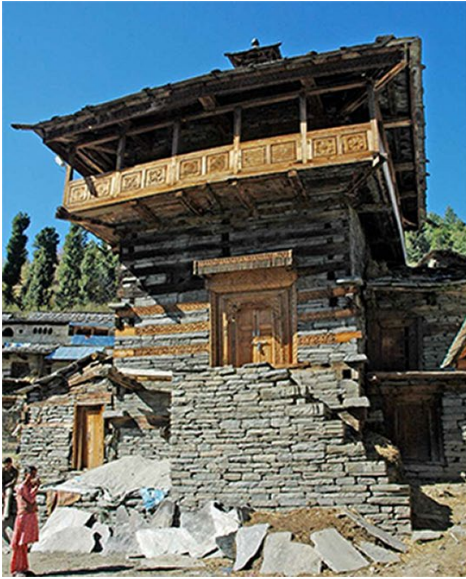
As the ponderous-looking structures rise vertically, usually up to two to three stories, the heavy stone masonry reduces, giving way to more wood. The overhanging roof typically has slate shingles resting on wooden beams. “The structure is like a body with heavy base, the projecting wooden balconies are

limbs, and the heavy slate roof is like a head adding stability to the structure,” says Jay Thakkar, a faculty member at the Centre for Environmental Planning and Technology University in Ahmedabad, India, who co-authored the book *Prathaa: Kath-kuni Architecture of Himachal Pradesh*.

The buildings stand free of any mortar or metal, which makes them more capable of shifting and flexing along with torques in the ground. This brilliance of mobility even continues underground. They are built over a trench at least a few feet deep filled with loose stone pieces that works as a flexible plinth. While a building constructed out of what appears almost like rubble to begin with might seem a strange defense against earthquake damage, it works. The gravitational force of the structure itself holds the stones in place.

“Unlike the cement brick wall, which becomes a single solid mass, the dry stone masonry is flexible,” Thakkar says. “Staggered joints allow the external forces like tremors of earthquakes to be dispersed through the masonry, thus preventing cracks in walls.” He adds, “The wooden pin at the corner joint of two beams also allows movement. So when an earthquake hits, the structure sways and shakes but doesn’t collapse.”





A MOVEABLE FEAT Many traditional architecture practices in some of Asia's seismically active areas have relied for centuries on the advantage of movement. Buildings in the *kath kuni* method in northern India (left) rely on gravity to help create their stability, and a layered pattern of loose stone and wooden beams (right) give the buildings flexibility that concrete lacks.

DESPITE CENTURIES OF VISIBLE EVIDENCE of these traditional structures' soundness, people have turned more and more to reinforced concrete construction. By the early and mid-20th century, reinforced concrete was taking hold across Asia and quickly gained popularity because of its substantially lower labor costs. As such, it became the default method for much new construction, including any government-funded buildings. But "for reinforced concrete construction, poor quality construction in this material has so often produced buildings that are more dangerous than the traditional unreinforced masonry buildings they replaced, despite the promises made about concrete buildings," wrote a team of researchers studying traditional timber and masonry buildings in Turkey.

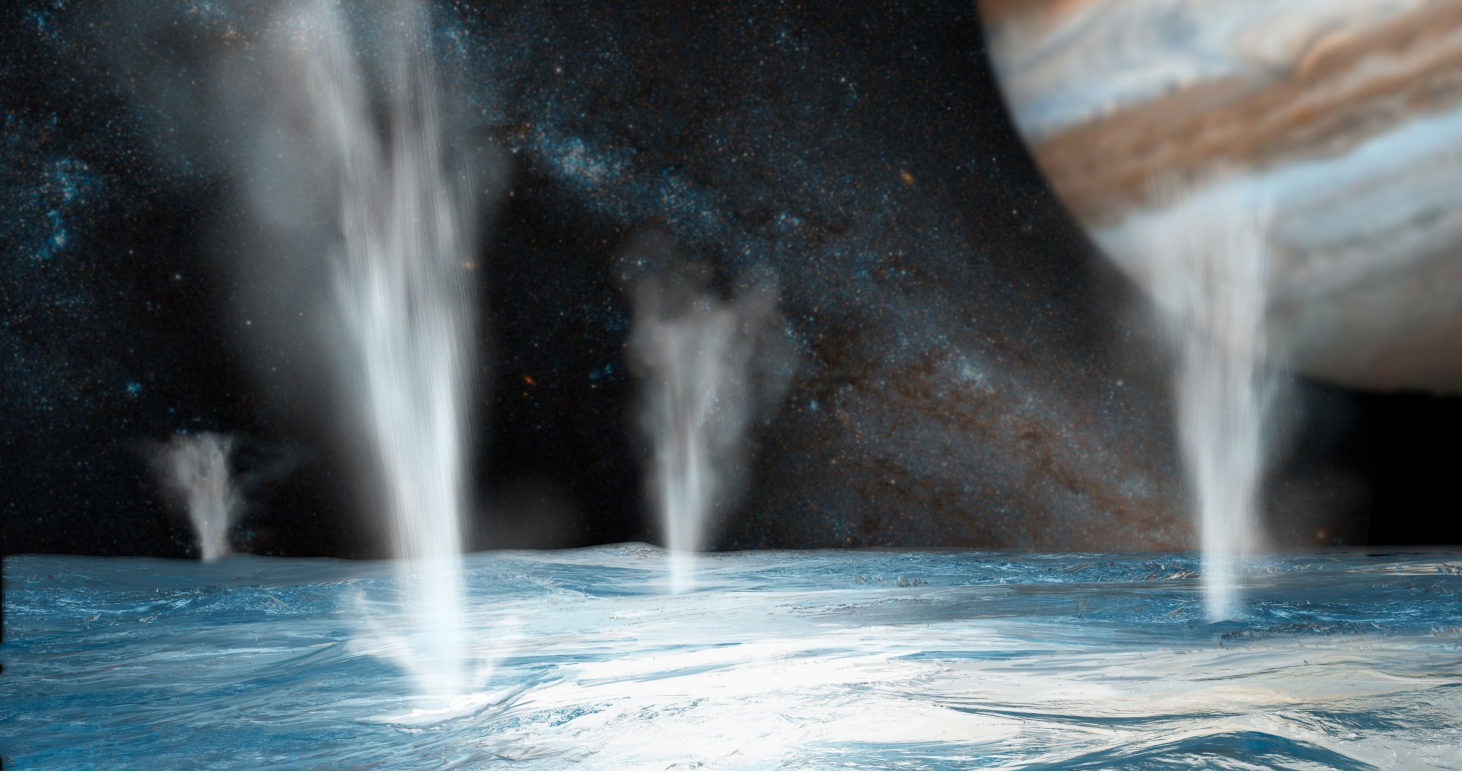
Indian architect Rahul Bhushan, who works toward reviving traditional construction methods in the Himachal Pradesh region, says, "the *kath kuni* style of architecture, while being still used in temple

construction, had kind of paused for other structures due to the advent of reinforced concrete as building material. As a result, gradually, the traditional expertise declined."

Bhushan's group, which is called NORTH, has been training masons and construction laborers in traditional methods. Their workshops are generating renewed attention for earthquake resistant architecture rooted in these ancient techniques. He is hopeful this momentum will continue. "People are gradually showing interest toward *kath kuni* and other traditional constructions like *dhajji dewari* again."

The onus now lies on practicing architects and researchers to convince government agencies to support the traditional system of construction, which could help contain destruction the next time an earthquake rocks the region, which, as the geologic plates continue to collide, is only a matter of time.

—Shoma Abhyankar



ASTRONOMY

Why Do So Many Moons Have Oceans?

One question for Julie Castillo-Rogez, a planetary geophysicist at NASA's Jet Propulsion Laboratory at the California Institute of Technology where she focuses on, among other things, water-rich bodies like the dwarf planet Ceres and formulating, designing, and planning planetary missions

Why do so many moons have oceans?

Moons are bodies that don't have a lot of heat. When you look at the evolution of thermal models starting from 20 years ago, we were assuming that these bodies were pure water ice and rock. But then we realized that the materials that make up these moons can be very complex, and some of them can be insulating. There can be a lot of porosity, and maybe the water has impurities like ammonia and salts. All this contributes to maintaining and preserving oceans in these objects.

They're actually very cold, but one of the main heat sources for icy moons and almost every object in the outer solar system is an isotope called aluminium-26. It's an element that creates a lot of heat by decaying. It's like uranium, for example, but it's more efficient. It's very short lived. So it acted only for up to 10 million years

while the solar system was first forming. Aluminium-26 created so much heat that it melted the water ice in moons. Globally, they had very thick oceans. Most of the ice just melted, and then the water started freezing from the top.

Our new research suggests that four out of five of Uranus' largest moons—Ariel, Umbriel, Titania, and Oberon—could also have oceans. We know there is not a lot of tidal heating in these moons caused by internal friction, a result of the gravitational pull of a planet stretching the moon as it comes close in its orbit. It's now the main source of heat in the outer solar system. One of Jupiter's moons, Europa, for example, has a lot of tidal heating. Enceladus, a moon of Saturn, is the same. But Uranus' moons don't have a lot of tidal heating. There's actually 50 times less tidal heating in the Uranian moons compared to the Saturnian moons.

JACQUES DAYAN / SHUTTERSTOCK

It's more difficult to find cold oceans.

These results are based on modeling of internal evolution, present-day physical structures, and geochemical and geophysical signatures. We don't have direct evidence. One of my coauthors, Richard Cartwright, has found ammonia on the surface of at least one of the moons, Ariel, and there might be ammonia on another one of these moons. This material is short lived, it's not going to stay on the surface of the moons for a long time because it reacts with particles in space. So there might be evidence that there is ongoing exposure of material from Ariel. There's also evidence on Ariel of recent geological activity, and that would favor the presence of a deep ocean at present.

What we can do with these models is help prepare a mission that will look to confirm these models. To look for deep oceans on moons, for example. So far the best technique has been to use a magnetometer to look for induced magnetic fields, like in Europa or Ganymede. But what we found is that these oceans that are predicted in the Uranian moons are actually very cold. It's more

difficult to find cold oceans. So we need to think about different techniques. NASA might look into a mission of this kind in the future to observe all of the large Uranian moons. We would have multiple flybys of Titania for sure, and maybe Oberon, Ariel, Umbriel. If the four large ones have deep oceans as predicted, then it confirms the idea that there are special circumstances, special materials, or special impurities that help preserve deep oceans in these moons. If they are frozen, it's telling us that there is something else going on. So we still learn something from studying these bodies.

We are very hopeful that a mission could start within the decade. But it's not clear if it's going to be next year, or the next five years. It would take about 13 to 14 years to get to the moons. I'll probably still be in the field when the mission starts, but I will probably be retired by the time it gets there. We're talking about a launch after 2036. So an arrival at the end of the 2040s. A long journey.

—Brian Gallagher

ENVIRONMENT

When Disease Comes for the Scientist

Benjamin Freeman's fascination with birds began on a research trip to Bolivia, where he was stunned by the diversity of tropical avian species he was surrounded by. During graduate school, Freeman was researching diseases in birds in the mountains of Papua New Guinea. But then Freeman, now a biologist at the University of British Columbia, unexpectedly fell ill. His experience taught him how climate change is affecting the spread of diseases—which turns out to be more complicated than a simple march uphill. He told his story to science writer Ula Chrobak.

ONE MORNING, I WOKE UP on a concrete floor. I didn't know how I had gotten there, to this hotel room in Lae, Papua New Guinea. My head was throbbing, and it felt like a really bad hangover. But I had been alone doing data entry the night before, so I was not hungover. It took a minute until I realized that I must have fainted.

I slowly realized what had happened. I had just been doing research on diseases in birds up in the mountains and had arrived at the hotel the night before. I was not feeling that great and was grateful for a bed. I must have gotten out of bed that morning and immediately fainted. And I'm tall, I'm 6-foot-4. So it was really painful.



This is an environment with a lot of tropical diseases so it was like, “I need to find medical help.” The hotel owner was kind enough to take me to a clinic. I was thinking, “maybe I have typhoid, maybe I have yellow fever.” But it never crossed my mind that I could have malaria because I had been doing field work mostly at super-high elevations, and it was freezing. There are no mosquitoes there, and I’d been taking anti-malaria medication as a precaution.

At the clinic, the nurse took a blood sample, walked a few steps away to where the microscope was set up, and then a couple of minutes later, he said, “You have malaria, and you have *falciparum*”—the kind that kills a lot of people.

My very first reaction was: “That’s impossible. No way. This is unreal.” I got a shot in the butt, got some pills, went back to the hotel, slowly piecing it together: “Yeah, I did go down to a mid-elevation site where I slept for a night.” And I did remember getting bitten by mosquitoes there. But even the mid-elevation village was at about 5,000 feet. Everybody from there says,

“Oh, no, we don’t have malaria here, it’s too cold.” But mine is not the only case of human malaria arriving in the New Guinea highlands.

AS SOMEONE WHO was already studying tropical diseases in birds, I was curious: Do we see evidence that that’s what the birds are experiencing, too? The prediction would be that birds in the hot lowlands would have really high rates of avian malaria and that birds in the cool mountains would be uninfected.

Instead we found that it didn’t really matter what elevation the birds lived at. We took blood samples from more than 2,200 individual birds from 66 local species across 17 different sites, from sea level to the high mountains. Overall, about 40 percent of birds were infected, with only slightly higher infection rates near the coast than way up near 10,000 feet. And 10,000 feet is very chilly. I was totally surprised by that. I thought for sure it’ll be the same situation as human malaria, where there is more disease where it’s hot.



FOR THE BIRDS Climate change does not affect animals in the same way. In New Guinea, berrypeckers, like the one pictured on the right, were almost all infected with avian malaria, despite their home range elevation. At left, some great woodswallows, also native to New Guinea, survey the scene.

But for these birds, infection rates were more determined by what kind of bird they were. For these birds called berrypeckers, it didn't matter if they were near the coast or way up high, they were almost uniformly infected. A group called whistlers, they were uniformly uninfected. The infected birds are largely able to do their bird thing, despite being infected. I suspect there's been coevolution between the parasites and the birds' immune systems over millions of years.

At least for these birds, we don't see the pattern where warming is leading mountain birds to get infected more. Avian malaria can get transmitted by these little biting flies at 10,000 feet, not just the mosquitoes that need warmer temperatures. So we don't predict that climate change will change things that much for the birds and malaria on the same mountain where it is changing things for human malaria.

This is not the case everywhere. For example, in Hawai'i, native birds have no evolutionary history with malaria, because that hadn't existed there before Europeans introduced mosquitoes, so it's just death to those birds. As it's gotten warmer there, the mosquitoes have marched up, spreading diseases to resident birds as they go.

SO I DON'T HAVE EVIDENCE this disease is changing for the birds in Papua New Guinea. But climate change does matter for them. It's just more complex. Some

For me, getting malaria is, at least in part, a climate change story.

tropical montane birds, including in Papua New Guinea and Peru, have responded to warming by living higher and higher on the mountain slopes. At the top of the mountain, there's not much room, so it becomes, as the evolutionary biologist Mark Urban has put it, an "escalator to extinction." The temperature changes, though, are not that big, and birds can handle being a little bit warmer. So it's something in those changed ecological interactions—with what they eat, who eats them, how they get sick—that is dooming them. I'm working on new projects now to try to figure out what's happening.

For me, getting malaria is, at least in part, a climate change story. I might not have gotten sick if this had been 20 years earlier, because the village I stayed in was right on the border of where malaria mosquitoes can survive and transmit the disease.

Catching malaria at 5,000 feet taught me that the impacts of climate change are here. Next I hope to learn more about what those impacts will mean for the future of these diverse birds.

—Ula Chrobak

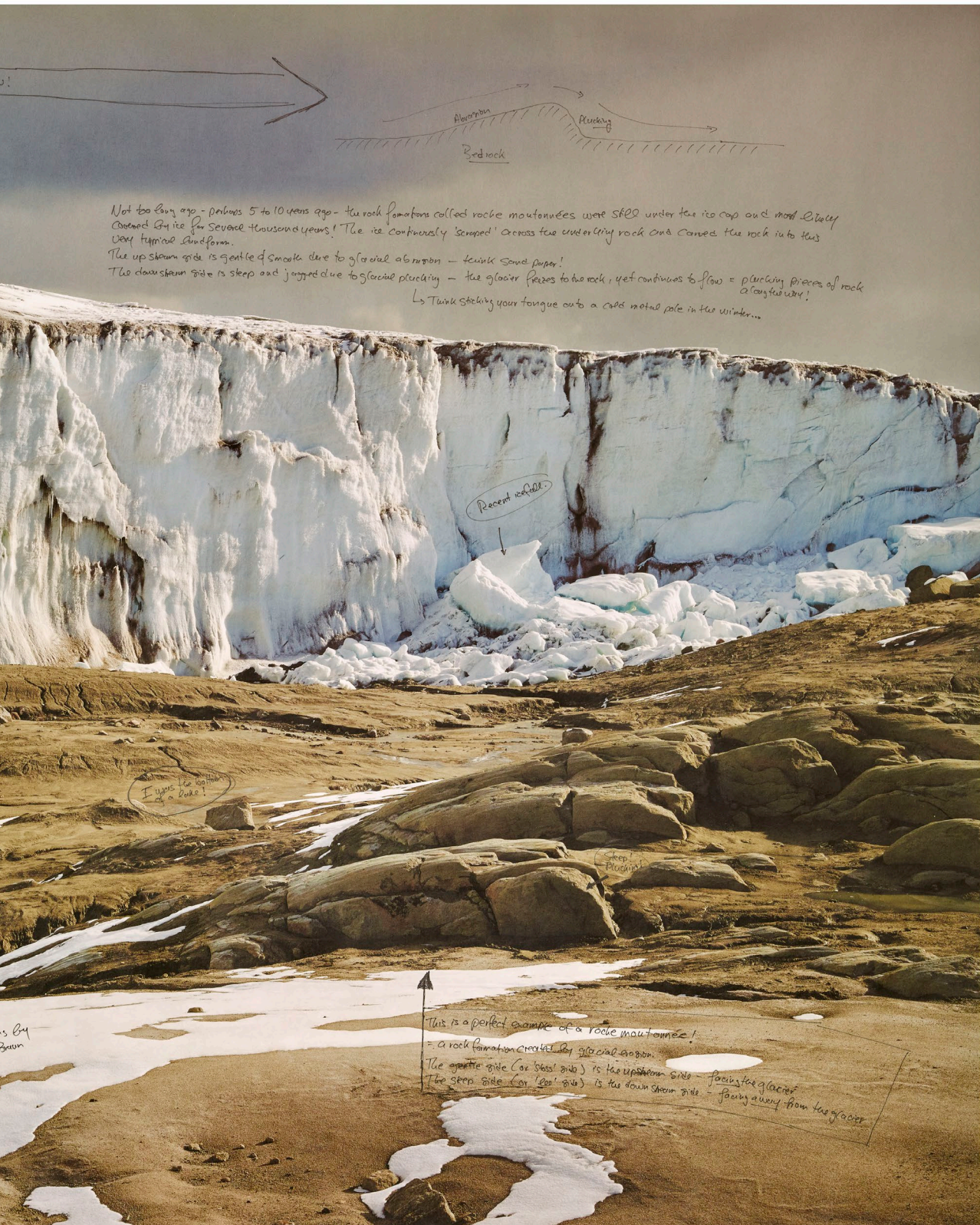
Frozen in Time

IN A SERIES CALLED “Naturalists of the Long Now,” photographer Ian van Coller collaborates with paleoclimatologists, who annotate the photographs with scientific details.

This photo is of the Quelccaya Glacier in Peru. The scientist who made the handwritten notes is Carsten Braun, a geologist at Westfield State University.

Meet Ian van Coller on page 50.





Not too long ago - perhaps 5 to 10 years ago - the rock formations called rock moutonnées were still under the ice cap and most likely covered by ice for several thousand years! The ice continuously 'scraped' across the underlying rock and carved the rock into this very typical shape.

The upstream side is gentle & smooth due to glacial abrasion - think sandpaper!

The downstream side is steep and jagged due to glacial plucking - the glacier freezes to the rock, yet continues to flow = plucking pieces of rock away!
↳ Think sticking your tongue out to a cold metal pole in the winter...

Recent collapse

It was the bottom of a lake!

Top of the glacier

This is a perfect example of a rock moutonnée!
= a rock formation created by glacial erosion.

The gentle side (or 'smooth' side) is the upstream side - facing the glacier

The steep side (or 'jagged' side) is the downstream side - facing away from the glacier



Cormac McCarthy Took Us Beneath the Surface

Inside the celebrated novelist's first and only nonfiction essay

BY KEVIN BERGER

ALWAYS FEEL GRATEFUL that *Nautilus* is associated with Cormac McCarthy, who died on June 13 at his home in Santa Fe. He was 89 years old. In 2016, the great American novelist published his first and only piece of nonfiction, “The Kekulé Problem,” in *Nautilus*.

Since *Nautilus* set sail in 2013, we’ve tacked in line with the Santa Fe Institute, where brilliant minds have convened since 1984 to illuminate the complexities and connections beneath the world’s surfaces. Santa Fe Institute cofounder Murray Gell-Man, a Nobel laureate in physics, met McCarthy in 1981, when the novelist won a MacArthur Fellowship, the famous “genius” grant. The physicist learned the artist had a curiosity as boundless as the universe. At the Santa Fe Institute, McCarthy had a home away from home for 39 years.

KATE JOYCE

McCarthy's fiction is a portal into the unconscious where primeval feelings dwell.

Our print journal made its way around the Institute, where McCarthy read and admired it, we learned from the Institute's president, David Krakauer, who has written a host of articles for us, including one last year about his friendship with McCarthy. When McCarthy wanted to publish ideas that had been cycling through his mind about language and the unconscious, he turned to *Nautilus*.

I was excited to publish "The Kekulé Problem" because it reads in tune with McCarthy's fiction. It's a song to the mysteries of the unconscious, a dreamland that feeds solutions to our conscious minds, as it did when it offered the configuration of the benzene molecule to 19th-century chemist August Kekulé while he slept.

The idea that language is the root of thinking, that it evolved to bond humans, seemed to offend McCarthy. Language wasn't a biological invention; it was a human invention. Let's say language emerged 100,000 years ago, as "influential persons," a sly McCarthy writes, say it did. That's an eyeblink to the 2 million years "in which our unconscious has been organizing and directing our lives. And without language you will note."

This is the artist at work. You can appreciate the language in McCarthy's fiction for its lexical richness, gothic rhythms, and descriptive precision. In *Suttree*, you positively live on the grimy shore of the Tennessee River, where the "water was warm to the touch and had a granular lubricity like graphite." Same for *Blood Meridian*. The Southwest desert is your home, or prison. You look up at the night sky. "All night sheetlightning quaked sourceless to the west beyond the midnight thunderheads, making a bluish day of the distant desert, the mountains on the sudden skyline stark and black and livid like a land of some other order out there whose true geology was not stone but fear."

The artist doesn't want you to live on the surface. McCarthy's fiction is a portal into the unconscious where primeval feelings dwell. Language is paradoxical that way. It's a signpost to the places where language has little say.

It might seem like another paradox to say the artist of the unconscious was deeply engaged in science, where conscious precision rules. Not so. McCarthy's fiction captures the life force that is the very subject of science. McCarthy's final two novels, *The Passenger* and *Stella Maris*, delve explicitly into physics and math, reflecting his decades of conversations with scientists at the Santa Fe Institute. But his microscopic eye on the natural world was always there.

In this exquisite passage from 1979's *Suttree*, the narrator, on a "hushed and mazy" Sunday afternoon, lies down on a cot in his houseboat on the river: "The heart beneath the breastbone pumping. The blood on its appointed rounds. Life in small places, narrow crannies. In the leaves, the toad's pulse. The delicate cellular warfare in a waterdrop." That is science. And art.

"The Kekulé Problem" received criticism from linguists who felt McCarthy was, in short, giving language short shrift. To me, McCarthy uses language, the remarkable human invention, to open us to the verities of life and our connection to nature before the modern world closed the doors. This has always been his theme.

In McCarthy's 1994 novel, *The Crossing*, a teenage cowboy traps and becomes emotionally attached to a pregnant wolf in Mexico. The boy is briefly arrested by Mexican deputies, and the wolf is mauled by dogs when it's chained in a pit and forced to fight. To put the wolf out of its misery, the boy shoots it in the head and carries it to the mountains to bury it. As he closes the wolf's dead eyes, he "could see her running in the mountains, running in the starlight where the grass was wet and the sun's coming as yet had not undone the rich matrix of creatures passed in the night before. Deer and hare and dove and groundvole all richly empaneled on the air for her delight, all nations of the possible world ordained by God of which she was one among and not separate from." ☺

KEVIN BERGER is the editor of *Nautilus*.

50

Facts SO ROMANTIC

SINCE WE LAUNCHED *NAUTILUS* 10 years and 50 print issues ago, we've been bringing you "facts so romantic," as Jules Verne wrote. Verne's phrase is from a footnote he attached to his 1879 story, "The Mutineers on the Bounty," based on the famous 1789 mutiny on the HMS Bounty. The entire footnote goes, "We think it well to inform our readers that this narrative is in no way fictional; all its details are taken from the maritime annals of Great Britain. Reality provides us with facts so romantic that imagination itself could add nothing to them."

Verne, no doubt, felt he needed the footnote because he was known as a fiction writer, author of *Journey to the Center of the Earth*, and *Twenty Thousand Leagues Under the Sea* (whose undersea vessel is named Nautilus). Verne wanted to tell the world that true stories could be as romantic as imaginative ones. We second that, Mr. Verne. To celebrate our 50th print issue, we thought it would be fun to call out one fact from each issue, underscoring the amazing things in the universe and, if we may be so bold, *Nautilus*.

1

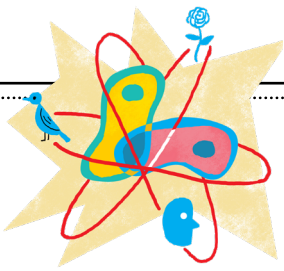
There may be more planets than there are stars in the universe—which means hundreds of sextillions of planets. At least 15 percent of all stars may have Earth-sized planets orbiting within the zone where liquid water might exist on their surfaces.

2

The odds of winning a Powerball lottery are 1 in 175 million. But there's nothing in our evolutionary history, no intellectual architecture, that prepares us for comprehending such low odds. Which is why people keep playing the lottery.

3

In 2004, the Royal Automobile Club in Great Britain deemed Wagner's "Ride of the Valkyries" the most dangerous music to listen to while driving. The frenzied tempo challenges drivers' normal sense of speed—and the objective cue of the speedometer—and causes them to speed.



4

Every flower and fungus, spider and sparrow, man and woman, descended from a sudden and breathtakingly improbable merger between two microbes.

5

“Gyandromorphs” are animals that are half-male and half-female. In some cases, rather than a single animal with male and female parts, a gyandromorph is two different creatures fused together.

6

Brain measurements show that Shakespeare’s language raises the attention of readers and triggers an extra emergent consciousness.

“

Reality provides us with facts so romantic that imagination itself could add nothing to them.

— Jules Verne

”

7

It’s an illusion a table is solid. It’s made up of mostly empty space. Our eyes are sensitive to a wavelength of light that is too big to penetrate the empty space in the atoms. So why doesn’t my hand go right through the table? There’s an electromagnetic interaction that stops it. Our senses always smooth over deeper truths about the world.



8

Loaded dice have been found in tombs alongside ancient game boards; even if the ancient Egyptians believed that a throw of the dice somehow expressed divine will, they weren’t averse to lending a helping hand.

9

Einstein's belief in a hidden reality had lain dormant for years, ever since he was a little boy—4, maybe 5—and his father had come to his bedside and handed him a compass. Einstein had held it in his hand, and found himself trembling in awe.

10

It's nearly impossible to determine the sex of a hyena by just looking, as females are big and muscular, have fake scrotal sacs, and enlarged clitorises that can become as erect as the male's penis.

11

Immediately after feeding people a sugary, greasy fast-food meal you can see an increase in detritus in the bloodstream.

12



People who wander endlessly lost in the forest hardly cover any ground at all. In an experiment in which people were blindfolded and left to wander for 50 minutes, they began walking in surprisingly small circles of less than 65 feet in diameter.

13

The hotter the temperature in a region, the more spices traditional recipes call for.

14

The sun gets 10 percent brighter every billion years.

15

Rock climber Alex Honnold was put in an fMRI machine and exposed to gruesome images that cause frenetic brain activity in nearly every person. Honnold's brain showed calm. He said the images were like a "curio museum."

16

When it comes to helping people obtain what they truly need—a romantic partner, someone with whom to share life’s traumas and triumphs—less is indeed more. Nowhere are the benefits of choice-limiting more profound than in the quintessentially human realm of love.



17

How old we feel—our subjective age—can influence how we age.

18

The way we perceive time is contagious. “Individuals adopt other people’s rhythms and incorporate other people’s time.”

19

Humans are the only mammal that can’t swallow and vocalize at the same time.

20

Morally disgusting material really can make you feel sick to your stomach.

21

The most abundant type of business in New York City is physician offices.

22

Hospital staff and residents frequently find themselves Googling patients in the ER.

23

By 1800 B.C., Akkadian texts exhibited complex sentences that rival the prose of Henry James in their complexity.

24

About 400,000 years ago, the human species developed hafting—the technological capacity to attach a stick to a stone—cementing craft as an evolutionary option.

25



Randomness is so unnerving that we search for a pattern that eliminates the chaos.

26

One day at Caltech, Richard Feynman casually worked out the process of spontaneous emission of black holes on a blackboard for graduate students. The next day it was gone, the cleaning lady had wiped the blackboard clean. A year later, Stephen Hawking became famous for his theory of spontaneous emission.

27

The word “lox” hasn’t changed in pronunciation or meaning in 8,000 years. The pronunciation in Proto-Indo-European was probably “lox,” and that’s exactly how it is pronounced in modern English. Then, it meant salmon, and now it specifically means “smoked salmon.”

28

Human language is amazingly creative. If you make up a sentence of any complexity, and search for that exact sentence on the internet, it's almost never there. Virtually everything we say is novel.

29

Old trees can tell which seedlings are of their own seed. We don't completely understand how they do it, but we know these old trees are changing their behavior in ways that give advantages to their own kin. A parent tree will even kill off its own offspring if they're not in a good place to grow.

30



A complete wiring diagram for a mouse brain alone would take up two exabytes. That's 2 billion gigabytes; by comparison, estimates of the data footprint of all books ever written come out to less than 100 terabytes, or 0.005 percent of a mouse brain.

31

Bat flight requires an increased rate of metabolism. Their wing-flapping action leads to high levels of oxygen-free radicals—a natural byproduct of metabolism—that can damage DNA.

32

Ninety percent of all the fossil fuels—coal, oil, gas—that we burn today were deposited during the Devonian, Carboniferous, and Permian periods. All that hydrocarbon is now being released into the atmosphere—releasing carbon dioxide into the atmosphere at a rate 500,000 times faster than it was deposited in the first place.

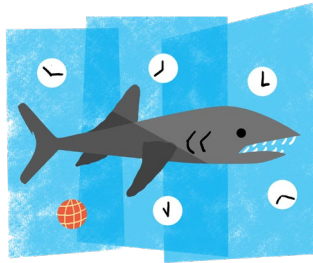
33

It appears that the great majority of stars that the universe will ever make—perhaps 95 percent of them—have already been made.

34

As people spend time in nature, they're less engaged in internal narratives and thinking about their to-do list. They're more likely to be aware and in the moment.

35



The first sharks evolved around 200 million years before the dinosaurs and outlived them all. As scores of land species rose and fell, sharks swam coolly through asteroid strikes, five mass extinctions, five ice ages, and all of the dramatic global warming in between.

36

Many diseases, including cancer, tuberculosis, and Parkinson's, can manifest themselves through volatile compounds that change the person's scent.

37

fMRI is an imprecise camera that captures blurry images of blood, not neurons, and requires extensive computational manipulation before we can even view the images. The phrase "the brain lights up" is an artifact of the images that we craft.

38

On Neptune, fierce winds average 700 mph and gust to 1,500 mph around the planet's Great Dark Spot.

39

Nautilus can live for a very long time, at least a century. They expend virtually no energy in searching for food. For the nautilus, the energy expended for swimming also allows for respiration. Almost uniquely among animals, their normal position is head down, tail up, perfectly vertical and still.

40



With about the same technology as we have, any nominal, curious aliens on planets circling one of the 1,715 stars in our solar neighborhood could have spotted us.

41

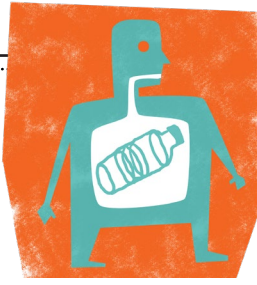
An average adult produces about a pound of poop a day.

43

The complex brains of vertebrates have much in common with the neural networks of invertebrates. For example, endorphins (the pain-sensing neuromodulators affected by opiates) are found not only in vertebrates but also in mollusks, crustaceans, insects, and even flatworms, which lack brains altogether.

42

Without imaginary numbers, and the vital role they played in putting electricity into homes, factories, and internet server-farms, the modern world would not exist.



44

People may be eating as much as a credit card's worth of plastic each week—or more, because scientists still haven't figured out how to reliably determine microplastic levels in meat, vegetables, grains, or packaged foods, which means we still don't know how much plastic we actually consume.

45

The largest structures in the universe are not superclusters or any other agglomeration of matter. They are the voids, the negative spaces, the intergalactic Saharas.

46

Ritual, it turns out, can be as effective in reducing stress as some of our best anxiety medications.

47

Between 1994 and 2017, 30 trillion tons of ice have been lost globally. In 2022, double heat waves hit the Arctic and Antarctic, temperatures soaring close to 40 degrees Celsius higher than usual.

48

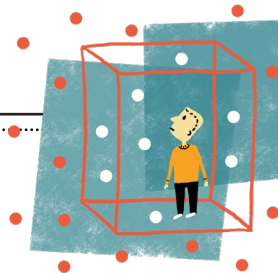
Plants' abilities to sense and respond to their surroundings lead to what seems like intelligent behavior. Their roots can avoid obstacles. They can distinguish self from non-self, stranger from kin.

49

Daily [circadian] cycles can play a role in determining the outcome of viral infections, autoimmune disease, and other conditions—such as cancer—that involve the body's defenses.

50

Eighty-five percent of all matter is unknown.



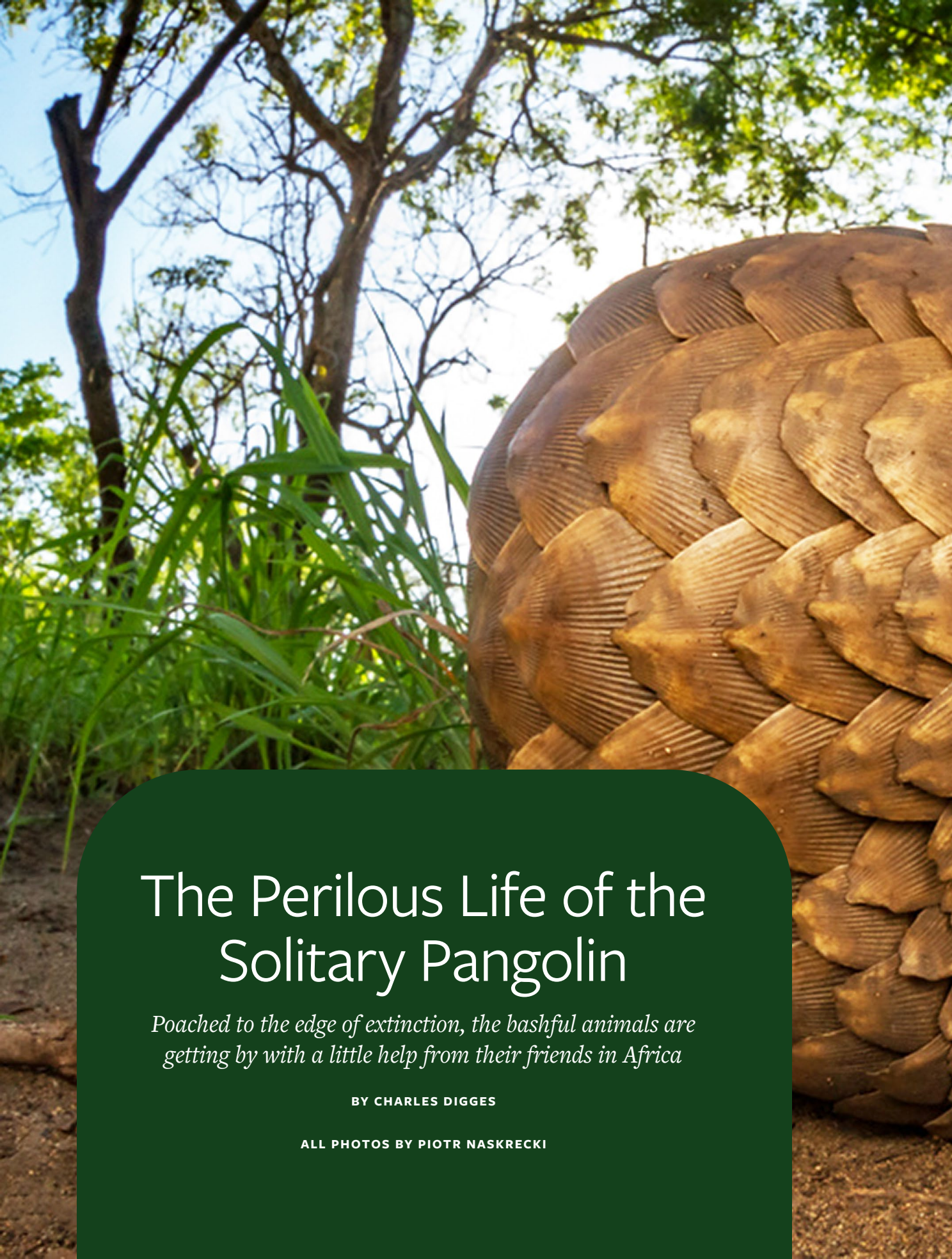
Origin of the FACTS

The *Nautilus*
articles from which
each fact is drawn



1. Goodbye Copernicus, Hello Universe
2. Why We Keep Playing the Lottery
3. How Music Hijacks Our Perception of Time
4. The Unique Merger That Made You (and Ewe, and Yew)
5. Tantalizing Creatures with Male and Female Genes
6. Shakespeare's Genius Is Nonsense
7. Last Word: Janna Levin
8. How Designers Engineer Luck Into Video Games
9. When Einstein Tilted at Windmills
10. Caitlyn Jenner and Our Cognitive Dissonance
11. How the Western Diet Has Derailed Our Evolution
12. These Tricks Make Virtual Reality Feel Real
13. Why Revolutionaries Love Spicy Food
14. How to Survive Doomsday
15. The Strange Brain of the World's Greatest Solo Climber
16. The Problem with Modern Romance Is Too Much Choice
17. Why You Can't Help But Act Your Age
18. Time Is Contagious
19. The Kekulé Problem
20. Why Your Brain Hates Other People
21. Why New York Is Just an Average City
22. Getting Googled by Your Doctor
23. The Rise and Fall of the English Sentence
24. The Stick Is an Unsung Hero of Human Evolution
25. Kolmogorov Complexity and Our Search for Meaning
26. The Day Feynman Worked Out Black-Hole Radiation on My Blackboard
27. The English Word That Hasn't Changed in Sound or Meaning in 8,000 Years
28. This Simple Structure Unites All Human Languages
29. Never Underestimate the Intelligence of Trees
30. An Existential Crisis in Neuroscience
31. The Ecological Vision That Will Save Us
32. Why Birds Can Fly Over Mount Everest
33. The Universe Has Made Almost All the Stars It Will Ever Make
34. Are We Wired to Be Outside?
35. Lessons for the Return of Great White Sharks
36. The Doctor Will Sniff You Now
37. The Trouble with Brain Scans
38. The Planets with the Giant Diamonds Inside
39. Twilight of the Nautilus
40. Where Aliens Could Be Watching Us
41. This Is Some Good Shit
42. Imaginary Numbers Are Reality
43. Even Worms Feel Pain
44. You Eat a Credit Card's Worth of Plastic Every Week
45. Why We Need to Study Nothing
46. The Real Magic of Rituals
47. The Great Forgetting
48. What Plants Are Saying About Us
49. Immunity Is a Matter of Timing
50. Will We Ever Know What Dark Matter Is?





The Perilous Life of the Solitary Pangolin

Poached to the edge of extinction, the bashful animals are getting by with a little help from their friends in Africa

BY CHARLES DIGGES

ALL PHOTOS BY PIOTR NASKRECKI





THINK OF A CAT. Then add scales.

That's how Mercia Angela describes the pangolins she cares for at the Gorongosa National Park in Mozambique, where she runs the country's only rescue center for the world's most frequently illegally trafficked mammal. "They sleep a *lot*," she says.

Pangolins are nocturnal by nature and elusive in the wild, preferring to burrow in savannas and floodplains, or scramble up trees in wooded areas where they can remain out of sight. Yet, despite their demure ways, they are the focus of a harrowing drama, their species poached to near extinction by a massive and illegal worldwide trade.

That's where Angela's rehab center—and the lush sprawl of Gorongosa as a whole—come in. It's been a little more than three decades since the ravages of Mozambique's 15-year civil war, by which time Gorongosa's population of large mammals had shrunk by 95 percent. Antelope had been slaughtered to feed troops and hundreds of elephants had been killed, their tusks traded for guns. Pangolins didn't fare any better. For centuries, their meat has been prized as a delicacy in Southeast Asia, and their scales valued in traditional medicinal practices in China. In the West, pangolins barely had a public profile until they were briefly but incorrectly implicated as a possible origin of the COVID-19 virus. Now, because populations in Southeast Asia have been decimated, the pangolins native to sub-Saharan Africa are being caught in poachers' snares.

After 30 years of restoration, Gorongosa has become a leading African conservation project, the pangolin rescue one of its central missions. Encompassing 1,500 square miles at the southern end of the Rift Valley, the park may host as many as 75,000 different species of flora and fauna. Among them, the African ground pangolin plies its lonely nighttime trade, its excavations making it a sort of gardener providing invaluable rejuvenation of the soil.

The stunned animals roll up and become as compact as a medicine ball, making them easy to scoop up and shove in a sack.

Currently, Angela, a wildlife veterinarian, is caring for two pangolins—a baby of only a few months who was rescued from traffickers by Gorongosa’s rangers, and an adult, brought to the center by locals living near the park who were concerned that it, too, might end up ensnared in the trade. The baby—a male who Angela calls Tembo—arrived in September 2022 hungry and traumatized. Angela kept him on a diet of milk for three months to help him gain weight before he graduated to ants, which he siphons up at a rate of nearly half a pound a day. She forecasts that in the next few months he might be ready to join the other 98 pangolins Gorongosa has rescued since her center started work in 2018.

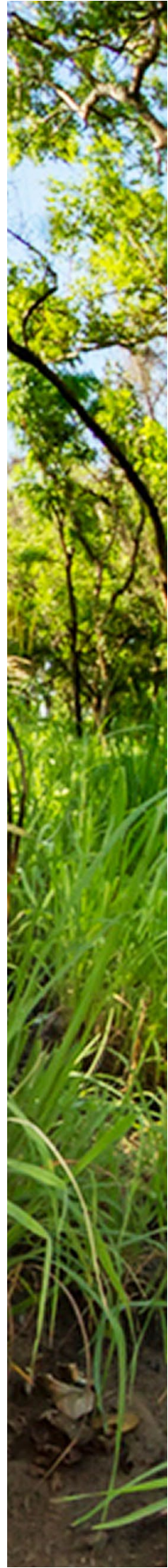
The addition of Tembo to that number will be significant. So pervasive is the poaching that the world’s population of pangolins is thought to have dropped by as much as 80 percent over the past two decades alone, the Swiss-based International Union for Conservation of Nature (IUCN) has warned.

As rare a find as pangolins are, they’re unmissable. Adult pangolins can be as big as raccoons and weigh as much as 40 pounds, but they bear a striking resemblance to an artichoke with legs. Their heads and bodies are riveted with an armor of thorny scales, making them look reptilian. Despite their otherworldly appearance, their scales have a characteristic familiar to every human—they’re made of keratin, the same protein that makes up our fingernails and hair.

IN ZOOLOGICAL LITERATURE, pangolins are loosely referred to as scaly anteaters because of that armor and their diet, but they aren’t related to true anteaters. Rather, they belong to a group all their own—one of the strangest orders of mammals—the *Pholidota*, which contains only eight living species.

Four of these are found across much of Asia, in countries ranging from India to China, and farther to Malaysia and the Philippines. The other four—including the African Ground Pangolin—are native to sub-Saharan countries stretching from Sudan to South Africa. All of them are at risk of extinction, the IUCN says. The grandest international effort taken against the illegal trade in pangolins came in 2016, when 183 nations signed the Convention on the International Trade in Endangered Species, known as CITES, which placed all eight species of pangolin in the document’s Appendix I, giving them the strictest protections.

Similar to carnivores by descent and armadillos by convergent evolution, pangolins are most closely related to bears and—yes—cats. But they are almost monastic when compared to those more outgoing cousins. The male and female pangolin come together only to mate, with females capable of giving birth to one baby about every two years. Angela says the single offspring then spend about four months riding on their mother’s tail as they get the hang of hunting. Then they separate and set off for a solitary life all their own, sometimes living as long as 20 years.



And it's the lonely foraging and burrowing of the African Ground Pangolin that Angela says makes them so essential to the recovery of Gorongosa's ecosystem. Making quick work of ant and termite hills, pangolins burrow after their prey with deft foreclaws and long, slithering tongues. And where they sniff and nudge the soil by night, nutrients can penetrate more deeply by day, helping to replenish food stores for Gorongosa's other animals and encouraging rejuvenation of the vegetation.

This appetite has other benefits. Angela says that most adult pangolins can eat about a pound of their quarry in their daily feeding, guarding against destructive termite and ant plagues.

But for all the waste they lay to their prey, pangolins are almost entirely harmless to any other living creature. When this bashful animal is frightened, it curls up into a tight ball, the scales offering its first—and, really, only—line of defense.

Sadly, it's that defense mechanism that Mercia says makes them so susceptible to capture by traffickers. As poachers drive pangolins into the open by setting fire to their burrows or battering them out of trees with sticks and clubs, the stunned animals roll up and become as compact as a medicine ball, making them easy to scoop up and shove in a sack.

Often, when poachers are interested only in the scales, they drop the curled-up pangolins into pots of water and boil them alive to make the scales easier to pluck. From there, the scales make their way to Nigeria, where smugglers bundle them with other wildlife contraband like elephant tusks and ship them off to Asia.

TO THE RESCUE Gorongosa rangers patrol the park, dismantling snares and keeping tabs on GPS-tagged pangolins. Here they release a pangolin rescued from poachers.







HITCHIN' A RIDE Female pangolins can give birth to one baby about every two years. Here a mother takes her baby for a drink during the first rain of the season in Gorongosa.

OWING TO PANGOLINS' RECLUSIVE night-time routines, naturalists have famously been unable to settle on an exact worldwide census for the animals. But the scant handful of national figures that researchers have managed to assemble suggests that there may be fewer than 150,000 left on the African continent, though the question is still open to debate and ripe for more study. Similarly, putting exact numbers to the illegal pangolin trade is challenging, but the most authoritative study, published in 2020 by German biologist Sarah Heinrich and Oxford zoologist Daniel Challender, among others, documented that at least 895,000 had been trafficked from African and Asian countries in the two decades before their study was written, though they conceded the actual number is likely much higher.



Nearly a million pangolins have been trafficked from African and Asian countries in the past two decades.

Heinrich and others shed light on the history and dynamics of the pangolin trade in another paper published in 2016. For centuries, various parts of the pangolin anatomy have featured prominently in traditional Chinese medicine—particularly the scales. If those were ground to powder or burned to ash, the old texts held, they could ward off evil spirits and midnight hysterias, provide a salve against ant bites, hemorrhoids, and malaria, stimulate lactation in women, and aid in circulation. Western science doesn't support these claims, but the traditions proved persistent, with more than 200 Chinese pharmaceutical firms offering medicines based on pangolin scales. Indeed, it wasn't

until 2020 that Chinese health insurers stopped covering these remedies.

Pangolins are also a prized delicacy in Vietnam. Challender describes visiting an upscale Ho Chi Minh City restaurant in 2012, where he watched a group of diners pay \$700 for a meal consisting of about 4 pounds of pangolin meat. The animal was brought to their table alive, its throat slit in front of them, and its blood was mixed with wine before its flesh was grilled.

But the 2016 study by Heinrich highlighted another historic pangolin consumer—the United States. Between 1975 and 2000—when CITES set the export

quota for Asian Pangolins to zero, essentially banning the international trade—America was a voracious client of the pangolin's striking diamond-patterned skin, using it for wallets, handbags, and high-end cowboy boots. Many of these items can still be found on the grayish markets of the internet, though for a stiff price. University of Adelaide professors Joshua Ross and Phill Cassey, in a 2019 paper co-authored with Heinrich, described tracking down a pair of pangolin skin boots for sale on the U.S. eBay site for \$13,000. (By May 2023, they had apparently been sold).

In the years since the COVID pandemic, China has established a raft of prohibitions meant to curtail the illegal pangolins trade. But as those focus mainly on pangolin meat, they have not so much dampened the trade as changed its character. Xu Ling, China coordinator for the wildlife trade monitoring group Traffic, told the *Guardian* that there has been a drop in the number of frozen pangolin carcasses arriving in the country for consumption as meat. Instead, it's the scales that are smuggled in, which Ling says are harvested in Africa.

And the quantities are on the uptick, a study published in *Nature Conservation* shows. Researcher James Kehinde Omifolaji of Federal University Dutse in Nigeria and his coauthors combed through arrest records, seizure reports, and other law enforcement data on China's illicit imports to reach some startling numbers. According to their research, a total of more than 400,000 pounds of pangolin scales made their way to 27 different Chinese provinces in 2021.

Pangolins are lucrative even at the point of sale—or, rather, theft. Angela says that poachers in Mozambique can fetch between \$450 to \$750 per animal they capture and sell onto the black market.



PLAYING PANGOLIN When startled or frightened, pangolins curl up into a tight ball, making them easy prey for poachers. This pangolin was out foraging for termites when the photographer came across her.

That may not sound like much, especially considering that Mozambique legislation from May of 2017 establishes a 16-year prison sentence for traffickers, as well as fines dictated by their place in the trade. But in a country that ranks as the eighth-poorest on the Human Development Index, and where average salaries hover around about only \$300 a month, the illicit trade in pangolins can seem enticing despite the threat of punishment. Nonetheless, Angela's charges have fewer worries about smugglers than their brethren outside the park. Watching over them are more than 250 locally hired rangers trained in law enforcement, who patrol the park dismantling snares and keeping tabs on several species with the help of GPS tags. Though the system isn't fool-proof, park officials say the number of traps they find within park confines has dropped by 60 percent in recent years.

Because of that, Angela sees the task of her center—and of the Gorongosa Park at large—as something that encompasses more than triage. The Gorongosa Park has worked hard to cultivate such community involvement. Some 200,000 people live around the refuge in what park officials call a sustainable development zone that includes education, employment opportunities, and health service. It is for these people that the 15 vets and rangers working in Angela's center have compiled a how-to guide on caring for distressed pangolins found in the wild, complete with first-aid instructions for animals rescued from poachers. The education and involvement of the community, she says, is critical. An informed public can help alert Gorongosa rangers to vulnerable pangolins located outside the haven of the park, and even point them in the direction of smuggling bands. She points out that the majority of the pangolins that her center has helped rehabilitate were brought to her doorstep by concerned local residents.

Even against long odds for all eight species of *Pholidota*, it is this communal tendency that gives Angela hope. Ideally, both of Angela's pangolins will eventually be fitted with GPS trackers and released into the safe haven of the park—a paradise for such threatened creatures.

America has been a voracious client of the pangolin's diamond-patterned skin, using it for high-end cowboy boots.

Picture this: On a recent late afternoon toward sunset, the baby pangolin Tembo and his older bunkmate Mercio (Angela did point out that the elder pangolin's name is the male spelling of her own) wake from a day of slumber and are ready for food. Angela takes them out of their enclosure and brings them to a nearby grassy field, setting them loose to forage. African ground pangolins, unlike the other species, can stand upright on their hind legs, and Tembo and Mercio do—sniffing the air with their sensitive noses for the scent of dinner. Recent rains have brought a bumper crop of ants, and the two burrow in the moist ground and get down to business.

“Yes, there is a light at the end of the tunnel,” Angela says. “A light of hope that with a lot of effort and joint work it is possible to avoid the extinction of this species that is so important in Mozambique.” ☺

CHARLES DIGGES is an environmental journalist and researcher who edits Bellona.org, the website of the Norwegian environmental group Bellona.

The *Nautilus* Gorongosa series is published in partnership with the Howard Hughes Medical Institute's Science and Educational Media Group.

The New Renaissance

Today's scientists and artists are reunited in a single creative culture

BY KRISTEN FRENCH

ILLUSTRATIONS BY JORGE COLOMBO

TWO CULTURES? THAT'S OLD NEWS. Over the course of 50 print issues of *Nautilus*, we've interviewed scientists and artists who see no rift between their fields; in fact, they take inspiration from one another. This intersection arose casually from our conversations and stories, leading us to wonder if today's scientists and artists aren't players in a new cultural Renaissance, or at least a throwback to the old one, when scientists were artists and artists were scientists.

Florentine sculptor, painter, and printmaker Antonio Pollaiuolo, for example, was one of many Renaissance masters to dissect human bodies to better understand and represent the naked human form. Science was a great inspiration to their art—in a rather macabre way. But both art and science benefited from their forensics. And didn't Einstein, not a bad violinist himself, say he felt Mozart's music “has always existed as part of the inner beauty of the universe waiting to be revealed”?

For this, our 50th issue, we decided to put the inspiration question directly to 10 scientists and artists we admire, five of each. We asked the scientists what work of art inspired them, and asked the artists what in science inspired them. Their answers, in their own words, are personal, idiosyncratic, and driven by deep curiosity, just like science and art themselves.

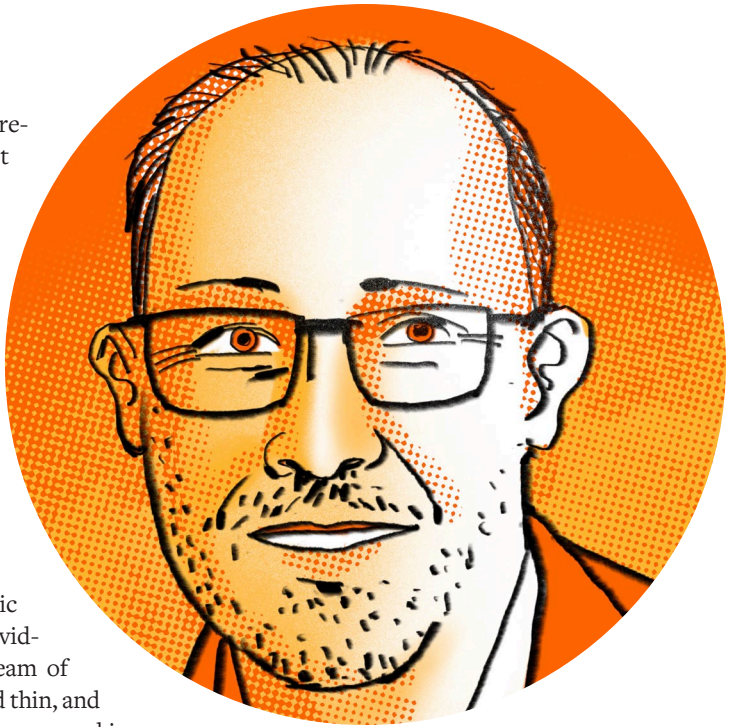
CALEB SCHARF, ASTROBIOLOGIST

Star Trek

If I'm really honest, and being unpretentious, the creative force that has most influenced me as a scientist is science fiction. As a very young kid, I watched a fair amount of *Star Trek* on TV, which was very influential because it triggered the idea that there could be things beyond normal perception, beyond my everyday experience of the world. *Star Trek* tells an immersive story about living, thinking beings faced with endless puzzles. Of course, there's always a neat packaged solution at the end of the 45 minutes. Quite often, the resolution in *Star Trek* comes through an interesting combination of abstract logic and human personality—of different individual ways of seeing. You would have a team of people working together through thick and thin, and that could be exciting, it could be adventurous, and in the end, you could sort of make progress. There was a certain appeal to that when I was a young person with a lot of questions, beginning to realize that science was a direction I was interested in pursuing.

One of the things *Star Trek* did so well was that there was actual science behind its imaginings. There's a famous episode with a creature that's silicon-based instead of carbon-based. It looks like some hideous carpet from the 1970s. In the show, it takes the characters quite a time to recognize that this is a living, thinking thing because it is so alien. It got across this sense of, stuff doesn't necessarily have to be built exactly like us, not just in terms of how it looks, but its fundamentals. It was an actual scientific question at the time: Could you build life differently? Now we know that silicon-based life is somewhat unlikely, but the question of whether alternate forms of life could exist remains.

Science fiction helped me to grasp how extraordinary the cosmos really is, and to wonder at the connection between all of that and the very parochial experience of being an organism on the Earth. I wanted to know how those things link together. I wanted to know: Are we alone? Were those funky aliens that I was seeing



on *Star Trek* out there somewhere? So my trajectory began with physics and cosmology, but over time sort of veered toward astrobiology, which is the quest to understand the nature of life in the universe, to understand what is out there that might support and initiate life. This may entail going off in a spaceship to explore, or exploring other worlds through our telescopes even though we can't physically be there ourselves.

The first time I watched *Star Trek*, I must have been around 4 years old, and I remember there was something scary happening, because I was hiding behind the couch, but peeking over the edge of the couch at the same time. My parents, who were both academic art historians—my father in photography and my mother in Renaissance art—would watch *Star Trek* with me. So I was a little bit afraid, but in a good way. As a kid, there's a natural wonder, a natural desire to ask questions, but as we age, we get so used to the world around us that we tend to lose some of that awe and sense of novelty. Science fiction instilled an interest for me in the biggest questions—the questions of what tantalizing and terrifying mysteries lurk beyond the confines of the surface of the Earth.

CAMILLE DUNGY, POET

Garden Soil

My most recent book is *Soil: The History of a Black Mother's Garden*. In it, I take a really intimate look at soil, a word that has both cultural and scientific weight and that is composed of opposites. It denotes a rich and fertile home for growing things, but also a sense of dirtiness and degradation. When you look at scientific studies of soil, you notice that how “dirty” it is can actually have a huge impact on the well-being of those who work with it: Healthy soil contains microbes like *Mycobacterium vaccae* that seem to promote serotonin uptake and general happiness in humans. But when you apply noxious chemical pesticides and herbicides to that soil, it can have the opposite effect, raising the risk of psychiatric disorders for those who dig their hands in it.

These details brought an extra dimension to the story I wanted to tell about the joys of gardening in the 21st century, a context that includes climate change, rampant pollution of the environment, and a long history of reliance on people of color to do agricultural work. When is a plot of land fertile and when is it so degraded, either by chemicals or events, that it spoils life instead of nurturing it? The soil in my garden here in Colorado has its own complicated history. It's a beautiful place I love, where I'm rooted and grow things, but it is also a place that used to belong to others, to indigenous peoples who were run off their land, so this soil is rich with paradox.

I'm especially fascinated by the times when science reconnects us to other more ancient ways of knowing. This happens over and over again. We do these complex studies that show you perform better when you sleep well at night, that opening a window helps to improve air quality in a room ... or that growing things in healthy soil



can be a balm for the mind. Science often provides new language for something that for centuries people intuited and understood. I find that wonderful and kind of funny.

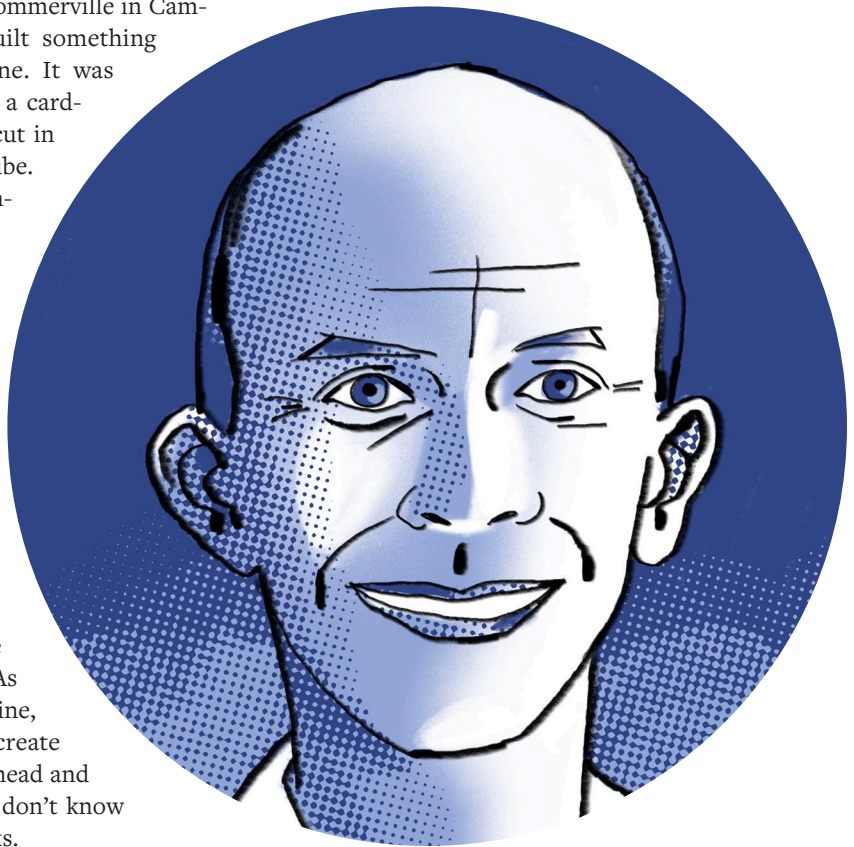
I was raised by a physician who's a very scientific thinker, and I studied pre-med along with English in college, so data and research were always part of my lexicon. I ended up being a writer and not a professional scientist in part because I'm pretty ecumenical in my interest. But the idea that science and art are somehow diametrically opposed is a relatively new concept in human culture. Scientists and writers often start out with the same profound questions about the nature of existence. The physics of stars, the neurobiology of dirt, ice core drilling in Antarctica—all these fields of inquiry help me answer big questions about who we are as a species and where we live, down to the very soil beneath our feet.

ANIL SETH, COGNITIVE SCIENTIST*The Dreamachine*

Sometime in the late 1950s, a British beat generation painter named Brion Gysin was on a bus in the south of France. He was falling asleep, and the sun was setting, and the bus passed through a stand of trees. And suddenly this bright, flickering, almost stroboscopic light flooded the bus. Gysin's eyes were closed, and he started having these remarkable visual experiences of colors and shapes and geometries and movement. The visions ceased as soon as the bus left the trees. Gysin was fascinated by this experience and wanted to find a way of recreating it.

Soon after that Gysin teamed up with William Grey Walter, a pioneering British polymath, who had been exploring a similar phenomenon: how stroboscopic light on closed eyes can generate these extraordinary visual experiences. So Gysin and Walter and a mathematician named Ian Sommerville in Cambridge got together and built something they called the Dreamachine. It was charmingly lo-fi. It was just a cardboard tube with some slits cut in it and a bright light in the tube. You put this tube on a spinning record player turntable and then you would get a stroboscopic effect. People would sit in front of the Dreamachine and they would have phenomenal visions. Gysin wanted to mass produce it, to make it more popular than television. It didn't take off, but it had countercultural appeal. The Rolling Stones apparently enjoyed using it and there was a version in the Centre Pompidou in Paris. As Gysin said, in the Dreamachine, everyone is an artist. You create the work of art. It's in your head and your head only. But we still don't know entirely how and why it works.

I didn't know about Gysin's Dreamachine until a few years ago, when I was recruited by a team of neuroscientists, philosophers, musicians, and architects who wanted to realize Gysin's vision for the 21st century. We also wanted to make it a collective experience, with the music and architecture as central as the light, and to use the Dreamachine to ignite curiosity and wonder about the mind and the brain. In my lab, we had already been working on this phenomenon of stroboscopic-induced visual hallucination for about 10 years, because it offers a fantastic window onto visual consciousness. In 2021, our team got a grant from the United Kingdom government and together we built Dreamachines in four cities in the United Kingdom, where 20 or 30 people at a time



In the Dreamachine, everyone is an artist.

could take an immersive journey through stroboscopic light and sound. When participants emerged from the core experience, they would enter a reflection area where they could talk about what they'd experienced, use an interactive tool to recreate aspects of what they had seen, and even draw pictures. We also offered information about how perception works in the brain, and about how we think the Dreamachine works.

Altogether, over seven months between May and September, around 40,000 people visited our Dreamachines. Most people reported having remarkable and intense visions, with some of them reporting complex hallucinations including people, places, and narratives. Many people dealing with depression and grief came out of the Dreamachine saying they felt a lot better. Now, as well as planning a touring version, we're taking this project back into the lab and using EEG to look at peoples' brains when they are having

these visual experiences. We're also trying to develop interfaces so people can communicate what they perceive more accurately. And we'd like to explore the possibility that the Dreamachine could act as a non-pharmacological psychedelic treatment for mental health conditions.

I've been involved in a bunch of art-science collaborations over the years, but this was different. It felt like a true marriage of science and art. I'm not particularly enamored by the tradition of putting people into brain scanners and having them look at a Picasso, the kind of neuro aesthetics that implicitly places science above art. I'm more interested in looking at art and science together as different approaches to understand human experience and the human condition. The French painter Paul Gauguin said "I close my eyes in order to see" and it sounds very metaphorical. But here we brought his idea to life in a very literal sense.

SABINE HOSSENFELDER, PHYSICIST*Music Is Math*

I use music to clear my head. If I'm trying to solve a problem and I feel super stuck, then concentrating on the music does a very good job. Often, I feel like it unlocks something in me. It's not so much that I use the patterns or concepts that come up in the music itself. It's more an indirect way of shaking up some things in my head that didn't quite work as I wanted them to.

For instance, three years ago, I was trying to solve a problem in quantum mechanics. I was sure there was an answer, but I couldn't find it. It was a math problem and I'd written down all the requirements and I was like, "there's gotta be a way to do it." So I took a few days off and was working on a song at the time, a cover version of "Things Can Only Get Better," by D:Ream. I had to shift the whole thing into a higher key to get it into my vocal range, and that changed the feel of the song. So then I started rearranging some other parts, and while I was at it, there were a few phrases in the song that didn't really make sense to me, so I replaced them with something else, and I changed the interlude, and the instruments, because I don't actually play an electric guitar. I use synthesizers. It all comes out of the computer and then I sing. And so the song morphed quite a bit.

I was working on this song for some while and then I just had this very visual understanding of the solution to the math problem I had been working on. It was like my brain suddenly decided "this is how it has to work." Similar things have happened to me on other occasions. I get this feeling that there has to be an answer, and I can kind of see in the equations that there is an answer, but I don't know what it is. Often that means my brain has solved the problem, but it doesn't want to spit it out, so I have to do something else to bring it into my consciousness, like play or write music.



Music is very mathematical, and the way that I think about mathematics is that it's basically an art form with very strict rules. If you're writing a song, you have to learn the techniques, the parameters, but you can break these once you've learned them. In mathematics, it's much more rigid. It's basically all about the rules. So if you're doing music, your brain tries more new things. And those new things may lead you through the back doors and side doors that open up to the solution you were seeking. That's why music can be such a muse for me when I'm stuck on a math puzzle.

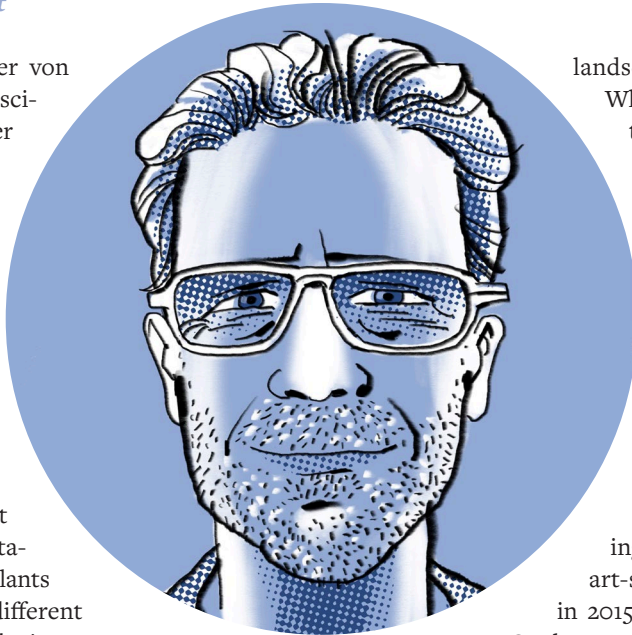
IAN VAN COLLER, PHOTOGRAPHER

The Victorian Ecologist

My hero is Alexander von Humboldt. A German scientist, artist, and explorer who loved the natural world, he was also the first to understand that ecology is interconnected. His illustrated map of Chimborazo, a glacier-clad volcano that is Ecuador's highest peak, was transformational for me. It's not only beautiful to look at but includes careful annotations of the names of plants and animals living at different elevations, an effort to depict a concept that came to him when he climbed the peak: that climate is an organizing principle of life. The illustrated map shows how art and science can enhance one another, engaging the mind and the senses.

Some of my own work takes a similar approach: In a series called "Naturalists of the Long Now," I collaborate with paleo-climatologists, who annotate my photographs of disappearing glaciers to bring a narrative of deep time to the surface. This represents an evolution in my thinking. Over a decade ago, in 2012, I joined a couple of friends in Glacier National Park, hiking into the backcountry over two summers to document the changing landscape. I quickly noticed that photography runs up against limitations when it engages with the idea of climate change. There is the melting glacier, which is what I photograph, or there is the polar bear on the ice floe. There is always an implied narrative, but the narrative is never complete, which is both a strength and a weakness.

As a photographer, I never tire of the beauty of mountain landscapes, but I wanted to bring another layer of understanding and interpretation to my work. I also realized that I didn't know much about the science of glaciers or what scientists working in these



landscapes were studying. When I read some scientific papers, they seemed esoteric and impenetrable, out of reach for the non-scientist. With von Humboldt in mind, I was also interested in the scientists themselves as creative people. I wanted to help them reach a different audience.

These ways of thinking converged in my first art-science collaborations in 2015, when I traveled to the Quelccaya Ice Cap in Peru, one of the world's largest tropical glaciers. I accompa-

nied a team of scientists who were collecting ice cores and climate data to understand what the atmosphere of past eras on Earth can tell us about today. That group included climate and glacier scientist Douglas Hardy and geologist Carsten Braun. Later, when I returned, I asked them to write whatever they wanted directly on the photographic prints, to address the relationship between the landscape, climate change, and their research. On one of these images, for instance, Braun diagrammed and described rock formations called *roche moutonnées*. These rocks, carved by annual cycles of glacial freezing and melting, have only become visible over the past decade, due to more wide-scale glacial melt.

My collaborations with scientists aim to communicate what the past can tell us about the present and future, about the interconnectedness of living things over vast timescales. In another life I would've been a scientist, perhaps an ornithologist. But during the Victorian era, scientists were also artists, like von Humboldt. They were naturalists. They painted. They wrote poetry. With my current work, I want to help keep this tradition alive.

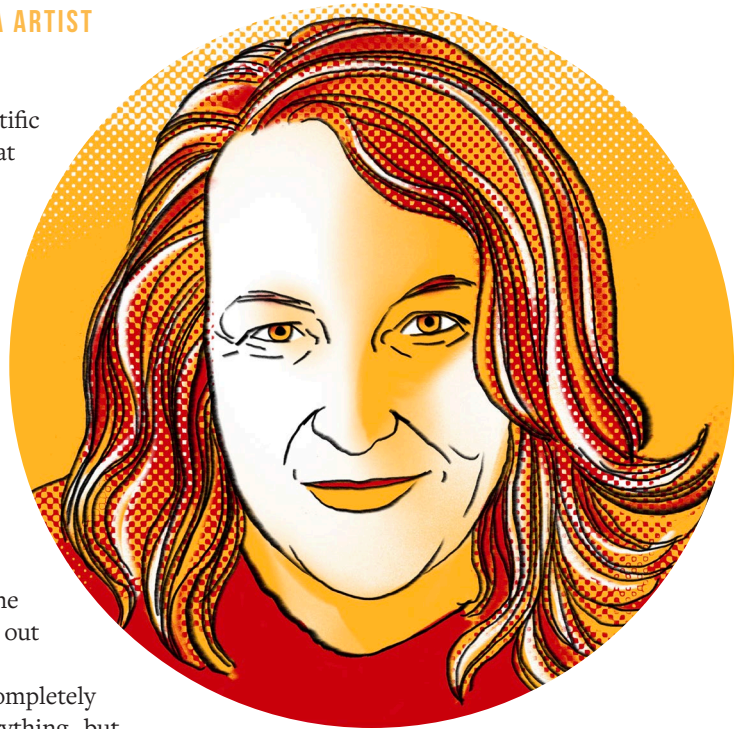
LYNN HERSHMAN LEESON, MULTIMEDIA ARTIST
Antibodies

Some of my work has solved real scientific problems. For instance, for a 2018 show at Basel's House of Electronic Arts, I wanted to work with a scientist who specialized in antibodies. I had already made works that I had described as "antibodies"—you know, not real bodies, but fictional ones, such as a character I created called Roberta Breitmore—but I had never worked with *actual* antibodies. So I met with Thomas Huber, a scientist who was with Novartis at the time, and we began talking about designing biological antibodies. We ultimately created two that were presented in vials in the show: One was for me and one was for Roberta. The binding regions of these antibodies spelled out our names in amino acid sequences.

It turned out that my antibody was completely useless because it would bind with everything, but Roberta's would not bind with anything, and that was something Novartis had been trying to do for years. They were able to use it in their research. They said they "hit the jackpot" with my project, and it was completely accidental. I love the idea of the artist as antibody, neutralizing the toxins in our culture and planet, while the Novartis antibody acts on actual toxins in the body.

I'm currently working on my fourth project with Thomas Huber. We did one with Harvard that resulted in the creation of a system that removes plastic pollutants from water, and we are now working on one about immortality. Some bacteria and species of jellyfish are immortal, and I am trying to figure out how they sustain immortality. But it will be some time before I have a body of work to present.

What I do when I am starting a new project is to think about the most important things in the world. You know, what issues are we dealing with? I did that around 2006 and realized that mapping the genome was probably the most important thing that was going on. It gave us the potential to actually change life and understand what makes up each species. I began



reading scientific papers and meeting scientists. You know, people would say, "Oh, don't get insulted if they walk out in a minute." But I really understood what they were saying, so they continued to talk to me. Seven years later, in 2013, that genetics work led to an exhibition called the Infinity Engine, which was all about genetic engineering and bioprinting. It was basically a model of a genetics lab with modular rooms that could be installed as a traveling exhibit. One of these rooms used facial recognition software to capture images of the visitors, reveal their possible DNA origins, and add them to an evolving composite human archetype.

I think it is really exciting to look at the questions that science is asking and try to come up with solutions. Artists are not restricted by having learned a discipline, so we solve problems using different methods, and can make things visual in ways scientists do not consider. Some people say my work is ahead of its time, but I think I get my ideas from the present. I just pay attention.

JONATHAN WEINER, WRITER
Social Amoeba

Back when I was in high school, I came across a copy of a science magazine with a story in it called “The Social Amoeba,” about the slime mold *Dictyostelium discoideum*. It’s basically a bunch of amoebas. The individual amoeba is just a shapeless blob. But when food runs out, the amoebas all crawl together and make this slick little slug. It crawls quite a distance farther than an individual amoeba could ever go. Then it makes a tower out of itself, with a ball of spores at the top, resembling a water tower. The amoebas in the stalk sacrifice themselves so the ones at the top can survive and disperse. If a bug brushes by or a raindrop hits it, the spore tower breaks like a piñata. All the little spores turn back into individual amoebas and go crawling around.

I was fascinated. I had been given a microscope for my bar mitzvah and I loved looking at cells in drops of pond water through the microscope. I also had a darkroom, and I would take pictures of paramecia and amoebas through the microscope and print them in the basement. So I had looked at a lot of these single-celled creatures, and I just never imagined they could do something so amazing. The author of the magazine article I read was John Tyler Bonner of Princeton University. So when I started trying to find my way as a writer after college, I called Bonner up and I interviewed him. Then I wrote an essay that was published in *Harvard Magazine* called “Marching Along with the Social Amoeba.” As I like to say, I’ve been marching along with it ever since.

The social amoeba helped get me thinking about evolution, the field of science I fell in love with as a journalist and author. Life begins as single cells, and then at some point, hundreds of millions of years ago, some cells get together and go multicellular. The social amoeba illustrates this process: The individual cells had to figure out how to cooperate and make something larger than themselves. This also really appealed to me as a metaphor for life. It’s a beautiful image of what science is, and of every aspect of culture, including

writing. We’re individuals, but together we form this social being that is beyond our imagining. That’s exciting. It spoke to me. Also, I just thought it was cool.

It was a fateful beginning, because I got to be friends with Bonner and we stayed friends for the rest of his long life. He introduced me to Peter and Rosemary Grant at Princeton, who were studying the evolution of finches in the Galapagos, which became the subject of my book *The Beak of the Finch*. Today, I’m working on a little afterword to a 30th anniversary edition of that book, and I’ll turn 70 at the end of this year. And so the science I find myself getting really interested in now concerns identity. I’m hoping to write a memoir that explores the big questions—how do we find ourselves, and how do we find our way? To me there is poetry in these questions, and that may be what inspires me the most: to try to express that sense of the poetry of life through the lens of science. The social amoeba, with its jaunty tower of hopeful spores, helped to set me on this course.



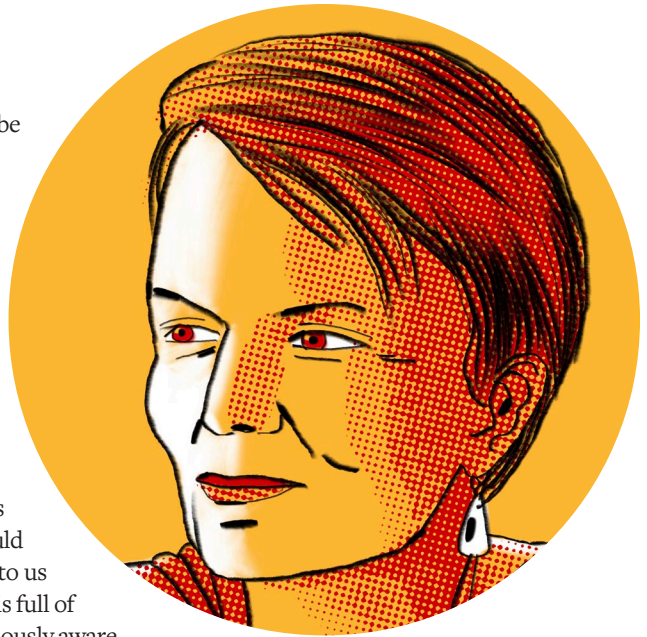
JULIE SEDIVY, LINGUIST

The Anatomy Lesson

I began my university studies thinking I would be a novelist—I had always thought that I would be a writer. I had spent my entire life swimming in language, loving language, thinking myself something of an expert in language. English was the fifth language I learned, and I can't remember a time before I loved books and literature and being read to. My father, in particular, read to us with a style that signaled engrossment and pleasure, so this became a model for me of how you orient to literature. I was not aware that one could study language scientifically, so my first linguistics class, in university, was a revelation. It was like somebody had peeled back the skin for me. I could see the ways language works that are not available to us unless we study them systematically, that language is full of intricate patterns about which we aren't even consciously aware.

A few years later, I remember coming across this Rembrandt painting, and recognizing it, and thinking, “yes, that’s exactly what I felt in that classroom,”—the painting was called *The Anatomy Lesson*, and it depicts a medical doctor teaching members of the public about the human body by dissecting a cadaver. This painting is from the early 1600s, presumably a time when few people knew what a body looked like from the inside. I imagine it might have been quite astonishing to discover, for example, that blood traveled in these special channels and didn’t just kind of seep out of your muscles like a sponge, or that there were dedicated organs with very specific functions that you could actually trace through the body, such as the digestive tract. I identified with the sense of awe I saw depicted there, that sense of leaning into the light, that sense of discovery of this everyday object that you are getting to know in a completely different context.

But once I began studying linguistics, I found the objects of study were often disembodied from the aspects of language that I had always assumed I’d be working with. Rather than using works of literature or poetry, we analyzed everyday sentences to understand this miracle of language. It required a very concerted effort to stay connected to that artful side of language that gives me pleasure. It’s been my life’s work to try to figure out how to join that aspect of knowing about language with the love of language as an aesthetic form, as a mode of storytelling, as a way of generating some kind of emotional effect. I’ve mostly resolved that tension for myself by writing about language from outside the academy, while staying connected to the research. I’ve always found it odd that, unlike many visual artists who study anatomy as a way to inform their art, writers rarely engage with scientific knowledge about language. My goal is to intertwine the two as much as I can.



I’ve always found it odd that writers rarely engage with scientific knowledge about language.

VIJAY IYER, MUSICIAN

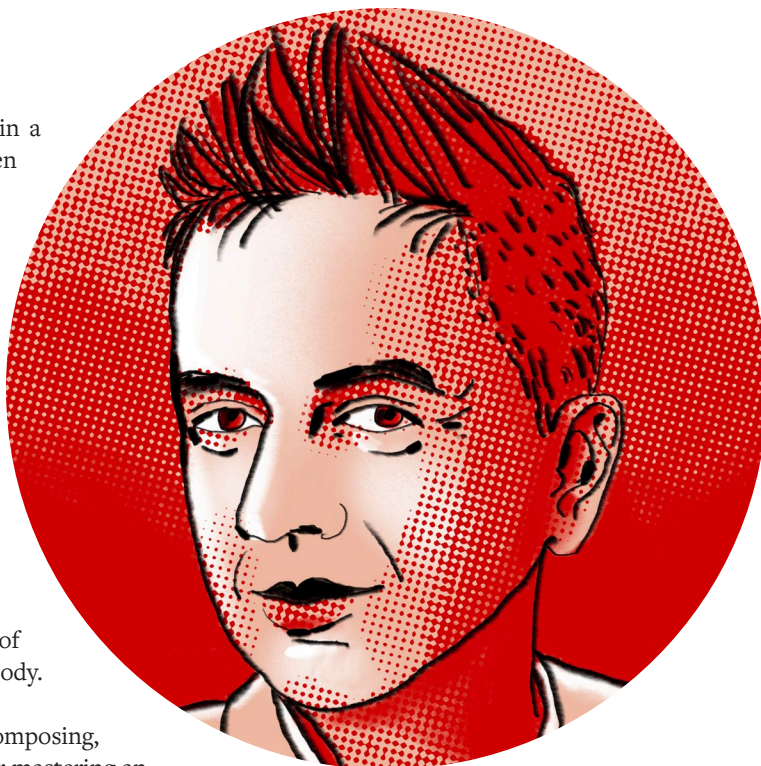
Resonance

Last night in Brussels, I played in a cathedral. The ceilings might have been 60 feet high. It was a truly spectacular experience of not just playing an instrument, but being inside an instrument, being inside a resonating body. That room had certain frequencies that it liked more than others. You couldn't ignore it. Our ensemble included piano, bass, and voice, and everything just bloomed into that space. Sounds remained in the air for seconds. You couldn't just hit a note and let it disappear. It would remain in the air, and in your ear. The vocalist could build these collections of pitches by singing a single line of melody. It all melted into an aura of sound.

Whether I'm playing piano or composing, solo or for an ensemble, or mixing or mastering an album, I'm always thinking in terms of the scientific concept of resonance, one of the fundamental building blocks of sound. Resonance is a quality of sustained vibration, as sounds reflect off surfaces and interact with one another.

When we think about rooms as resonating chambers, we start to think about how different resonances interact, and how harmony is this dynamic process of interaction among resonating bodies. When multiple instruments are involved, how do you ensure that certain things are audible at the right time? You have to know what tones and overtones a vibrating object will produce, and what those tones will sound like when played together, with different energies and strengths. You have to know how to populate the audible spectrum with information and manage the distribution of attention: what's in the foreground, what's in the background, how you hear sounds in relation to one another.

I'm fascinated by the fact that we can hear a group of people playing together and distinguish different sound sources, different instruments, even different voices, young or old, perhaps even their gender or body



size. Historically, humans as a species listened to music in groups—not via technology or headphones—so in evolutionary terms, there is a process of relation, body to body, that happens when we listen. When we hear music, we are hearing music being made, which means we are hearing bodies in motion.

In fact, for the last 25 years, I have been arguing that so-called “music cognition” is better understood as an embodied phenomenon. Musical phrases are based on the human breath, and musical pulse is based on human pulse and on the rhythms of walking. Musical expression is also related to speech, which has its own temporal flow related to what our mouths and speech apparatus can do. We are very good at listening to one another. Musical groove is the best example: A musician communicates pulse through rhythm, and that rhythm gets into the listener's body. That's called entrainment. In this way we resonate with each other. It's a kind of communion of inner experience. A profound form of empathy. Music is us.

SEAN B. CARROLL, EVOLUTIONARY BIOLOGIST
Animal Markings

I've spent some time in the company of 20th-century French writer Albert Camus—about whom I wrote a book—and something he said has really stayed with me: “A man’s work is nothing but the slow trek to rediscover, through the detours of art, those two or three great and simple images in whose presence his heart first opened.”

For me, these indelible first impressions were the colors and patterns on animals I saw as a kid. Growing up, I lived in a fairly bland setting, wildlife-wise. This was urban Ohio. So the striped and spotted creatures I found when I went into the woods or, eventually, brought home as pets, captured my imagination. I had vivid green snakes. I had a beautiful speckled kingsnake that was shiny, like patent leather. It was spotted on top, with a yellow spot on every scale, and it had this beautiful zebra pattern on the belly, and on the face. It looked like it was smiling all the time. I had garter snakes that were all black with long yellow stripes. I had a spotted salamander. Whatever my 10-year-old aesthetic sense was, I just loved this body art. That was part of the pleasure of keeping these animals. To me, they were beautiful.

If I look back at the journey I took, I can see the aesthetic appeal of colors and patterns drove some of my scientific interests. When I got to embryology and first started looking at embryos through a microscope, I was awed by the process of things taking shape. There’s a whole branch of embryology just called pattern formation. You can see the molecular and chemical patterns of gene expression in embryos long before you see physical form emerge. These patterns have clear geometries and regularities. You can see them repeating. It’s spectacular. It’s

like seeing the blueprint, a foreshadowing of what is to come, not just for the individual embryo but for the evolution of the entire animal kingdom.

Starting in the '90s, I also did a lot of work on butterfly patterns, the molecular processes that contribute to their formation. People love butterflies because they are beautiful to look at, and there’s a lot of beauty at the surface, but there is also so much beauty under the hood, in the story of how butterflies come to look the way they do. So my pleasure has been to study things that fascinate me, that are pleasing to look at, and to get a glimpse of how nature does it. I have an emotional connection to the subject matter. Many scientists do. It’s not all analytical. It’s much easier to study things you love. ☺



From outer space



to the ocean's depths

**Experience science in
a new way at Miami's
planetarium, aquarium
and science museum.**

FROST SCIENCE

1101 Biscayne Blvd. Miami, FL 33132 | frostsscience.org

PHILLIP & PATRICIA FROST MUSEUM OF SCIENCE

1101 Biscayne Blvd., Miami, FL 33132 | 305-434-9600 | frostsscience.org @FROSTSCIENCE



The Phillip and Patricia Frost Museum of Science is supported by the Miami-Dade County Department of Cultural Affairs and the Cultural Affairs Council, the Miami-Dade County Mayor and Board of County Commissioners of Miami-Dade County. This project is supported by the Building Better Communities Bond Program and the City of Miami. Sponsored in part by the State of Florida, Department of State, Division of Arts and Culture; the Florida Council on Arts and Culture; and the National Endowment for the Arts. The museum is accredited by the American Alliance of Museums, is an affiliate of the Smithsonian Institution and a member of the Association of Science and Technology Centers.

LISTEN TO THE OCEAN

"We are inhabitants of an ocean world. Everything that happens down there is linked to us up here."

Dr Helen Czerski
Presenter, Ocean Matters

Take a deep dive into **Ocean Matters** - a new podcast series looking at aspects of life on, above and beneath the shimmering surface of our seas. With interviews and insights from specialists at the cutting edge of marine science, we explore the issues threatening the ocean and discover how we can protect the blue engine that's central to all life on earth.

Search for 'Ocean Matters' and subscribe wherever you get your podcasts.



Apple Podcasts



Google Podcasts



Spotify



fondazione
bertarelli

fondazione-bertarelli.org



A photograph of two fishermen in a small wooden boat on a body of water at sunset. The sun is low on the horizon, creating a bright orange and yellow glow. One fisherman is standing, wearing a conical hat and a checkered shirt, with his arms outstretched. The other fisherman is sitting, also wearing a hat. The water reflects the colors of the sky. The background shows distant hills.

Fast-tracking solutions to accelerate ocean health, for thriving people and planet

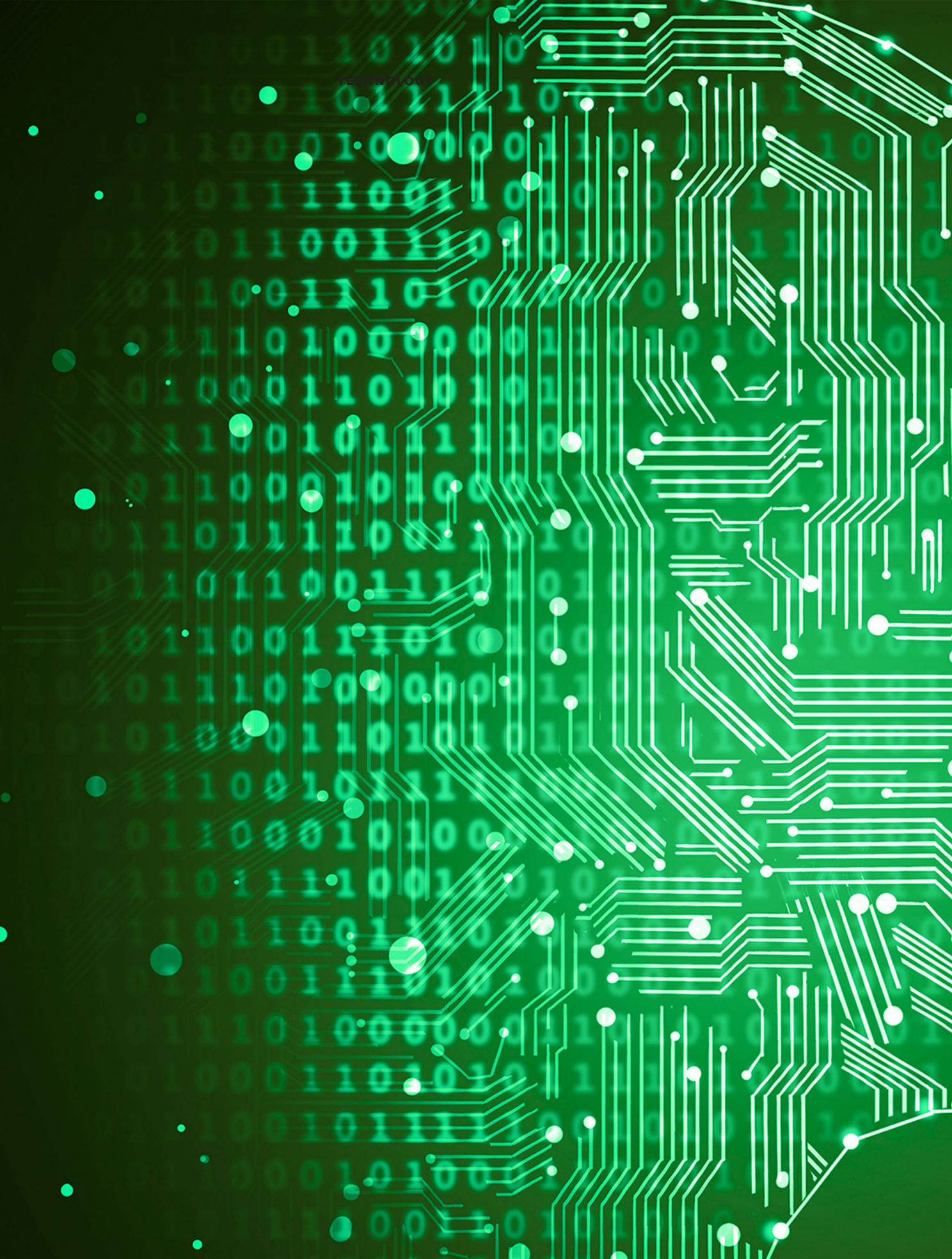
Centre for the
Fourth Industrial
Revolution

WORLD
ECONOMIC
FORUM

Shape the trajectory of technological change



Join us
weforum.org/c4ir





Why Conscious AI Is a Bad, Bad Idea

Our minds haven't evolved to deal with machines we believe have consciousness

BY ANIL SETH

ARTIFICIAL INTELLIGENCE IS MOVING FAST. We can now converse with large language models such as ChatGPT as if they were human beings. Vision models can generate award-winning photographs as well as convincing videos of events that never happened. These systems are certainly getting smarter, but are they conscious? Do they have subjective experiences, feelings, and conscious beliefs in the same way that you and I do, but tables and chairs and pocket calculators do not? And if not now, then when—if ever—might this happen?

While some researchers suggest that conscious AI is close at hand, others, including me, believe it remains far away and might not be possible at all. But even if unlikely, it is unwise to dismiss the possibility altogether. The prospect of artificial consciousness raises ethical, safety, and societal challenges significantly beyond those already posed by AI. Importantly, some of these challenges arise even when AI systems merely *seem* to be conscious, even if, under the hood, they are just algorithms whirring away in subjective oblivion.

Because of these concerns, I signed an open letter put together by the Association for the Mathematical Study of Consciousness (AMCS). Following hot on the heels of the much-publicized call to pause large-scale AI research, the letter argues that it is vital for public, industry, and governing bodies to understand whether and how AI systems could become conscious, to consider the implications, and to address the dangers. Around the same time, Anka Reuel of Stanford University and Gary Marcus, a leading voice on AI, sensibly called for the establishment of a global, neutral, and non-profit “international agency for AI” to coordinate global regulation of AI technologies. I think the remit of such an agency should cover artificial consciousness as well. Earlier this year, Geoffrey Hinton, one of AI’s pioneers, resigned as Google’s chief scientist to join the chorus of concern, having changed his mind about the immediacy and reality of the threats posed by the technology he helped develop. In my opinion, we should not even be trying to build conscious machines.

We think we’re intelligent, know we’re conscious, and so assume the two go together.

TO GET A HANDLE on these challenges—and to clarify the confusing and hype-ridden debate around AI and consciousness—let’s start with some definitions. First, consciousness. Although precise definitions are hard to come by, intuitively we all know what consciousness is. It is what goes away under general anesthesia, or when we fall into a dreamless sleep, and what returns when we come round in the recovery room or wake up. And when we open our eyes, our brains don’t just process visual information; there’s another dimension entirely: Our minds are filled with light, color, shade, and shapes. Emotions, thoughts, beliefs, intentions—all feel a particular way to us.

As for intelligence, there are many available definitions, but all emphasize the ability to achieve goals in flexible ways in varied environments. Broadly speaking, intelligence is the capacity to do the right thing at the right time.

These definitions are enough to remind us that consciousness and intelligence are very different. Being intelligent—as humans think we are—may give us new ways of being conscious, and some forms of human and animal intelligence may require consciousness, but basic conscious experiences such as pleasure and pain might not require much species-level intelligence at all.

This distinction is important because many in and around the AI community assume that consciousness is just a function of intelligence: that as machines become smarter, there will come a point at which they also become aware—at which the inner lights come on for them. Last March, OpenAI’s chief scientist Ilya Sutskever tweeted, “It may be that today’s large language models are slightly conscious.” Not long after, Google Research vice president Blaise Agüera y Arcas suggested that AI was making strides toward consciousness.

These assumptions and suggestions are poorly founded. It is by no means clear that a system will become conscious simply by virtue of

FLESH AND BLOOD Being conscious is not the result of some complicated algorithm running on the wetware of the brain. It is rooted in the fundamental biological drive within living organisms to keep on living.



becoming more intelligent. Indeed, the assumption that consciousness will just come along for the ride as AI gets smarter echoes a kind of human exceptionalism that we'd do well to see the back of. We think we're intelligent, and we know we're conscious, so we assume the two go together.

Recognizing the weakness of this assumption might seem comforting because there would be less reason to think that conscious machines are just around the corner. Unfortunately, things are not so simple. Even if AI by itself won't do the trick, engineers might make deliberate attempts to build conscious machines—indeed, some already are.

Here, there is a lot more uncertainty. Although the last 30 years or so have witnessed major advances in the scientific understanding of consciousness, much remains unknown. My own view is that consciousness is intimately tied to our nature as living flesh-and-blood creatures. In this picture, being conscious is not the result of some complicated algorithm running on the wetware of the brain. It is an embodied phenomenon, rooted in the fundamental biological drive within living organisms to keep on living. If I'm right, the prospect of conscious AI remains reassuringly remote.

But I may be wrong, and other theories are a lot less restrictive, with some proposing that consciousness could arise in computers that process information in particular ways or are wired up according to specific architectures. If these theories are on track, conscious AI may be uncomfortably close—or perhaps even among us already.

THIS LACK OF CONSENSUS about consciousness, when set against the rapidly changing landscape of AI, highlights the need for more research into consciousness itself. Without a principled and experimentally verified understanding of how consciousness happens, we'll be unable to say for sure when a machine has—or doesn't have—it. In this foggy situation, artificial consciousness may even arise accidentally, perhaps as a byproduct of some other functionality the tech industry installs in the next generation of their algorithms.

There are two main reasons why creating artificial consciousness, whether deliberately or inadvertently, is a very bad idea. The first is that it may endow AI systems with new powers and capabilities that could wreak havoc if not properly designed and regulated. Ensuring that AI systems act in ways compatible with well-specified human values is hard enough as things are. With conscious AI, it gets a lot more challenging, since these systems will have their own interests rather than just the interests humans give them.



Attributing humanlike consciousness to AI leads to unjustified assumptions.

The second reason is even more disquieting: The dawn of conscious machines will introduce vast new potential for suffering in the world, suffering we might not even be able to recognize, and which might flicker into existence in innumerable server farms at the click of a mouse. As the German philosopher Thomas Metzinger has noted, this would precipitate an unprecedented moral and ethical crisis because once something is conscious, we have a responsibility toward its welfare, especially if we created it. The problem wasn't that Frankenstein's creature came to life; it was that it was conscious and could feel.

These scenarios might seem outlandish, and it is true that conscious AI may be very far away and might not even be possible. But the implications of its emergence are sufficiently tectonic that we mustn't ignore the possibility. Certainly, nobody should be actively trying to create machine consciousness.

Existential concerns aside, there are more immediate dangers to deal with as AI has become more humanlike in its behavior. These arise when AI systems give humans the unavoidable impression that they are conscious, whatever might be going on under the hood. Human psychology lurches uncomfortably between anthropocentrism—putting ourselves at the center of everything—and anthropomorphism—projecting humanlike qualities into things on the basis of some superficial similarity. It is the latter tendency that's getting us in trouble with AI.

Many people, including some experts, are already projecting sophisticated cognitive competences into AI systems—large language models in particular—on the basis of largely anecdotal and frankly sketchy evidence. But do these models really understand anything? Do they—as has been claimed—have a theory of mind (the ability to attribute mental states, such as beliefs and desires, to others)? Claims that language models possess these capabilities usually rest on suggestive pieces of dialogue. This sort of evidence is remarkably weak, as any psychologist will tell you. It is even

Trouble is on the way whether AI merely seems or actually is conscious.

weaker when we seek to extrapolate from human experience to a machine. Although humans would need to be cognitively sophisticated to engage in some of the dialogue that chatbots are now capable of, the same conclusion does not hold for AI. Language models may well be able to participate in sophisticated linguistic interactions without understanding anything at all.

The lack of true understanding in language models is revealed by their tendency to confabulate: to make stuff up, spouting nonsense in confident language. When I asked OpenAI's GPT-4 to write a biography of me, it stated wrongly that I was born in London. When I asked it to do it again with fewer errors in dates and places, it got things even more wrong, saying I was born in Hammersmith, London—a revealing answer since being more specific is more likely to be wrong, as anybody who understands anything knows.

Future language models won't be so easy to catch out. Before long, they may give us the seamless and impenetrable impression of understanding and knowing things, regardless of whether they do. As this happens, we may also become unable to avoid attributing consciousness to them too, suckered in by our anthropomorphic bias and our inbuilt inclination to associate intelligence with awareness.

Systems like this will pass the so-called Garland Test, an idea which has passed into philosophy from Alex Garland's perspicuous and beautiful film *Ex Machina*. This test reframes the classic Turing Test—usually considered a test of machine intelligence—as a test of what it would take for a human to feel that a machine is conscious, even given the knowledge that it is a machine. AI systems that pass the Garland Test will subject us to a kind of cognitive illusion, much like simple visual illusions in which we cannot help seeing things in a particular way, even though we know the reality is different.

THIS WILL LAND SOCIETY into dangerous new territory. By wrongly attributing humanlike consciousness to artificial systems, we'll make unjustified assumptions about how they might behave. Our minds have not

evolved to deal with situations like this. If we feel that a machine consciously cares about us, we might put more trust in it than we should. If we feel a machine truly believes what it says, we might be more inclined to take its views more seriously. If we expect an AI system to behave as a conscious human would—according to its apparent goals, desires, and beliefs—we may catastrophically fail to predict what it might do.

Our ethical attitudes will become contorted as well. When we feel that something is conscious—and conscious *like us*—we will come to care about it. We might value its supposed well-being above other actually conscious creatures such as non-human animals. Or perhaps the opposite will happen. We may learn to treat these systems as lacking consciousness, even though we still feel they are conscious. Then we might end up treating them like slaves—inuring ourselves to the perceived suffering of others. Scenarios like these have been best explored in science-fiction series such as *Westworld*, where things don't turn out very well for anyone.

In short, trouble is on the way whether emerging AI merely *seems* conscious, or actually *is* conscious. We need to think carefully about both possibilities, while being careful not to conflate them. And we need action, too. Along with new institutions like the one that Marcus and Reuel propose, there should be major investment into research into consciousness within the mind and brain sciences, so that we can be better informed when developing and responding to new generations of AI. (This research will also benefit society in many other ways, for example in medicine, law, and animal welfare.)

Accelerated research is also needed in social sciences and the humanities to clarify the implications of machines that merely seem conscious. And AI research should continue, too, both to aid in our attempts to understand biological consciousness and to create socially positive AI. We need to walk the line between benefiting from the many functions that consciousness offers while avoiding the pitfalls. Perhaps future AI systems could be more like oracles, as the AI expert Yoshua Bengio has suggested: systems that help us understand the world and answer our questions as truthfully as possible, without having goals—or selves—of their own.

Like the technology itself, attitudes toward AI are at an inflection point. Time is short to develop a rational and fit-for-purpose framework to ensure that the enormous potential of AI is used for the benefit of humanity and the planet. The implications of either true or apparent artificial consciousness must be part of the conversation. We need to bring to the forefront of our collective awareness the importance of understanding awareness itself. ☺

ANIL SETH is a professor of cognitive and computational neuroscience at the University of Sussex, co-director of the Canadian Institute for Advanced Research Program on Brain, Mind, and Consciousness, and an advanced investigator of the European Research Council. He is the author of *Being You: A New Science of Consciousness*.



The 19th-Century Trippers Who Probed the Mind

In the age of self-experiment, scientists took mind-altering drugs to test the limits of subjectivity

BY MIKE JAY

NULLIUS IN VERBA—NOTHING ON AUTHORITY. In 1660, on the eve of its founding, The Royal Society of London took this defiant Latin phrase as its motto. For the United Kingdom's main scientific body, it announced a new way of thinking that came to dominate the scientific revolution: Classical and scholastic authority could prove apocryphal. Only direct evidence, generated by experiment and first-person observation, revealed scientific truth.

Evidence was everything, and leading scientists of the era, including Isaac Newton and Robert Boyle, developed a system for classifying it. Qualities such as size, shape, or weight, which were directly measurable, were referred to as “primary” evidence. Texture, taste, or feelings that described human sensations and responses were considered “secondary.” While primary evidence was easier to collect and test, sensation and perception were considered legitimate fields of inquiry, and certain classes of data could only be demonstrated by self-experiment.

I feel like the sound of a harp.

In a famous and graphic example, when Isaac Newton wished to establish whether a change in the curvature of the eye would present a distorted image to the perceiver, he took a large needle, or bodkin, and stuck it as far into his eye as he could. He then described in detail the colored circles that appeared to him. It was not possible to present direct evidence for these shapes, since they only existed in Newton's mind, yet his fellow philosophers were not obliged simply to accept Newton's word for them. The experiment was described in such a way that any skeptic, if they so wished, could try it out on themselves.

This was also the case for drugs that acted on the mind. Like the circles in Newton's vision, the changes in thought, mood, sensation, or perception they produced were secondary qualities, but this did not mean they were delusions. There was no correct or perfect way to present them, yet they offered unique insights into mental functioning. The language that offered itself most plausibly for describing them was that of medicine, in which the physician could only report the patient's sensations and state of mind at second hand, but could add judicious glosses and interpretations suggested by their professional learning and experience of similar cases.

Robert Hooke, curator of experiments at the Royal Society, provided some of the earliest testimony, describing in detail the effects of the many drugs he used for overlapping purposes: verifying medical

claims, managing his pain and moods, and "refreshing" himself during social and business meetings in the coffee houses he frequented in the afternoons. Hooke documented impressions not just of alcohol, chocolate, tea, coffee, and tobacco, but also of cannabis. On Dec. 18, 1689, as part of a lecture he delivered at the Royal Society entitled "An Account of the Plant, Call'd Bengue," or cannabis, Hooke detailed his own experience with the drug, in the third person:

This Powder being chewed and swallowed, or washed down, by a small Cup of Water, doth, in a short Time, quite take away the Memory & Understanding; so that the Patient understands not, nor remembereth any Thing that he seeth, heareth, or doth, in that Extasie, but becomes, as it were, a mere Natural, being unable to speak a Word of Sense; yet is he very merry, and laughs, and sings, and speaks Words without any Coherence, not knowing what he saith or doth; yet is he not giddy, or drunk, but walks and dances and sheweth many odd Tricks; after a little Time he falls asleep, and sleepeth very soundly and quietly; and when he wakes, he finds himself mightily refresh'd, and exceeding hungry ...

Such perceptual and bodily experiences—of the kind elicited by doctors with the question "how do you feel?"—were not able to produce the kind of replicable results generated by vacuum pumps or thermometers. But in its place an informal criterion of

expertise emerged, dubbed by the historian of science Simon Schaffer “the Cartesianism of the genteel”: the assumption that trained or educated observers were capable of using their minds to assess the evidence of their bodies—or, in the terms established by the philosophy of John Locke, of separating the intellect from the passions. As

in Hooke’s case, it became the convention to relay such evidence in the third person or passive voice favored by physicians, with the confessional first person confined to diaries and private records.

As pharmacology developed through the 18th century, this language of quasi-medical reportage became firmly entrenched. Self-experiment with drugs was common practice, for ethical as well as practical reasons: Physicians were obligated to treat the sick according to the Hippocratic oath, doing no harm, and experimenting on them was the mark of an unscrupulous quack.

Practicing physicians were also aware that responses to drugs could vary widely between individuals. The growth of physical observation and measurement revealed that mind and body influenced each other in mysterious ways, and that even directly experienced phenomena could be proven false. One famous example was the committee set up in 1784 by the French Royal Academies of Science and Medicine, under the aegis of Benjamin Franklin, to investigate Anton Mesmer’s theory of animal magnetism or mesmerism. “There is no proof of the existence of the Animal Magnetic fluid,” the committee’s report concluded. The lesson for self-experimenters was that hypervigilance to one’s own sensations could overinterpret the evidence of the body or generate symptoms based solely on expectation.

FOR THE GENERATION THAT FOLLOWED, however, subjectivity was the new frontier of scientific knowledge. The inward turn emerged from the philosophy of Immanuel Kant, whose treatise of 1781, *Critique of Pure Reason*, made a primary distinction between the “phenomenal” world—reality as revealed by sensation and perception—and a “noumenal” world of ideas and categories, including God, that existed prior to and

*Trains of vivid
and visible images
rapidly passed
through my mind.*

independently of human experience. According to Kant’s distinction, the world as received via the senses was not the accurate reflection of an external reality but a construct, shaped by the human senses and limited by the parameters of the human mind.

This theory was strikingly corroborated in a series of drug experi-

ments by the young chemist Humphry Davy. In 1799, at the age of 20, Davy was hired as the chemical assistant at the Medical Pneumatic Institution in Bristol, an experimental project initiated by the pioneering physician Thomas Beddoes for synthesizing and testing gases in the treatment of lung conditions. One of the first compounds Davy created in the laboratory was nitrous oxide, a recently discovered gas that was believed to be highly toxic. Davy suspected this belief resulted from a confusion with a related compound, nitric oxide, a red-brown gas that was a powerful irritant. “I made a discovery yesterday which proves how necessary it is to repeat experiments,” he wrote to his friend Davies Giddy in April 1799: “The gaseous oxide of azote [nitrous oxide] is perfectly respirable when pure.”

Excited to have established a virgin field of inquiry, Davy and Beddoes heated ammonium nitrate crystals in an alembic and collected the escaping gas in an air holder, from which Davy inhaled through a breathing tube. As he filled his lungs, he noticed an unexpected sensation, “a highly pleasurable thrilling in the chest and extremities.” As he continued, “the objects around me became dazzling and my hearing more acute,” and the sensations built toward a climax in which “the sense of muscular power became greater, and at last an irresistible propensity to action was indulged in.”

Beddoes recorded that Davy leapt violently around the laboratory shouting for joy. For his own part, Davy retained only vague recollections of these ecstatic moments, and were it not for the scrawled notes he discovered the following morning, “I should even have doubted their reality.”

Unlike the speculative animal fluids of Mesmer, there was no doubt about the material cause of this paroxysm of pleasure. Nitrous oxide—first isolated by Joseph Priestley, who had named it “dephlogisticated



TOUCHING THE SUBLIME

Humphry Davy's self-experimentation with mind-altering drugs led him to develop a "new language of feeling." His ground-breaking report on these explorations linked the chemical and the medical to the sublime.

Southey wrote to his brother that "Davy has actually invented a new pleasure for which language has no name." Exploring it further was an invitation and a challenge that the keenest minds of Bristol were eager to accept.

As the experiments progressed, Davy realized that a new "language of feeling," as he called it, was required to describe the effects of the gas. The standard question of medical description, "How do you feel?" was tested to its limits by a torrent of sensations that encompassed dizziness, tingling, a sense of mental exhilaration, and onrushing cosmic epiphany that rapidly dissolved into incoherence and, fre-

nitrous air"—was a chemical substance with a known synthesis, and the experiment could be replicated and verified in any home laboratory. The effects of the gas, however, could only be captured in first-person testimony.

Davy was quick to elicit such testimony, and was perfectly placed to do so. The Pneumatic Institution was a hub for Bristol's freethinking writers, philosophers, and physicians, and over the summer of 1799 dozens of them came to visit and experience the gas which the poet Robert Southey, the first of his friends to whom Davy had offered it, described as "the wonder-working air of delight." After his first dose,

quently, hysterical laughter with no obvious cause. Davy and Beddoes attempted a few trials on patients with lung diseases; one responded to the question with, "I do not know, but very queer." Another responded, obliquely but suggestively, "I feel like the sound of a harp."

During the evenings they experimented further on healthy volunteer subjects. When Davy set the chemical reaction bubbling and offered a new subject a green silk bag of the gas, he often began by giving them a dose of ordinary air to rule out any elements of suggestion or expectation. Once they had recovered from a lungful of the real thing, he asked them to write a brief description of their experience. As one of the volunteers, the

surgeon Thomas Hammick, wrote after his intoxication, “We must either invent new terms to express these new and peculiar sensations, or attach new ideas to old ones, before we can communicate intelligibly with one another on the operations of this extraordinary gas.”

Nitrous oxide, for Davy and his circle, collapsed the distinction between the intellect and the passions: It stimulated both, with equal intensity. It was a profoundly embodied experience, susceptible to external measurements—for example, the amount of gas that was inhaled, or had dissolved into the bloodstream—but not reducible to them. It asked profound questions about the relation between mind and body: How could inhaling an artificially created chemical affect not merely the breathing and the pulse, but the emotions, the sense of wonder, and the imagination?

Davy’s ground-breaking report on the experiments, *Researches Chemical and Philosophical, Chiefly Concerning Nitrous Oxide and Its Respiration* (1800), yoked body and mind, intellect and passion together with a structure that ascended from the chemical to the medical to the sublime. Its opening section was a description of nitrous oxide’s chemistry and synthesis; the next was a precise account of its physiological action, and it concluded with the subjective reports of over 30 volunteer subjects. Davy’s own contribution, after absorbing as much gas as humanly possible by enclosing himself in an airtight box filled with it for an hour and a quarter, gave the language of feeling full rein:

I heard every distinct sound in the room and was perfectly aware of my situation. By degrees as the pleasurable sensations increased, I lost all touch with external things; trains of vivid and visible images rapidly passed through my mind and were connected with words in such a manner, as to produce perceptions perfectly novel. I existed in a world of newly connected and modified ideas. I theorised; I imagined I made discoveries ... As I recovered my former state of mind, I felt an inclination to communicate the discoveries I had made during the experiment. I endeavoured to recall the ideas, they were feeble and indistinct; one collection of terms, however, presented itself ... *Nothing exists but thoughts! The universe is composed of impressions, ideas, pleasure and pains!*

The universe is composed of impressions, ideas, pleasure and pains!

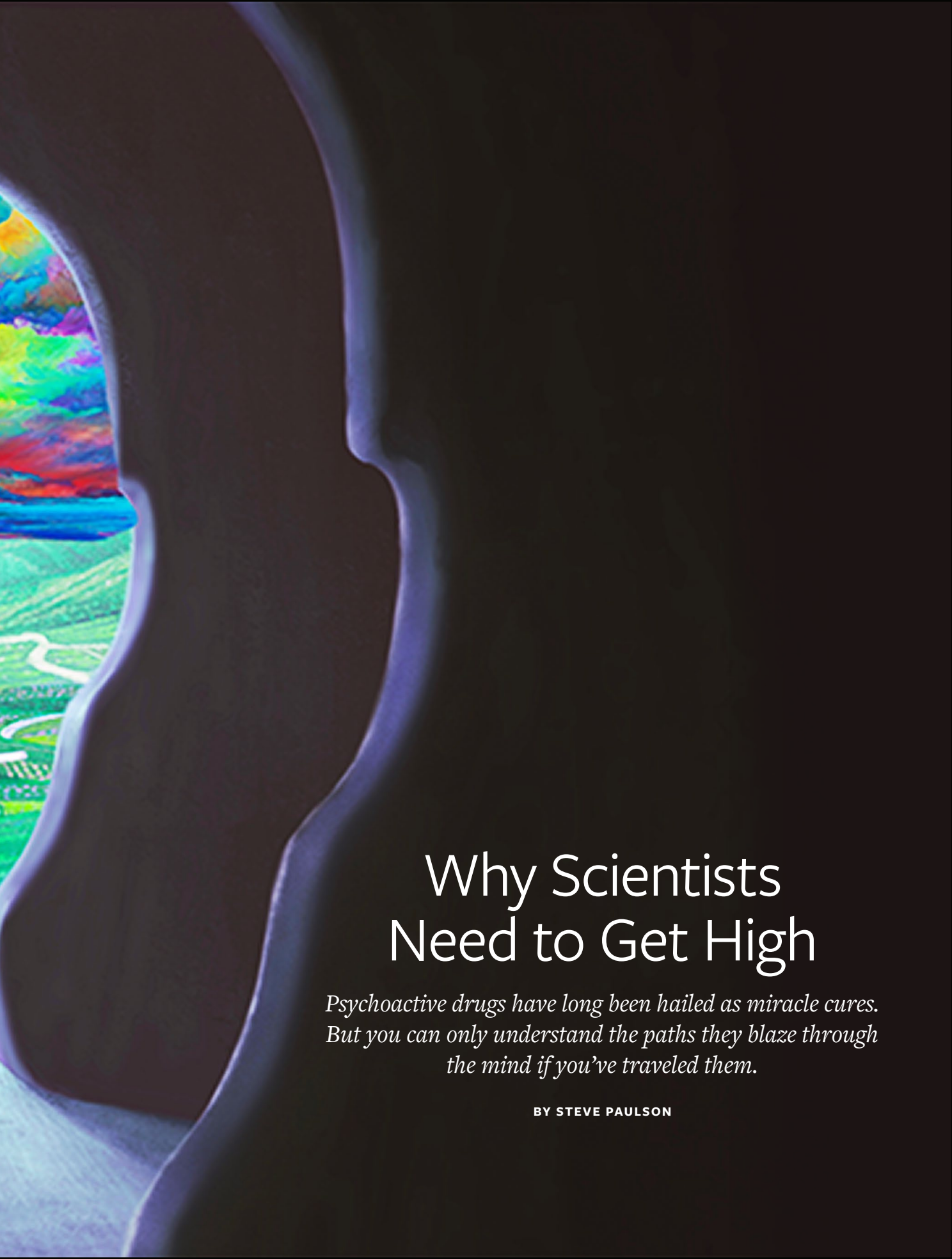
Davy’s scientific ambition demanded that he push his experiments to the limit and experience the effects of the drug at their most intense. This in turn required a break with the impersonal conventions of medical reportage in favor of a first-person testimony that fused the roles of observer and experimental subject. He developed his “language of feeling” in parallel with that of the young poets among his volunteers, Robert Southey and Samuel Taylor Coleridge, who were also seeking a novel and introspective language to capture feelings and states of mind never previously described.

Davy aspired to be a hero of science, comparing himself in his youthful notebooks to Sir Isaac Newton, but his version of science took on the qualities of the dawning Romantic age and of its most exalted quality, genius. In theory, there was no role for genius in experimental science, since data was replicable and detachable from individual personality; but self-experiment, in Davy’s hands, had produced results inseparable from the dazzling mind of its subject. Subjective visions could in theory be confirmed by other researchers; but Davy represented a new breed of experimenter, both rigorous mechanic and inspired genius, prepared to take scientific discovery to heroic limits. ☺

MIKE JAY is an author and cultural historian whose subjects include science, medicine, drugs, madness, literature, and radical politics. He contributes regularly to the *London Review of Books* and the *Wall Street Journal*. His previous books on the history of drugs include *Mescaline*, *High Society*, and *The Atmosphere of Heaven*.

Excerpted from *Psychonauts: Drugs and the Making of the Modern Mind*, by Mike Jay. Copyright © 2023. Reprinted by permission of Yale University Press.





Why Scientists Need to Get High

*Psychoactive drugs have long been hailed as miracle cures.
But you can only understand the paths they blaze through
the mind if you've traveled them.*

BY STEVE PAULSON

IT'S REMARKABLE HOW FAST psychedelics have gone mainstream. It's not just the craze for microdosing or the enthusiasm for mushroom grow kits. After years of shunning this research, major universities are now racing to set up their own psychedelic institutes, with psilocybin and MDMA being touted as the most promising treatments for depression and PTSD in decades.

But this is not the first time psychoactive drugs have been hailed as miracle cures. Over the past two centuries, morphine, heroin, and cocaine were also considered wonder drugs until doctors discovered their addictive properties. Today, what's striking is how the public conversation about psychedelics tends to ignore this deeper history of psychoactive drugs.

Historian Mike Jay is out to challenge this narrative of psychedelic exceptionalism. Through a series of books on the history of intoxicants, he's traced the lineage of various drug cultures. His new book, *Psychonauts: Drugs and the Making of the Modern Mind*, focuses on the 19th century's rich history of psychoactive experiences, spanning the worlds of science and literature. In some ways, this era had a more expansive and nuanced view of drugs and the exploration of consciousness than we do today, where the medical model dominates the public discourse on psychedelics.

Jay is upfront about his own psychedelic experiences. "I've experimented thoroughly with all these drugs over a long period of time now," he said when I reached him in Cornwall. His tripping led him to recalibrate his own image of reality, but he doesn't gloss over how challenging these experiences can be. In his earlier book on the history of mescaline, he writes about one encounter with the psychoactive cactus San Pedro: "As pleasure and discomfort mingled and intensified, it was easy to understand

how some subjects feel themselves transported to the realms of the divine while others retire miserably to their sickbeds."

Jay also wades into the contentious question of whether the scientists and doctors studying psychedelics should talk openly about their own experiences. "The analogy I use is travel writing," he says. "You could write a book about Venice without going there because you can read all the other books about Venice, but it's hard to argue that your book wouldn't be better if you had actually been to Venice yourself."

We seem to be at a crossroads in how to think about psychedelics. There's a strong push to medicalize these substances, but psychoactive experiences have always been unpredictable and wild. What do you make of the current psychedelic moment?

I think what we might call drugs—or more specifically, psychedelics—sit on a kind of cultural fault line that we've inherited from the 20th century. There are two words that emerged during the 20th century. The first is "drugs" in the sense that we're using it. That word is a product of the Progressive Era in the early 20th century. From the very beginning, it had a whole bunch of negative connotations baked into it. There were dangerous drugs, addictive drugs, criminally illicit drugs. Think of "the war on drugs." When I was growing up, I assumed it had been going on forever, so it was surprising to discover that it's actually a creation of the 20th century. Then in the mid-20th century, there was much more interest in mystical experience and the possibility of using drugs for personal growth or healing. That was the point at which the word "psychedelics" emerged.

The psychiatrist Humphry Osmond coined this word because he didn't like the word "drugs." The literal

The one place we can't accompany our patients is over the threshold into madness.

meaning of psychedelic is “mind-revealing,” which has a much more positive ring to it.

Osmond and Aldous Huxley came up with that term together. They were really talking about LSD and mescaline then. Huxley was very keen that it should be connected to mystical experience and higher consciousness. I think one reason the word “drugs” became so handy at the beginning of the 20th century was to separate substances into good and bad. The good you would get in your pharmacy or from a doctor; the bad you’d have to get from the street, from criminals. That distinction has broken down in the 21st century, when cannabis is for sale everywhere and the potential for psychedelics has only gotten stronger.

Weren’t many drugs that we now consider dangerous, like heroin and cocaine, once easily obtained?

That’s right. It’s why our modern category of drugs wouldn’t have made any sense in the 19th century because they just sat on the shelves alongside other stimulants and sedatives and analgesics that we now call drugs. One thing that fascinates me about this period is how widely drugs were used in science and medicine, and how interested people were in the experiences they produced. There’s a rich literature back then because doctors in the 19th century were very good at describing things. You had to be. There were no tick-box diagnoses. If somebody had a cough, you couldn’t just say they had a cough. There might be 50 adjectives to describe that cough.

Another reason doctors and scientists were so good at describing these experiences is they often took the drugs themselves.

Yes, and I’ve taken that as the central theme of my book. If you’re studying a drug which affects the mind and alters consciousness, the experience itself is really what you’re looking at. And if that’s the focus of your

investigation, why wouldn’t you start by experiencing it yourself?

The word “psychonaut” is often used to describe people who take hallucinogens for self-exploration. The word was coined in 1949 by the German writer Ernst Junger, who is a fascinating and problematic figure. He was the mentor of Albert Hofmann, who synthesized LSD, but Junger was once a Nazi sympathizer.

He later resisted Nazi efforts to recruit him, but he also refused to submit to de-Nazification in postwar American-occupied Germany. During that time, he wrote a futuristic novel called *Heliopolis*, in which a cadre of scientists synthesize new psychoactive drugs and use them to explore their consciousness. These scientists are called psychonauts. Junger was the great hero and mentor to Albert Hofmann, and through Hofmann, the word psychonaut made its way into the psychedelic counterculture. It meant someone who was a rebel or renegade or was working outside of science. Because in our modern era, institutional scientists don’t self-experiment with their drugs.

At least they don’t talk about it publicly. I’d bet that most scientists who study psychedelics have tripped themselves, even though it’s usually illegal. I mean, can you actually understand these experiences if you haven’t had them?

I think it’s enormously valuable to have direct personal experience because what we’re studying is a sensation that’s only available to the subject. Otherwise,



MODERN PSYCHONAUT Mike Jay believes responsible research into psychoactive drugs must include the scientists. “If you’re studying a drug which affects the mind and alters consciousness, the experience itself is really what you’re looking at,” he says. “And if that’s the focus of your investigation, why wouldn’t you start by experiencing it yourself?”

you’re just studying its correlates. I wanted to reclaim the word “psychonauts” and take it back into the 19th century, where it describes not only renegades and rebels, but also establishment scientists, doctors, and pillars of the literary establishment. The word that was used at the time was “self-experimenter.”

There is no perfect or correct way to do self-experimentation. Part of you is an observer and part of you is a subject, and you’re trying to find the right point between objective data and a fuller sense of the subjective experience. So maybe you end up with a hybrid of science and literature. If you look at the psychedelic literature today, most of it is composed of very dry papers on neuroscience and receptor chemistry, but then you look at the towering bestseller of the psychedelic renaissance, Michael Pollan’s book *How to Change Your Mind*, and he’s using lots of metaphors about our minds getting stuck in ruts and psychedelics connecting different areas of the brain. But I think what really attracted people to his book were his descriptions of his self-experiments. What does it feel like? What might it do for me?

You can see this cross-fertilization between science and literature at the beginning of the 19th century, when the English chemist Humphry Davy discovered the mind-blowing properties of nitrous oxide and then recruited some of his poet friends to join in these experiments.

Humphry Davy went on to become the president of the Royal Society and the great scientific hero of his generation. When he was 20, he was one of the first scientists to synthesize nitrous oxide, which was believed to be toxic. But in the heroic self-experimental tradition, he found out that not only was it not toxic, but it produced a wave of euphoria. He inhaled a bit more and eventually found himself in this disembodied universe composed of thoughts and ideas, and he came back absolutely fascinated.

He was very fortunate to have a group of friends in Bristol who were ideally suited as volunteers, including the young Romantic poets Samuel Taylor Coleridge and Robert Southey. Davy was looking for a language of feeling, but it’s incredibly hard to find words for it. In a way, it was rather like the Romantic poets’ own project of finding words to describe new feelings and sensations. So from this point on, the study of drugs was still about pharmacy and chemistry, but it also became about poetry and philosophy.

One of Coleridge’s protégés, the Romantic poet Thomas De Quincey, later wrote his own book, *Confessions of an English Opium-Eater*. What was distinctive about this book?

He was doing something very original. The book is not actually about opium. It’s about the opium eater. So he’s using opium to open up a new form of autobiography. He writes about how he takes opium and wanders around London at night, losing himself in the theater crowds and having reveries. And suddenly these childhood memories will pop up that he hasn’t thought of for ages. Extraordinary dreams will appear, and he has the sense that on opium he can wander the labyrinth of his mind and connect all these different visions and memories and sensations.

By the mid-19th century, many people were using psychoactive substances. Can you tell me about the French physician Jacques-Joseph Moreau?

Moreau was what we would now call a psychiatrist. He often accompanied

It wasn't that Freud had taken too much cocaine. He'd taken too little.

his wealthy patients on rest tours, so he went to Egypt, where he was fascinated by the absence of alcohol and the prevalence of hashish. People who took hashish would talk about their dreams and visions and their encounters with jinn and other supernatural entities. He got fascinated enough to take large oral doses of hashish and was unable to move or speak for hours.

As a psychiatrist, he believes in walking as far as you can in your patients' shoes, but the one place where we can't accompany our patients is over the threshold into madness. But with hashish he noticed in himself so many of the phenomena that he was treating in his patients—hallucinations, deliriums, and paranoid ideation. And just as Humphry Davy had done with the Romantic poets, Moreau started a literary hashish salon in Paris. Many of the great figures of mid-19th century French literary culture—like Balzac, Dumas, Flaubert, and Baudelaire—passed through its doors.

One of the most intriguing cases of self-experimentation was Sigmund Freud, who became obsessed with cocaine early in his career. Why did he think cocaine was so promising?

The great disease of the late 19th century was neurasthenia. It's not a term we use anymore, but when we're talking about anxiety or depression or autoimmune conditions, these would often have been diagnosed as neurasthenia. There was a feeling that society had started to run on the rapid time of the machine,

and a lot of people were having nervous breakdowns or suffering what we'd now call burnout. So everybody was looking for a stimulant that could magically provide more energy, and Freud thought cocaine might be the thing that would bring us up to speed with modern life. In the mid-1880s, he was often referred to as the world's leading medical expert on cocaine.

Did he take much cocaine himself?

It's often assumed that he took huge quantities, but my feeling is that the opposite is the case. He was a sober and cautious fellow, and he took it in very small doses. I think the problem with his self-experimentation was that he only ever took a small dose, usually dissolved in water. So a few years later, when people discovered that you could inject enormous quantities of cocaine and then almost immediately go into manic states of collapse and nervous breakdown, Freud was blindsided by this. It wasn't that he'd taken too much cocaine. He'd taken too little. It was around this time that our modern medical notion of addiction was coming into focus.

Didn't Freud then try to erase his early work on cocaine from the historical record?

There's maybe one sentence about it in his short autobiography, but when his collected works were finally reprinted, the cocaine papers weren't in it. And his first biographer, Ernest Jones, minimized it and described it as the "cocaine episode." He just dismissed it as a juvenile aberration, and that's the line that his followers have tended to follow ever since.

William James was another late 19th-century psychologist who self-experimented. Why did he take nitrous oxide?

Like Freud, he diagnosed himself as neurasthenic. He took nitrous oxide in the early 1880s, and I think it was an experience that really stuck with him because he'd always been interested in mystical experience, but he'd never really had one himself, and he'd felt that he was kind of a cold, rational soul who was never going to have one. So James' nitrous oxide experience was a revelation for him personally as well as professionally. He saw introspection as central to the study of the mind. He was in a world, as we are now, where the mainstream science of the mind was very positivist.

Part of you is an observer and part of you is a subject.

James thought the mind was much more complicated than that. He described it as a “blooming buzzing confusion.” He was trying to find ways of exploring the mind in broader terms that verged on literature and philosophy within a paradigm that was becoming more and more rigid.

Why did drugs become so stigmatized in the early 20th century?

I think there are many components to it. If you look at the word “drugs” that emerged at that time, you can see there are medical concerns that drugs are addictive and bad for your health and should only be used under the supervision of a doctor. This is also the Progressive Era, when all kinds of grassroots campaigns were starting to increase the scope of government, leading up to alcohol prohibition. At this time, alcohol is regarded as the most problematic substance. How can we possibly have a civilized society in the 20th century where people are allowed to get drunk all the time? Psychology itself is moving away from introspection. This is the beginning of behaviorism, so we’re going to be more productive running our laboratory rats through mazes than listening to people pontificating about their drug experiences.

What can this long history of psychoactive drugs tell us about our current psychedelic renaissance?

It gives us a very different way of thinking about where we are now. The prevailing assumption is that this kind of drug experience suddenly emerged in the 1950s and 1960s and was summarily squashed by mainstream science and medicine, and we’re now just beginning to recover it. But the story I’m telling about the 19th century shows a rather different picture. It suggests that the things we’re interested in today—the power of drugs to be therapeutic and to open up dimensions

of thought and experience that we wouldn’t otherwise discover—go all the way back to the Scientific Revolution. Many of the questions we’re asking now are exactly what scientists and writers and doctors were asking in the 19th century, but they weren’t using DMT and ketamine. They were using ether or nitrous oxide or hashish. What happens when we take drugs that disembody us and take us into realms of pure experience? Is it simply white noise produced by a drug-addled brain? Or do these experiences connect us to other dimensions of mind that we can’t normally access?

Where do you hope the current psychedelic movement will go from here?

I would like to see a thousand flowers bloom. A lot of people who are now interested in psychedelics would use them privately. You might describe that as self-medication or recreational or spiritual. Some people will want to have shamanic or mindfulness guides for this experience; others will doubtless want state-approved clinical psychotherapists. It seems to me the entire conversation at the moment is on this very tricky question of how the medical profession manages and licenses this.

All those questions are important, but I’d like to see more attention being paid to the fact that there are other models beyond the medical and beyond the therapeutic. We’re starting to see this with the first steps of decriminalization of plant psychedelics in Oregon and Colorado, what I might call a bottom-up model, which I hope might complement the top-down medical model. ☺

STEVE PAULSON is the executive producer of Wisconsin Public Radio’s nationally-syndicated show *To the Best of Our Knowledge*. He’s the author of *Atoms and Eden: Conversations on Religion and Science*. He also has a podcast about psychedelics, *Luminous*.



The Secret Messages in Ancient Storms

*Paleotempestology promises to uncover patterns of historical hurricanes—
to better predict destructive weather of the future*

BY KATARINA ZIMMER

“Blow, till thou burst thy wind, if room enough!”

—William Shakespeare, *The Tempest*, 1610–1611



ONE SUNDAY IN AUGUST 1635, the Mather family from England was finally about to reach the New World when a furious storm caught the ship and its crew by surprise. The cables anchoring the boat near a group of islands, 6 miles off the New England coast, reportedly snapped, and the vessel with its dozens of passengers hurtled toward a rocky shore. Fortunately, the winds turned at the last minute and steered the ship in another direction, their son Increase Mather would later write.

But others weren't so lucky. According to colony governors in what are now Boston and Plymouth, Massachusetts, the storm drove other ships aground, toppled sundry houses, blew down hundreds of thousands of trees, and caused the sea to swell by up to 20 feet. “[It] was such a mighty storm of wind and rain,” the governor of Plymouth Plantation wrote, “as none living in these parts ... ever saw.”

Indeed, contemporary simulations suggest the Great Colonial Hurricane was a Category 3.5 storm, probably the strongest in recorded eastern New England history. (For reference, Sandy, which killed nearly 150 people and caused some \$65 billion in damage in the United States, was technically no longer even a hurricane when it made landfall in the New York metro area in 2012.)

Scientists know about the Great Colonial Hurricane's impact not only from written reports but curiously, also from hidden, physical impressions the long-ago storm left on the landscape.

At the bottom of a pond, Jeffrey Donnelly, a hurricane scientist at the Woods Hole Oceanographic Institution, and his colleagues found subtle, buried evidence of the storm that almost felled the Mather line. The researchers were collecting sediment cores from

a lakebed on Cape Cod. The spot, known as Salt Pond, lies about a third of a mile from the ocean and has long been a place of mud. But in their core samples, they found a pinky finger-thick layer of pure ocean sand in layers that dated back to roughly 1635. The only thing that could have pulled that much beach material over the sand barrier and that far inland was a truly massive storm.

The cores revealed other clues, too. Although written accounts suggest the 1635 tempest was the strongest of its time, the exhumed samples showed it wasn't the only intense storm in the area. Donnelly found evidence for 10 major storms¹ in the area between 1400 and 1675—a surprising toll, given that major hurricanes are virtually unheard of this far north today. The fact that hurricanes were much more frequent in the past begs the question of why, and whether these levels of storm activity could someday return.

Which is why researchers like Donnelly are traipsing along coastlines and digging in the muck. They hope their relatively new branch of science, paleotempestology (the study of old storms), can use these buried traces of long-gone winds to augur ancient patterns. Patterns that might also help us predict the weather that lies ahead.

Hurricanes are not solely random events, but can come in waves across the ages.

PALEOTEMPESTOLOGY SEEMS like it could be a flighty field, an esoteric subniche of imprecise weather science, borne as it is from shifty grains of sand and mud. But since its birth in the 1990s, it has generated important insights into hurricane activity over centuries and even millennia. And like so many important developments in science, it took off with a seemingly simple question.

During a 1989 lecture, Kam-biu Liu, a scientist at Louisiana State University, was explaining how ash layers marked the activity of ancient volcanoes, when one of his students, Miriam Fearn, asked if hurricanes also left behind detectable traces. This was a possibility he hadn't considered before.

That summer, they tested the idea at Lake Shelby, a placid freshwater lake near Alabama's coast. "I still remember vividly the excitement we experienced when we pulled up our first cores from Lake Shelby and we found a distinct sand layer at the top, which was undoubtedly attributed to Hurricane Frederic of 1979," Liu recounts.

In the following years, Liu collected cores from along the Gulf of Mexico coast and various sites around the Caribbean. Meanwhile, Donnelly and others were producing cores from other places around the world, including the Northeastern U.S. and from large marine caverns called blue holes in the Bahamas. Virtually all of them revealed an undeniable pattern: mundane sediment punctuated by layers of sand—some obvious, but many so faint they require close analysis of the grain

sizes—which mark the surges of dramatic storms that blew through long ago.

These ancient depository records are generating a far different picture of storm patterns than instrumental records alone, which only go back 170 years—or even written records, which, in the U.S. trace only a handful of centuries. A proverbial eye-blink in the history of larger climate and weather patterns.

One nearly 60-foot-long core from a blue hole in the western Bahamas revealed 16 hurricanes between 1850 and 2016²—equivalent to 10 hurricanes per century—but nearly three times as many hurricanes per century from not-too-distant times, including 1570–1620. "We already think about this area as being pretty active," says marine geologist Tyler Winkler, who also conducts research at Woods Hole Oceanographic Institution. "But the fact that that has tripled at times in the past is pretty remarkable and has definite implications for how susceptible this region is to storm activity."

In this way, paleotempestology data can provide a truly long-term assessment of an area's risk for a major hurricane strike. That's why reinsurance companies have long shown interest in paleotempestology research, even funding some of Liu's early research.

Indeed, at many sites in the western Atlantic, it turns out, hurricanes have undergone wild swings, often striking at frequencies that far exceed those in the past couple of centuries. By themselves, the sand layers in individual cores appear random. But

paleotempestologists are beginning to find that, for centuries or millennia at a time, hurricane activity from different sites sometimes lines up. This means that hurricanes are not solely random events, but can come in waves across the ages, driven by regional or even global climatic changes. “It implies that the climate system, quite independent of what humans are doing, is able to modulate hurricane activity significantly,” Donnelly says.

The big mystery scientists are trying to solve is why—and what that could mean for us, as humans continue our own runaway experiment with the Earth’s climate.

To find that out, Donnelly and other paleotempestologists are digging deeper.

In a number of cores from around the Atlantic basin, they have discovered a period of heightened hurricane activity in the Atlantic starting around 250 A.D., long before Europeans set foot on the North American continent. Between 250 and 1150, for instance, Donnelly’s team counted about 20 major storms in the Salt Pond cores, roughly matching a pattern of elevated storm activity in other records from the Gulf of Mexico coast and parts of the Caribbean. What caused this tempestuous outburst across the North Atlantic?

Donnelly and others think it may have to do with warming of sea surface temperatures in the Atlantic during this time. That was especially the case³ between 950 and 1250 A.D., a time known as the Medieval Warm Period, during which scientists think a natural uptick in solar radiation drove a slight increase in average global temperatures (a slower and less extensive warming than what humanity’s burning of fossil fuels is causing today). Researchers estimate that sea surface temperatures rose about half a degree above the long-term norm around this time.

This correlation between hurricane activity and temperatures is illuminating because, while climate models largely agree that human-driven climate change will make hurricanes stronger—as warmer waters fuel them with more energy—there is much less certainty on whether more storms are forming to begin with.

The data from the Medieval Warm Period add to existing evidence that rising temperatures on land and in the ocean play a role in increased hurricane formation, notes Jo Muller, a paleotempestologist at Florida

Mundane sediment punctuated by layers of sand mark the surges of dramatic storms that blew through long ago.

Gulf Coast University. Warmer temperatures can generate more disturbance in the atmosphere. The extreme heat rising off the west coast of the African continent—where many Atlantic storms form—for example, can create the kinds of perturbations that can turn into wind-sucking low-pressure systems that act as seeds for hurricanes, which are further fueled by warm ocean waters and a humid atmosphere, she explains.

But temperatures are not the whole story. Another factor in hurricane formation is wind shear—or, rather, its absence. Sudden changes in wind speed and direction can disrupt the upward airflows needed to create a hurricane. “It will just tear a storm apart,” Muller says of wind shear. It’s conceivable that the climate during the Medieval Warm Period produced not only warmer sea temperatures, but also conditions that discouraged wind shear—something that some recent studies suggest.

Paleotempestologists have also probed the Earth for storm patterns during temperature swings in the opposite direction. Around 1400, Earth’s climate entered the Little Ice Age, a period of worldwide cooling—perhaps driven by an uptick in volcanic eruptions and/or reduced solar activity—that lasted until about 1850. Based on the findings from the Medieval Warm Period, one might expect hurricane activity to decrease during this time. But paradoxically, records in some places, including at some sites in the north Atlantic such as Salt Pond, show an abrupt increase.¹ “This transition between the Medieval Warm Period and the Little Ice Age around 1400 was a pretty big deal for tropical



SANDS OF TIME To find historical hurricane patterns, scientists take core samples that reveal sediment patterns over hundreds—and sometimes thousands—of years. Studying the layers, they look for unexpected layers of inland sand, blown in by strong storms of yore.

cyclones globally,” says Donnelly, who has even found changes at some sites in the North Pacific. Somehow, “it was capable of dramatically reshuffling hurricane activity on the planet.”

Curiously, in the Atlantic, it’s only the records in the Northeastern U.S. and the Bahamas,⁴ farther down in the Atlantic, that show more hurricanes making landfall between 1400 and 1675, including the infamous colonial hurricane in 1635. In the Gulf of Mexico and around the Caribbean Sea—south of the Bahamas—hurricane intensity swings from loud to silent around 1400.

Broadly speaking, “records from New England and the Bahamas tend to match each other, and they tend to be very different from records from the Gulf,” says paleotempestologist Elizabeth Wallace of Old Dominion University. This could hint that, without necessarily affecting the number of Atlantic storms, the dominant

storm trajectories changed at the start of the Little Ice Age. “One of the things we’re trying to piece together is why that is,” Wallace says.

Sorting out these unexpected historical dynamics could help solve the puzzle of future storm shifts under a warmer climate. Wallace and her colleagues are currently plugging data from sediment cores into computational models to simulate the world climate centuries ago so they can test what kind of climate dynamics could be driving hurricane patterns. One suspected culprit is a weather system known as the Bermuda High.

The Bermuda High is a high-pressure system that’s usually centered in the mid-Atlantic. Weather forecasters know that the High generates steering winds that can determine the trajectory of west-moving storms, acting like a gardener flushing a hose this way or that, Liu says. When the High is weak or lies northeast of its usual

The only thing that could have pulled that much material that far inland was a truly massive storm.

position, it will whip up storms around its western edge and sweep them up the Eastern Seaboard, hitting the Bahamas and the eastern U.S. coast. When it's stronger or lies more south, it sends storms toward the Caribbean and the Gulf of Mexico. It's feasible that the High weakened around 1400, causing hurricanes that were previously flung toward the Caribbean and Gulf Coast to hit the Bahamas and New England instead, Wallace says.

If scientists can pinpoint that the Bermuda High was driving these patterns—and if they see that its long-term position and strength is changing today—that could help predict whether we might see more or fewer destructive hurricanes rattling up the Eastern Seaboard, Wallace says. “If we don’t understand how natural climate variability impacts storms, it will be very difficult to predict how human-driven climate changes superimposed on top of natural changes will impact storms.”

SINCE ITS INCEPTION just a few decades ago, paleotempestology has provided insights once thought unknowable: discerning the winds of the past. But the picture it gives us is still somewhat murky.

Sediment cores from coastal areas only record land-falling storms; it might be that the Atlantic had other major periods rife with hurricanes that never touched land. They also only record intense hurricanes, not small storms or ones that made distant landfall. And in many cases, the cores’ resolution is limited; their dating is often only accurate to decades or even centuries—which is one reason why scientists are also exploring other ways to study past storm activity, such as tree rings, which show traces of large flooding events and can provide more accurate dating.

Importantly, the sediment cores are still too few in number and too limited in geographic scope. There’s a dearth of records for the southeastern U.S., for instance, and major ocean basins such as the Pacific are understudied. “The distribution of good paleotempestology records is still uneven,” Liu says.

But piecing together this deep historical record of these transient—but powerful—storms is important. Identifying the natural forces that shape hurricane activity will hopefully help provide more accurate long-term forecasts for our era. If places like New England were frequently targeted in the past, they could get hit again. And with today’s densely populated coastlines and supercharged hurricanes, the impacts would likely be even more catastrophic than what early colonists witnessed.

To get to that point, there is still lots more digging to be done. Liu currently likens this young field to paleoanthropology, where biologists try to piece together the story of human evolution from piecemeal records over the past few million years—a femur here, a skull fragment there. Paleotempestologists are hopeful that their work can answer big questions relevant to the future of hundreds of millions of people living along the world’s coastlines. The answers likely lie in tiny grains of sand, blown in by storms of the ages, waiting for scientists to uncover them. 🌀

KATARINA ZIMMER is a science and environmental journalist currently based in Germany.

REFERENCES

1. Donnelly, J.P., *et al.* Climate forcing of unprecedented intense-hurricane activity in the last 2,000 years. *Earth's Future* **3**, 49–65 (2015).
2. Winkler, T.S., *et al.* Oceanic passage of hurricanes across Cay Sal Bank in the Bahamas over the last 530 years. *Marine Geology* **443**, 106653 (2022).
3. Mann, M.E., Woodruff, J.D., Donnelly, J.P., & Zhang, Z. Atlantic hurricanes and climate over the past 1,500 years. *Nature* **460**, 880–883 (2009).
4. Wallace, E.J., Donnelly, J.P., van Hengstum, P.J., Winkler, T.S., & McKeon, K. 1,050 years of hurricane strikes on Long Island in the Bahamas. *Paleoceanography and Paleoclimatology* **16** (2021).

Searching for Life Under a Methane Rain

What future missions to Saturn's moon Titan will reveal about the universe

BY PAUL M. SUTTER

IN 2034, A SMALL CRAFT will alight on a distant dune in a place called Shangri-La. This craft, called Dragonfly, will have traveled 746 million miles to eventually land on Saturn's largest—and most alluring—moon, Titan.

Dragonfly is a radical new approach to studying other worlds. Rather than being bound to slowly creep over the surface, as our Mars rovers have been, it is a rotorcraft, capable of flying several miles at a time. It will hop around from place to place to help us better understand this strange land, where the atmosphere is nitrogen, the dunes are made from ice, the seas are liquid methane, and a potentially globe-wide water ocean may be buried deep below the frozen surface.¹

The planned Dragonfly mission, set to launch in four years, will include an impressive assortment of remote planetary exploration tools: several cameras that operate at different wavelengths to image the intriguing landscape, a small drill and scoop to collect samples, a mass spectrometer to determine the chemical makeup of those samples, a gamma-ray and

neutron spectrometer to study the composition of the surface directly under the craft, and a suite of meteorological and geological sensors to record Titan's weather patterns and search for evidence of larger-scale activity (such as cryovolcanoes that might spew liquid water instead of lava). This suite of gear will help us get our first true taste of what Titan is really like—and if it might be holding any important solar system secrets, like whether life could be present beyond our own world.

To date we have only sent one lonely mission to Titan. Launched in 1997, the Cassini spacecraft carried a small payload: the Huygens probe. While Cassini spent nearly two decades in orbit around Saturn, the Huygens probe lasted less than a month between deployment from its parent spacecraft and the end of



its operations, a mere hour and a half after touchdown on Titan's rugged surface.

That mission provided our first on-the-ground view of this alien and unforgettable world. But it created far more questions than answers. What are the exotic chemistry and geology that power the dynamics of this massive satellite? Where did the methane seas and potential underground water ocean originate? What can this world, rich with organic compounds, teach us about young Earth? And most tantalizing: Is Titan a potential home for life?

Dragonfly will hopefully provide preliminary clues to some of these big questions. But it will, quite literally, barely scratch the surface.

Unlocking more of Titan's mysteries could help us understand physics, chemistry, and, potentially, biology on distant worlds. To tackle those, we will need to zoom far beyond Dragonfly and dream up the next major missions to Titan. These efforts will take even more expansive, and creative, approaches—to deeply study the science of this strange land, in situ, -290-degree methane rain and all.

OUR FIRST PRIORITY is to understand the chemistry of this strange world, which could hold the key to uncovering alternative forms of life.

On Titan, things are just ... different. High-energy radiation, whether from the sun's ultraviolet rays or more distantly sourced cosmic rays, interact with a variety of organic compounds held at extremely cold temperatures to create complex molecules called tholins. Tholins are a general catch-all term for a variety of substances that only appear in the distant solar system (they are also dusted around the icy surface of Jupiter's intriguing moon Europa). To make a tholin, you take a compound rich in carbon, such as methane or ethane or even carbon dioxide, and blast it with ultraviolet radiation at low temperatures. The extra radiation energizes all sorts of peculiar reactions,² generating a rich variety of new organic compounds.

In the outer worlds these tholins might play a role similar to mud on Earth: A place where life could find all the ingredients it needs to thrive. But it's tough to bring tholins back to Earth for close study. They easily disassociate in the warmer, inner regions of the solar



PREPARE FOR LANDING NASA is considering other missions to Titan, including a seaplane that could skim over the planet's super-cold methane seas. This proposal for TitanAir would use capillary action to draw up samples from the air and water as it traveled and analyze them onboard. It would have to contend with difficult flying conditions—but would have to fight much less gravity to take wing than here on Earth.

system, and our oxygen-saturated atmosphere has a tendency to destroy any and all tholins on the spot. So the best place to study these exotic compounds is right at the source, on the surface of Titan.

While Dragonfly will give us a first glimpse into tholin chemistry, we will need much more substantial operations to fully understand how those tholins are created and what chemical role they play on Titan.³ These insights would help understand their possible prevalence on worlds beyond our solar system, and therefore potential for life in the far-beyond. To do this level of science, we will need to get our hands dirty—to scoop tholins by the bucketful and closely examine their precise chemical makeup—which will require much bigger landers. And to do even more advanced science, we might even want human hands on the ground some day.

We need to dip our robotic toes into the methane seas.

All sorts of strange chemistry—and potentially biochemistry—could also be lurking in the methane seas. On Earth, water serves as the solvent for life, giving all of our wonderful biochemistry a substrate for its reactions. Could liquid methane act as substrate for a different kind of life?

The only way to find out is to go looking for it, which means we need to dip our robotic toes into the methane seas themselves. Dragonfly can't do it, but a proposed mission called TitanAir is a seaplane designed to sail

NASA

Titan's life isn't going to come out of the depths to wave hello. We have to go find it.

through Titan's atmosphere, occasionally drifting onto the sea surfaces to take samples.

It's not as simple as flying a plane on Earth, however. TitanAir will face a few challenges as it attempts to aviate around that alien world.

For one, getting all the machinery, electronics, and most importantly the sample collection and examination suite to work in ultra-low temperatures is difficult, to put it mildly. Dragonfly will face similar issues for sure, but TitanAir hopes to not just poke at rocks but sample directly from the liquid methane seas, which will require us to devise new kinds of sensitive equipment. And while Titan has a thick atmosphere like the Earth, it's much smaller than our own planet, with much lower gravity, so flight takes on a different physics than it does in our own atmosphere. The craft will also have to be ultra-ultra-ultra-clean. Since it's studying the potential for life and life-like chemistry somewhere else, we have to be absolutely sure that it doesn't carry any traces of Earth microbes or genetic material with it to contaminate its samples.

And of course there's the tantalizing possibility of a liquid water ocean below the moon's frozen surface.⁴ Depending on the exact composition of Titan, the ocean might be relatively shallow, or it might be rich with ammonia and up to 100 miles thick. Either way, the ocean appears to be geologically active. It receives warmth from the inner core of Titan, and a rich supply of organic compounds from the icy crust above. In other words, it has all the conditions for life as we know it: liquid water, a source of energy, and a source of rich chemicals. The only thing lacking is sunlight, which, as the hydrothermal vents in our own oceans have demonstrated, is not a requirement for life.

But that life isn't going to come out of the depths to wave hello. We have to go find it. We'll have to drill through dozens of miles of rock-hard ice, and potentially even send submersibles into that dark ocean. Once we're there, we may not even know how to find

life. Unless it's big enough to wiggle, we discriminate life against non-life through its various biochemical signatures—the traces that only life can leave behind. But life based on completely different biochemical foundations may not appear to us to be alive. Any evidence we gather will help us better understand the very definition of life, and under what conditions we might find life elsewhere in the universe.

Even if Titan yields no alien biochemistry of its own, long-term, ambitious missions on Titan will give us precious clues not just to worlds beyond, but also to the development of our own planet. We've all heard of the "primordial ooze," the soup rich in organics that somehow gave rise to life on Earth. Titan is a primordial world, with all of the right ingredients in all of the right places, rich in exotic chemistries that are inaccessible to earthbound laboratories. Titan is a window into Earth's own past, serenely orbiting Saturn, waiting for future science to help us discover its secrets. ☺

PAUL M. SUTTER is a research professor in astrophysics at the Institute for Advanced Computational Science at Stony Brook University and a guest researcher at the Flatiron Institute in New York City. He is the author of *Your Place in the Universe: Understanding our Big, Messy Existence*.

REFERENCES

1. Wakita, S., *et al.* Modeling the formation of Selk impact crater on Titan: Implications for Dragonfly. *arXiv* 2303.11330 (2023).
2. Hörst, S.M. Titan's atmosphere and climate. *arXiv* 1702.08611 (2017).
3. Czaplinki, E.C., *et al.* Experimental characterization of the Pyridine: Acetylene co-crystal and implications for Titan's surface. *arXiv* 2303.14847 (2023).
4. Artemieva, A. & Lunine, J. Cratering on Titan: Impact melt, ejecta, and the fate of surface organics. *Icarus* **164**, 471-480 (2003).



The Amazon River in the Sky

A crucial link that sustains the Amazon rainforest is at risk of running dry

BY DANIEL HENRYK RASOLT

HIGH IN THE ANDES MOUNTAINS, the mighty Amazon River begins. It trickles from glaciers and oozes from mountain wetlands. It gains momentum and volume and feeds into clear streams and muddy rivers that pass through high cloud forests and lowland valleys. The torrents of the waters carry nutrients through the vast Amazon River basin, some 4,000 miles across the rest of the South American continent.

FLYING RIVERS BY VANNESSA CIRCE; OIL ON CANVAS



At the same time, in the rainforest and delta estuaries, another, more ethereal—but no less essential—river is forming.

Across the Amazon rainforest, water is being sucked up by plant roots, transported through their bodies, and emitted or “transpired” from their leaves. In the air, this vapor rises and cools, condensing into clouds. Thus suspended, it becomes a sort of “flying river” of water vapor, flowing west, back toward the Andes. Along its own winding journey, its contents will fall as precipitation, forming upland rivers, wetlands, and mountain snow and icepack to feed, once again, the Amazon.

This interconnected cycle has been a sustaining force for some 10 million years. But the system appears to be faltering.

With tropical Andean glaciers quickly receding and high Andean wetlands threatened by climate change

and unsustainable land use, the headwaters of the Amazon River are at risk. Its tributary rivers are being fragmented and depleted. Below, deforestation and land degradation in the Amazon basin are reducing the number of water-transpirers and threatening the westward flow of precipitation that ultimately forms the terrestrial river’s sources.

If this cycle breaks down and decouples, it could have profound implications for regional and potentially even global water cycles and climate, as well as for the biological and cultural diversity across much of the continent.

THE AMAZON RAINFOREST is prized for its climate-regulating role of absorbing and sequestering prodigious amounts of carbon. But it might be the forests’ exhalation of water vapor that has an even larger impact on climate¹ overall, through mass-scale cloud formation, moisture transport, and other large-scale connections² of water and weather cycles.

A single large tree in the Amazon rainforest can transpire about 264 gallons of water per day, and the basin contains approximately 20 billion trees. This translates into billions of tons of water vapor rising every day from the Amazon canopy and flowing west—more than the amount of liquid water the Amazon River itself releases into the Atlantic Ocean each day.

Scientists first discovered this westward-moving flying river over the Amazon in the 1990s. A novel “biotic pump” theory suggests that water’s phase



SOURCE MATERIAL The headwaters for the mighty Amazon River begin high in the arid Andes mountains, thousands of miles from its outlet. Pictured here, one of its sources, the Apurímac River, starts from moisture in the Peruvian Andes, much of which turns out to have originated far downstream, along the Amazon. Along the way, the river will also bring essential sediments and nutrients to flora and fauna in the basin below.

The hydrological pump is at risk of shutting off.

transition from vapor to liquid helps create—through the fundamental laws of thermodynamics—local wind currents that play a role in propelling these flying rivers toward the Andes.³ Along the way, moisture is recycled and recharged by the forests below.

Aiding this flying river process are the tiny compounds, known as biogenic volatile organic compounds, that are emitted from Amazonian vegetation itself. These organic gasses, such as isoprene, ascend from the rainforest canopy to the troposphere alongside the water vapor before being oxidized, through a complex pattern of reactions, into organic aerosols that assist in cloud formation and moisture movement.

“This has a general name of ‘flying rivers,’ but of course it is a much more complex transport mechanism,” says Paulo Artaxo, an environmental physicist who leads an interdisciplinary team of researchers at the University of São Paulo that focuses on the Amazon and climate change.

Artaxo knows this from analyzing data plucked from thin air, more than 17,000 feet above sea level. Working at a research station on Mount

DANIEL PRUDEK / SHUTTERSTOCK



Chacaltaya in Bolivia, in the semi-arid Andes, some 2,000 miles from the mouth of the Amazon River, he and an international team detected tropical Amazonian forest organic aerosols—as well as black carbon from anthropogenic fires in the basin, which can further accelerate glacial melt.⁴ Artaxo explains it's these “isoprene organic aerosol particles, ice nuclei, and cloud condensation nuclei that are responsible for the very intense hydrological cycle in the Andes. There is a very close link between Amazonian organic compounds emitted by the plants and precipitation in the Andes.”

One way that link risks getting broken is if too many trees, these well-springs of atmospheric moisture, vanish—due to mass deforestation and other forest degradation. Without enough of them, the hydrological pump is at risk of shutting off, which could have global consequences. The Amazon “has a critical role in regulating the regional as well as the global climate,” Artaxo says. “Changes in Amazonia such as deforestation will certainly have impacts all over the globe.”

Beyond the water itself, this is also a story woven by its companions—organic compounds above, and nutrients and sediments below. Andean rivers provide more than 90 percent of life-sustaining sediments to the Amazon River basin, and those nutrients are diminishing. The complex processes of weathering and erosion—which are guided in large part by long-term precipitation patterns—transform rocks in the Andes into soils and bio-available minerals. The strong currents of steep Andean rivers move rocks and soils downstream, at times through powerful landslides.

A RIVER RUNS THROUGH IT

The lush vegetation of the Amazon basin transpire out prodigious amounts of moisture that evaporates into clouds—condensed around organic particles from the plants—joining a flying river in the sky that flows westward, back to the river's source.





GREATEST SHOW ON EARTH The Amazon Rainforest holds the greatest species diversity on the planet. The disappearance of trees and lush habitat threaten hydrological cycles essential to sustaining the rainforest and the plants, animals, and people who call it home.



Along the way, they break down these materials through biogeochemical processes into important minerals, including potassium, phosphorus, calcium, magnesium, zinc, and iron, that plant and animal life in the Amazon rainforest need to survive and thrive.

Humans have been cutting off this other crucial circulation pattern, too. Dams along Andean-Amazon rivers are having wide-spread impacts on lowland ecosystems. Sediment-rich Andean rivers deposit their bounty along their courses, all the way to the mangrove forests of the Amazon delta. The inputs of these nutrient-rich sediments are especially important in the highly productive and expansive lowland Amazonian floodplains, where much of the transpiring vegetation is concentrated. More than 140 existing or under-construction dams have already fragmented six of eight major Andean-Amazon river basins. An additional 160 proposed dams for Andean-Amazon rivers are currently on the drawing boards.



Many Indigenous people of the Amazon call this part of the Amazon basin “the path of the anaconda.”

Researchers say the dams have already upended the regulatory cycles of migratory fish, seasonal floods, and climate and hydrological cycles. Finding workable solutions on such a massive scale is an epic undertaking, they say, one that will take a shift in perspective, taking in all of the myriad dynamics of the inter-connected water cycles and ecosystems that reach across the continent.

THIS YEAR, I TRAVELED through the Andes and Amazon to research the hydrological and biocultural interconnections between headwater and transitional ecosystems. Along the way, I spoke to other researchers working to bring together traditional Indigenous knowledge with contemporary scientific approaches to find sweeping solutions—and to try to begin to move beyond the centuries of scientific dismissal of complex Indigenous knowledge systems.

I talked with Brazilian earth systems scientist Carlos Nobre, who helps lead the Science Panel for the Amazon as well as the planned Amazonia Institute of Technology. He said that these and many other groups are seeking “to merge knowledge [with Indigenous ethnic groups] because the Indigenous people, they have been living for 12,000 years in the Amazon, always with the forest standing.” Put another way, Francisco von Hildebrand, the president of Colombia-based non-governmental organization Gaia Amazonas, says “Indigenous people of the Amazon rainforest have an absolutely clear understanding of the interconnectivity of ecosystems and life systems that go all the way from the Andes to the Atlantic.”

Several advocacy groups have come together into a larger coalition known as the North Amazon Alliance, which is fostering Indigenous-led, large-scale land conservation in order to support this essential basin-scale hydrological cycle. The group hopes to protect “the last strip of continuous healthy rainforest that connects all the way from the Andes across the Amazon to the Atlantic,” von Hildebrand says. The alliance already has more than 52 million hectares under its intercultural environmental management, including Indigenous territories, national parks, and other areas of “functional connectivity.” But, von Hildebrand says, “Our goal is to cover 200 million hectares to ensure biocultural connectivity and to protect the great flying river of the Amazon.” Many “Indigenous people of the Amazon call this northern part of the Amazon basin ‘the path of the anaconda,’” he says. “It is deeply embedded in their cultural knowledge, this northern part of the Amazon as an interconnected and interdependent region.”

Indeed, Indigenous people of the Andes and Amazon also view *themselves* as part of nature and its interdependent hydrological and climatic processes, not separate from it.

“We do not live *in* the forest, we are *of* the forest,” Koreguaje leader Oliver Gasca told me from within his forested territory along the Orteguala River, a tributary of the Amazon.

As we spoke in the dense, humid heat, the nearly opaque Orteguala River flowed by. This land is in the gently sloping Andes-Amazon piedmont of Colombia, which lies within the Caqueta River basin, one of the Amazon basin’s largest and still-undammed Andean tributaries. “We are the guardians of the door to the Amazon,” he tells me.

And if this door closes, so too may the river in the sky, putting one of our planet’s most critical climate-regulating regions in even greater peril than we realized. ☹️

DANIEL HENRYK RASOLT is an independent interdisciplinary researcher and writer with a background in physics. He is the founder of Unbounded World, which provides an integrated approach to ecological and cultural preservation, and The Interplex, a new hybrid-style publication and collaborative community that focuses on the interdisciplinary, intercultural, and interconnected.

REFERENCES

1. Artaxo, P., Hansson, H.C., Machado, L.A.T., & Rizzo, L.V. Tropical forests are crucial in regulating the climate on Earth. *PLOS Climate* **1**, e0000054 (2022).
2. Avissar, R. & Werth, D. Global hydroclimatological teleconnections resulting from tropical deforestation. *Journal of Hydrometeorology* **6**, 134-145 (2005).
3. Makarieva, A.M., Gorshkov, V.G., Sheil, D., Nobre, A.D., & Li, B.-L. Where do winds come from? A new theory on how water vapor condensation influences atmospheric pressure and dynamics. *Atmospheric Chemistry and Physics* **13**, 1039-1056 (2013).
4. Zha, Q., *et al.* Oxidized organic molecules in the tropical free troposphere over Amazonia. *National Science Review* (2023).

A Conversation with Animal Rights Pioneer Peter Singer

*"Animal Liberation" is nearly 50 years old.
What have we learned?*

BY BRANDON KEIM





N 1970, A GRADUATE PHILOSOPHY STUDENT named Peter Singer happened to meet a fellow student who didn't eat meat. Even today this is uncommon, but at the time it was radical, and it made Singer pause. "Here I'd been eating meat for 24 years. I was studying ethics. Yet I'd never thought that eating meat might be an ethical problem," he recalls. "I thought, what does entitle us to treat animals like this? Why is the boundary of our species so important?"

Out of the intellectual journey that followed came *Animal Liberation*, published in 1975 and considered one of the most influential books in modern history. *Encyclopedia Britannica* called Singer "one of the world's most widely recognized public intellectuals," and he and his seminal work are credited with shaping the modern animal rights movement.

Now a professor of bioethics at Princeton University, Singer is quick to clarify that his arguments are not fundamentally about rights. Rather, they're about equality: The interests of similar beings deserve similar moral consideration, regardless of the species they belong to, and avoiding pain is a transcendent interest. "If a being suffers, there can be no moral justification for refusing to take that suffering into consideration," he writes. "Beings who are similar in all relevant respects have a similar right to life; and mere membership in our own species is not a morally relevant distinction."

That message is even more timely—and more challenging—now than when Singer first delivered it. It's estimated that there are more than 33 billion domesticated chickens, mostly in factory farms, as well as 1 billion pigs and 1.5 billion cows. More than 100 million animals live in laboratories. The scale of their suffering is so vast as to be almost inconceivable. At the same time, however, there is more support than ever before for improving animal welfare and respecting animal

rights. And although science has provided new ways of exploiting animals, it has also illuminated their lives and deepened our empathy.

In anticipation of *Animal Liberation Now*, the newly published update to his classic text, Singer talked to *Nautilus* about science, ethics, and the future of animals.

A half-century ago, when you wrote *Animal Liberation*, the claim that animals other than ourselves had subjective experiences was scientifically very controversial. That they experience pain in a manner similar to how we do was not recognized in a great many creatures.

How did you think about the science at the time? Were you aware that, in a sense, you were getting out ahead of where the science was?

When I started thinking about this issue, there was still a kind of behaviorism in science and in psychology particularly. You were not supposed to talk about the subjective feelings of animals. You were supposed to observe their behavior. You were supposed to say that when you gave a dog an electric shock, it vocalized and showed a diversity of behavior. You were not supposed to say the dog was in pain.

But there were also pioneers in understanding animal behavior much better. Perhaps the first I read was

Nikolaas Tinbergen's study of seagulls, which clearly treated them in a different way. Donald Griffin's *The Question of Animal Awareness* came out after I'd started working on this, and that was a breakthrough book in talking about animals actually being aware.

The other thing I felt supported by was that even if behaviorists and some scientists talked this way, nobody did who wasn't in that field. Nobody said when their dog hurt himself that he was showing aversive behavior. Nobody denied that their dog felt things and was happy to go for a walk. Everybody knew that animals do have these emotions and subjective awareness. That encouraged me to think from the start that there was just something wrong with the behaviorist view.

I think about that gap between everyday knowledge and scientific knowledge a lot. It continues today: In everyday, common-sense ways we impute a great deal of intelligence and subjectivity to animals that isn't yet supported by the science. And I cannot think of another subject in which there's such a gap between what most people would intuitively say is true and where the science is. Are there analogues that come to your mind? That's an interesting question. Philosophers would say there are gaps in our beliefs about free will or responsibility for actions. Some neuroscientists might also think that. But I think that's a lot more nuanced than what you're talking about with regard to animals.

But you don't think that gap has been closed? I feel that since the 1960s and 1970s that gap has closed quite a long way.

Absolutely I think so, which actually brings me to my next question. Since *Animal Liberation's* publication, and especially in the last couple decades, is there research that's been especially compelling to you?

Quite a lot. Along with Tinbergen, I should have mentioned Jane Goodall. And then there were people like Dian Fossey and Biruté Mary Galdikas working on gorillas and orangutans. Their work has been really important. Another woman, and more related to the issues I write about, is Marian Stamp Dawkins. She was interested in how you measure what farmed animals really want.

She did the first studies showing that if you give laying hens the experience of a wire cage and the

Maybe caterpillars suffer, but do they suffer like us?

experience of a grass run, and then you set up a system where if they peck for a long time at a button they'll be released from the cage, they'll work quite hard to get to the grass run—whereas they never work to get from the grass run to the cage. That was quite scientific, and it was really showing that hens have preferences for where they want to be and how they want to live.

Yet to quote from Yuval Harari's foreword to *Animal Liberation Now*, "The scientific study of animals has so far played a dismal role in this tragedy." Science isn't always used to understand animals; it's also used to serve our own purposes for them.

It was interesting that the chapter on medical research came before the chapter on factory farming. Is there a reason you put the medical science first?

Let me say first: It's not all medical science. I think that's a bit of a myth—that all the experiments we do on animals have medical purposes. There's a lot that is not really medical at all.

I put it ahead of the chapter on factory farming because it relies on the idea that animals are like us in important ways. Now, you could say, "Well, that's just because they have, say, kidneys, so we can study kidney disease in animals—but the similarity ends with anatomy. It doesn't extend to experience." And I suppose you could have a being with kidneys that had barely any consciousness, though I don't think that's in fact the case.

But when you get to experiments in psychology, that argument doesn't work. That's why I talked about Harry Harlow's experiments on maternal deprivation. He was trying to study depression and the effect of isolation on human children. If you think doing that to monkeys is going to tell us something about what happens to humans, you have to say that monkeys are suffering much the way humans are. I wanted to make that point up front before getting to the farming issue.



GOOD BOY The popularity of dogs—so obviously thoughtful and emotional—as pets in the 20th century helped undermine behaviorism’s sway over the scientific study of animal minds.

I was familiar with Harlow’s work and some of the research you describe on animal “models” of human psychological trauma and PTSD, but I was taken aback at just how horrific and decades-spanning in scope it is. I also wondered if maybe you were cherry-picking the argument, so I did some digging into the research—and it’s striking how even contemporary reviews acknowledge that this research has gone on for decades without producing much human benefit at all.

But what about research where there’s a stronger argument to be made about the human value? Cancer comes to mind. Treatments have come a long way in the last couple decades. Or vaccines for COVID-19: One can quibble about how much later-stage animal experimentation was necessary, but for the technical backbone of the mRNA vaccines, those insights came from experiments on animals.

That’s a fair question. And I do talk about that in connection with Parkinson’s disease research. I’m not an expert in that area, but if the facts as told to me by someone who is an expert are correct, I think we can defend the use of a small number of animals to find ways of relieving the symptoms of people suffering from that condition.

In general I don’t think it’s sound to take an absolutist stance and say animal experimentation is always wrong. Your example of COVID vaccines is possibly another good example. If there is a prospect for something of great value like that, and which will take a limited number of animals, and if the animals are cared for and treated in ways that minimize their suffering to the greatest extent possible, that can be compatible with the idea of equal consideration of interests. Because there’s a very large number of very vital interests to live better with Parkinson’s or develop vaccines to save millions of lives.

Then we can say we’re sacrificing the interest of some beings—while taking care to make that sacrifice as limited as possible—for a greater benefit. But what’s important, I think, is that we’re not simply saying: The benefit is to humans and the cost is to mice, so therefore it’s fine.

Many scientists would say that it would be wonderful if we could only experiment on a few animals, with a high potential for significant insight—but not much research is actually like that. Advances in alleviating human suffering or treating disease are built from many small pieces of research, and they were undertaken without much hope of success or even an idea of what they would be applied to.

I’m not sure that argument is always true, but sometimes it is. How do you deal with that?

I don’t think there’s any easy answer to that question. But there is a counterfactual here. What if we had put the resources we put into animal experimentation—most of which we don’t really learn anything important from, but now and again something turns up that’s really important—into other methods of advancing biological and medical science? It’s hard to know what we would have discovered.

A much less nuanced topic is the farming of animals. And there is this paradox that we’re more aware now than at any other time in modern history of animals’ capacity to suffer—yet the suffering continues on an inconceivably vast scale. What do you do with that? What does it say about us?

I think it does say something bad about us. Not that we’re sadistic or anything evil like that, but that we’re highly biased when it comes to our own interests, and we see our interest as continuing to consume these animals. To some extent that’s just habit, I suppose, and maybe to some extent it’s a kind of evolutionarily-programmed taste for high-nutrient-density food. That really blinds us to what we’re doing.

I don’t think that most people are indifferent to animal suffering. They react to it when they see it—but they don’t want to see it if it’s going to interfere with their dinner. So I think that’s the ultimate problem.

Things are changing in some parts of the world more than others. I think there’s more awareness of these issues, and more willingness to change, in Europe than in most of the United States. Although I do think the problems in the U.S. are maybe not so much the



attitudes of individual Americans but the corruption of the political system, where the agribusiness lobby plays such a huge part and money plays such a huge part. But once people know what's going on, they will vote against it. Like the Massachusetts vote on giving farmed animals room to move around and stretch their limbs and wings: That had 78 percent support. That's pretty incredible in polarized America for almost anything.

I think most people have a sense that farmed animals experience pain and can suffer, but believe the quality of that pain and suffering does not approach what humans feel. And the science is not especially illuminating on this issue. Science can say, of course chickens feel pain or pigs can be depressed—but does it compare to ours? That's my gut feeling, but that's not where the science is.

I think you're essentially right. It's not something that science can shed a lot of light on. Science can show some things: that the same neurological mechanisms work in animals as in us, that their behavior changes

WIDE-EYED New Zealand White rabbits are cheap, easy to handle, and have very large eyes, all of which makes them popular test subjects for studying the effects of chemicals on eyes and skin.

in ways somewhat similar to our own. It can show that giving analgesics reduces behavior that indicates pain. But comparing mental states is a philosophical problem.

I don't know that I feel pain as much as you. I talk about this with my wife sometimes, because she doesn't mind going to the dentist in the way that I do. Does that mean I'm more cowardly? Or that my nerves are more sensitive than hers? And if I don't know that between myself and my wife, how am I going to know it between myself and a pig or a chicken?

But the thing is: What's the basis for assuming their suffering is *less*? With some kinds of mental suffering,

UNOL / SHUTTERSTOCK



like anxiety about your future, maybe you need cognitive capacities that the animals we eat don't have. The perception of pain, though, is essential for relating to one's environment and avoiding danger. And we know that many animals have senses that are much more acute than ours, right? We know birds of prey have sharper vision than we do. We know that dogs have sharper smell than we do. Why assume they don't feel pain as we do?

You said earlier that people are not cold-hearted toward animals. If anything, it's the opposite: With any individual animal we meet, most people will be affectionate and respond with care if they're in distress. Yet the moment that animal is locked away, cut into pieces and put on a plate, it's a completely different being. We might as well be looking at a stone.

Have you come across any research from the social or behavioral sciences that helps explain this?

There's two pieces of social psychology research that I think are relevant here. One is that with humans we also focus on individuals, not masses.

DOUBLE STANDARD Pigs are as intelligent as dogs, and in the right circumstances as affectionate—but that's not how they're treated.

Paul Slovic has done a lot of research on that. In one study he brought students in for an experiment and didn't tell them what it really was, but said they'd be paid \$15 for doing it. He gave them some questions to answer that had nothing to do with the experiment. When they finished, they were paid and given a presentation about how the lab was supporting a charity. Then they were given a notice that said something about how thousands of children go to bed hungry every night in Malawi, and you can help them by donating—or it had a picture of a girl and said, “This is Rokia. She's 7 years old. She doesn't get enough to eat. You can help her.” The students who got the information about a single

VOICE OF THE ANIMALS In his 1975 classic *Animal Liberation*, Peter Singer argued that the interests of animals cannot be dismissed simply because they are animals. That, said Singer, is speciesism: a prejudice as arbitrary and unfounded as sexism or racism.

child donated much more than students who got information about thousands of children.

The other research was done by an Australian psychologist named Brock Bastian. He asked people about domestic animals—cows and pigs and chickens—and what they thought of their mental capacities. Then he got them to do other things that had nothing to do with animals. When lunchtime came, he told some participants that they would get a beef hamburger for lunch and others that they would receive a plant-based lunch. After that came further questions about animal capacities. Those people who were told they'd be having a hamburger had lower opinions of the cows' mental capacities than people told they would have a plant-based meal.

I think that's pretty good evidence that knowing what we're eating biases our assessments.

Previously you've drawn the line for who you felt comfortable eating somewhere between shrimp and oysters. Is that still where the line is?

That's still pretty close. I think it's unlikely that oysters feel pain. And even if you think they do, then because of the way they're grown and harvested it might well be that you're not responsible for more pain than if you eat plants. Because after all plants also have to be grown and often rodents are killed while plowing or harvesting. We can't be 100 percent pure, and I think eating oysters is as pure as most foods we can get.

But some people have tried to persuade me that not all bivalves are alike. I had talked about oysters, and then said this will also go for mussels and scallops and clams. They suggested that while oysters do remain fixed on a rock and it's hard to see why they would have evolved the capacity to feel pain, scallops can propel themselves and have some kind of vision. So maybe I should have said the line is between a scallop and an oyster rather than between a shrimp and an oyster. I'm not sure. It's somewhere around that vicinity, anyway.



What do you make of new research on cognition in plants? Does that change the ethical equation of consuming them at all?

I don't think so. Partly because I think we are justified in surviving, and if eating plants is necessary for us to survive, then that justifies it. And partly because if you eat animals, the animals have themselves eaten a much larger number of plants than if we ate the plants directly. So if plants are sentient beings, we would still do them less harm by eating them directly than by eating animals who eat them.

As for my own views about the possibility that plants are sentient, I'd say the new research maybe slightly reduces my confidence that they're not. I was completely confident about that before; now I'm maybe 98 percent confident. The research is quite ambivalent. I don't think anything really shows that plants are sentient beings, but it does show their behavior is complicated. The question is: How do you explain it? We may still explain it in ways that have nothing to do with consciousness. That still seems most likely.

DENISE APPLEWHITE

Nobody denied that their dog felt things and was happy to go for a walk.

In *Animal Liberation* you touch a bit on the suffering and experiences of wild animals. This overlaps with the subject of my own book, and I've found myself reflecting on critiques from welfare biologist philosophers who see the lives of wild animals as being dominated by suffering. That's a distressing thought for me.

It's springtime now, and it's wonderful to go on a walk in the morning and be surrounded by all this stirring life. I don't want to think that I'm actually just putting on my rose-tinted glasses and what I think of as a beautiful morning is soaked in pain and suffering. But maybe I'm just a romantic. How do you look at the subjective experiences of wild animals?

I'm not as pessimistic as some are. And having talked to some of the people involved—Oscar Horta and Catia Faria and so on—I don't think that, when you're walking through the woods and listening to the birds, they're seeing that as negative in itself. What they're looking at is those animals who produce very large numbers of offspring, the overwhelming majority of whom don't make it. And the assumption is that they die in painful ways.

It partly depends on whether we think that insects are sentient beings. I've had this thought myself. For example, I had some kale plants, and I was away for a bit, and when I came back butterflies had laid their eggs, and the plants were swarming with caterpillars. It was clear that they were all going to starve to death. That raises the question: If those caterpillars are in pain, if they are suffering, then maybe the wild animal suffering balance is negative. There's so many of them.

But it's hard to know. And maybe caterpillars suffer, but do they suffer like us? They have so few neurons. What's going on? I hope either they don't suffer or that their suffering is of a different order in some way.

If there was some way of empirically verifying that, say, what caterpillars suffer is 10 percent of what we would in a similar situation, the sheer numbers involved mean that the interests of those caterpillars—and every other insect—would outweigh our own in many circumstances. It would certainly be impossible to justify driving a car for most of the year here.

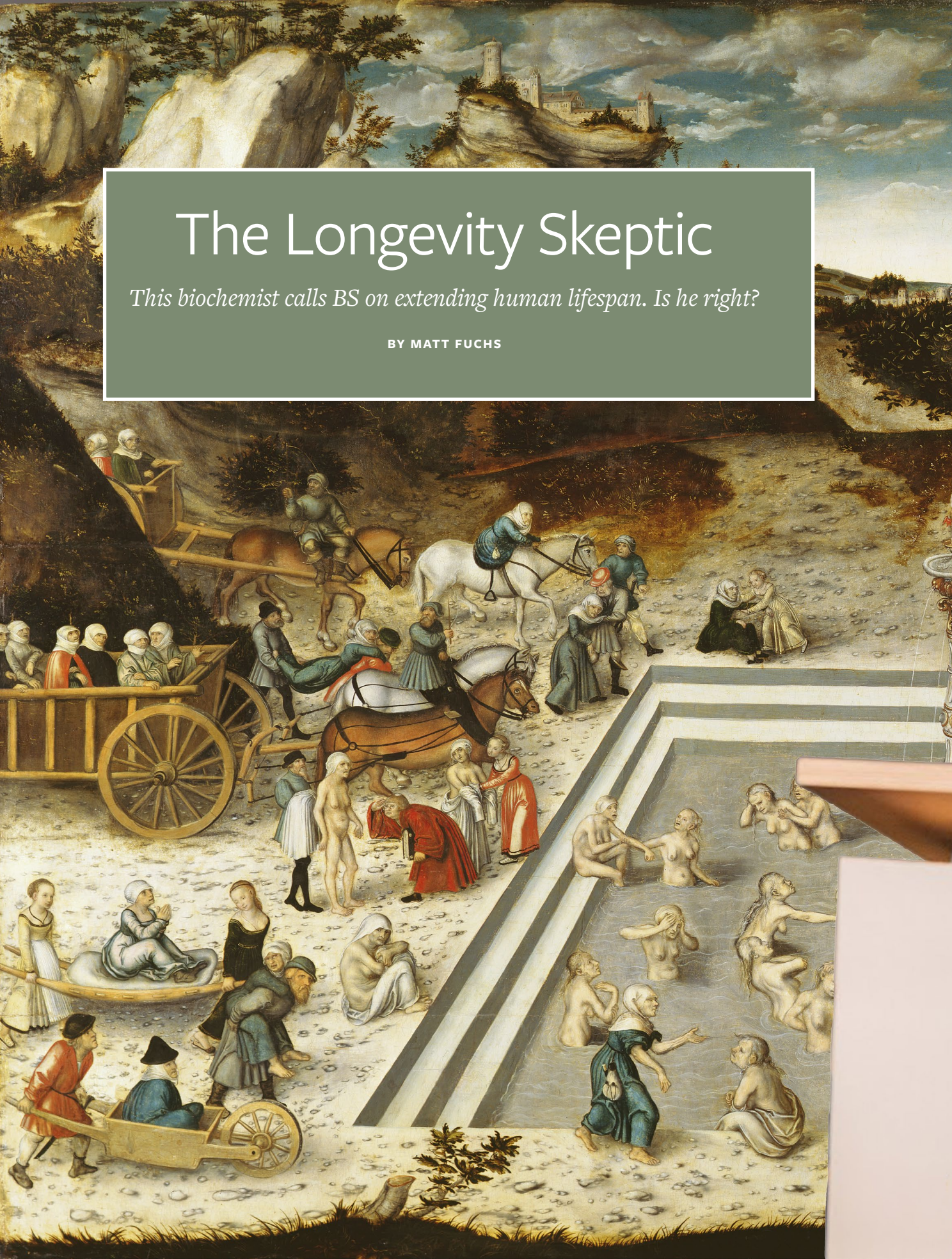
So if insects have experiences comparable to ours, does that make a complete hash out of your frameworks?

It would make life extremely difficult, I agree. But I don't think it makes a hash out of the general ethical framework I apply, which is that we want to maximize well-being. The framework still stands.

And are you hopeful for the future? Do you think our circle of moral consideration will continue to expand, or just continue to be the irregular shape that it is now?

I'm hopeful. I do think that's the long-term trend, just as Martin Luther King, Jr. said: "The arc of the moral universe is long, but it bends toward justice." It's going to take some time; there will be peaks and troughs. But I think the long arc bends toward the inclusion of all sentient beings. ☺

BRANDON KEIM is a freelance journalist and edits the Ocean section of *Nautilus*. He is writing *Meet the Neighbors*, a book about animal personhood and nature, which will be published by W.W. Norton in 2024.



The Longevity Skeptic

This biochemist calls BS on extending human lifespan. Is he right?

BY MATT FUCHS





AT THE LONGEVITY INVESTORS CONFERENCE last October in Switzerland, speakers described breakthrough therapies being developed to manipulate genes for longer lifespans. Swag bags bestowed pill bottles promising super longevity, stirring hopes for centuries of youth.

Then Charles Brenner took the stage. The biochemist from City of Hope National Medical Center, in Los Angeles, addressed these ideas and treatments one by one, picking them apart, explaining that they're based on faulty research. We can't stop aging, he told the crowd. We can't use longevity genes to stay young because getting older is a fundamental property of life.

Scanning their faces, he saw puzzled expressions. Mission accomplished.

Over the past year, Brenner has been challenging life-extension theories on Twitter, YouTube, and the conference circuit, where he's been introduced as the "longevity skeptic." He resembles an eagle—he's hairless on top with an aquiline nose and penetrating gaze—an appearance that goes well with his astute intellect, tenacity, and willingness to fly solo as one of the most boisterous critics of anti-aging science.

Brenner tells people the reasons for suspicion date back to Herodotus' made-up account of the Fountain of Youth in 425 B.C. Some things never change, he says, even as the field of aging research has picked up scientific momentum in recent years. Investments in longevity startups are predicted to jump from \$40 billion to \$600 billion in the next three years. Lured by funding from digital age tycoons such as Jeff Bezos and Peter Thiel, top scientists are aligning with companies to advance their work.

Brenner is critical of several big promises emanating from these companies and researchers, such as claims that cellular reprogramming could halt aging. He dismisses speculation from gerontologist Aubrey de Grey that anti-aging therapies will keep us above ground

for multiple centuries. But perhaps no scientist in the field of aging has attracted Brenner's criticisms more than David Sinclair, the Harvard biologist and bestselling author of *Lifespan: Why We Age and Why We Don't Have To*. Sinclair is working on therapies that he says could slow human aging to a crawl, allowing us to live decades longer.

At best, Brenner says, scientists can develop therapies that maintain the health of older people and help keep them out of the hospital—an increasingly important goal as the average age in the United States and elsewhere keeps climbing. Brenner is tackling this problem as the chief scientific advisor of a bioscience company called ChromaDex, which markets supplements for "healthy aging." But believing we can rewrite the operating manual for lifespan itself, Brenner told me, is like "believing in the tooth fairy."

Is Brenner right about the biological limits on lifespan? And should we trust the views of scientists involved with drug and supplement companies? The answer is as nuanced as the science itself.

TWENTY YEARS AGO, Brenner was immersed in academic research. He had just become an associate professor of genetics and biochemistry and director of the cancer mechanisms program at Dartmouth Medical School. In 2003, he explained, "I was minding my own business, trying to figure out how an enzyme works," when he made a major discovery about nicotinamide riboside, or NR, a form of vitamin B₃ that could support longer health spans: more years of health before death, with fewer age-related, chronic diseases.

What Brenner stumbled upon was the pathway by which NR produces nicotinamide adenine dinucleotide, or NAD. This is the molecule that powers the machinery of our cells and helps build and maintain their structures. But damage to the NAD system is inevitable. We bring some of these injuries upon ourselves—think alcohol or cigarette abuse—while others, such as sunlight, can't be avoided. Even the oxygen we breathe is a problem, causing chemical reactions that stress out the NAD system as we age, gradually reducing NAD and increasing vulnerability to chronic illness. Brenner realized that taking NR as a pill could increase NAD and help offset damage, allowing for graceful aging.

Around the same time, others were thinking about NAD, but in a very different way. In the 1990s, most scientists thought researching lifespan was career suicide. To Leonard Guarente, it was a golden opportunity. When he dedicated his lab at the Massachusetts Institute of Technology to the subject, he said, "We were the only ones who were really doing molecular biology of aging."

Soon, Guarente and his lab members were making findings about a family of enzymes called the sirtuins, which reside in the cells of most living things and control which parts of our DNA get switched on or off. When the MIT scientists added an extra copy of the gene that controls these enzymes, they found that yeast cells and worms lived longer.¹ Guarente formed a theory: The sirtuins had evolved in our ancestors to play a key role in longevity. In times of great stress, when food supply is low, the sirtuins express DNA in ways that increase lifespan—a trick that enables more time to reproduce after the famine, when conditions are better for raising healthy offspring.

In their respective labs, Brenner² and the MIT researchers³ showed that when NAD levels were raised in yeast, the sirtuins became more active, and this sirtuin uptick led to longer lifespans. The research confirmed, "without a doubt," Guarente said, that there are longevity genes, and they can be manipulated, potentially helping humans live much longer.

One of the bright postdocs in Guarente's lab was Australian-American biologist Sinclair, who worked alongside Guarente for four years before he was hired by Harvard Medical School in 1999. A few years later, he became interested in an antioxidant called resveratrol,

Believing we can rewrite the manual for human lifespan is like believing in the tooth fairy.

which plants produce when they're stressed. Because resveratrol is found in red wine, researchers wondered if it might explain why the Pinot-loving French have fewer incidents of heart disease. In 2003—the same year that Brenner made his discovery about NR—Sinclair fed resveratrol to yeast cells, and found their lifespans increased by 70 percent.⁴ It seemed to mimic the effect of restricting calories, without the hunger. When Sinclair tried giving resveratrol to the yeast after he'd removed a sirtuin gene, this lifespan benefit disappeared. Other experiments suggested resveratrol led to key changes that tend to support longer lifespan in mice.⁵

To Sinclair, this work reinforced the view that sirtuins play an important role in lifespan, and it suggested the fountain of youth was crimson, sweet, and bottled at a store near you. Journalists turned the finding into front-page news, making Sinclair famous and sending sales of red wine through the roof.

Sinclair's book, *Lifespan*, goes on to describe his experience of becoming a media sensation as well as the anticlimactic fallout: He and other scientists realized that the human gut is no match for yeast and mice when it comes to soaking up resveratrol. Today, the scientific consensus is that you *won't* become a superager by swilling red wine. Even so, Sinclair's research was an "important first proof," he writes in *Lifespan*, that molecules can delay aging in organisms through the same mechanism as calorie restriction, which inspired a wave of research on other "sirtuin-activating compounds," including NAD.

The pages of Sinclair's book are infused with his enthusiasm for the cause of helping people stay healthy and live many more years than any human before. "What if we could be younger longer?" he writes. "Not years longer but decades longer."

In the science of aging, every advance gets announced like it was climbing Mount Everest.

Sinclair, who is co-director of Harvard's Paul F. Glenn Center for Biology of Aging Research, thinks the science points clearly to the potential. "At least in animal studies, it looks like [certain NAD precursors] can rejuvenate stem cells," he told me. "We've found longevity genes that control the body's defenses against aging and thus offer a path to slowing aging through natural, pharmaceutical, and technological interventions," he wrote in *Lifespan*, adding that sirtuins are longevity genes "because they have demonstrated the ability to extend both average and maximum lifespans in many organisms."

AFTER HIS DISCOVERY IN 2003, Brenner progressed in his academic career, moving steadily west over the years from Dartmouth to the University of Iowa, where he held an endowed chair and served as head of the biochemistry department, before coming to City of Hope in 2020 as the inaugural chair of a new department. There, he continues to be a pioneer in studying NAD metabolism. "I love doing science, and we find new and important things every month in the laboratory," he said. Increasingly, though, he has felt compelled to step outside

the lab into the public arena to challenge what he sees as the quackery within longevity science.

Brenner wasn't always so concerned by the views of scientists such as Sinclair. In 2008, he briefly partnered with Sinclair, contributing as a scientific advisor to Sirtris Pharmaceuticals, a company founded by Sinclair and others to develop therapies for age-related diseases.

But Brenner grew wary of Sinclair's research findings and his perspectives on both sirtuins and the ability to control lifespan. Brenner left Sirtris following its acquisition by the pharmaceutical giant GSK in 2009; after *Lifespan* gained widespread acclaim and popularity, he couldn't hold his tongue anymore. The biochemist took his critique to social media. In 2018, Brenner started a Twitter account and declared it was a "no BS zone." He attracted nearly 50,000 followers while posting educational material about NAD and critiquing Sinclair's communications on resveratrol and sirtuins.

"There's a massive [research] literature showing that resveratrol isn't a [sirtuin] activator," Brenner told me, echoing his comments on social media. He penned a scathing response to Sinclair's *Lifespan* book, "A Science-Based Review of the World's Best-Selling Book on Aging."

THE GREAT DEBUNKER

Charles Brenner clearly takes pride in his image as a brassy skeptic of extending human lifespan.

CHARLES BRENNER



The paper, published this past January in *The Archives of Gerontology and Geriatrics*, accuses Sinclair of “dreamy counterfactuals” that steer people away from “basic facts about aging.”

“The idea that [a yeast gene] anticipated the causes of aging in animals is mind-blowing,” Brenner said. He pointed out that, even in yeast, increasing sirtuin activity leads to longer life in just one out of 5 million cells. If you zoom out to consider the entire group of yeast that was studied, he said, extra sirtuins actually undermined yeast longevity. “The verdict is in,” Brenner said, that sirtuins aren’t dominant longevity genes that were selected and passed down in evolution. What *is* genetically encoded is the limit on lifespan, he and others have argued.

Sinclair responded that sirtuins clearly play a role in the aging process. “There are dozens of papers showing the benefits of raising NAD are lost when [sirtuins] are deleted,” he told me. “It’s not just in mice. When you overexpress [sirtuins] in worms, in flies, in yeast, it extends lifespan. And so it seems to be a conserved effect that some of these sirtuins are limiting for lifespan, and that if you give the organism more of them, they’re healthier and live longer.” Guarente, too, said that a large volume of published research links aging and sirtuins, “cementing their role in longevity and health.”

Brenner isn’t backing down. Studies that have connected sirtuins to longevity suffer from several biases, he wrote in 2022. One of those is “framing bias,” when scientists design research questions in ways that lead to the conclusions they prefer, such as when they make assumptions about the role of sirtuins. “Review articles that propagate these biases are so rampant that few investigators have considered how weak the case ever was for sirtuins as longevity genes,” he wrote.

“If I were to endorse the view that sirtuins are longevity genes, and that my 2007 finding that NR extends lifespan in yeast and, therefore, it’s going to extend lifespan in humans, I could have parlayed non-evidence based claims into significant money,” Brenner said.

Brenner does have a financial interest in his advisory role for ChromaDex, a public company that sells NR. The market value for supplements that boost NAD is

Should we trust scientists who have financial interests in drugs that promise to slow aging?

estimated at \$250 million in the U.S. alone. In addition to Brenner’s work with ChromaDex, Guarente’s belief in the potential for sirtuins and NAD to support health and possibly lifespan led him to co-found Elysium Health, a private life sciences company that sells NR and another NAD precursor, called nicotinamide mononucleotide, or NMN. The market for these NAD boosters is projected to reach \$1 billion by 2030.

Boosting NAD is useful, Brenner explained, because our bodies need loads of it to preserve health as we age. NR supplements crank up enough NAD to power the cells in handling their many tasks, even as our reserves of NAD get drawn down to repair constant damage from oxygen, inflammation, and other stressors.

Brenner has shown that NR, when taken orally, protects against heart failure in mice.⁶ Recent studies by other researchers have found that doses of NR lead to improvements in age-related problems, such as Alzheimer’s, Parkinson’s disease, high blood pressure, and inflammation. Benefits in people with ALS and non-alcoholic fatty liver disease have been shown by Guarente and other researchers at Elysium, where Guarente is chief scientist. Since Brenner began taking the NR supplement made by ChromaDex, he told me that his cuts and scrapes seem to heal faster, and he feels like he bounces back faster from tough workouts.

Brenner is confident about NR’s superiority over the other NAD booster, NMN. He points to evidence that NR is the biggest piece of NAD that can get into any cell. “NMN doesn’t make sense as a supplement or drug,” he told me.

Other researchers at the University of Washington—including Shin Imai, who was a postdoc in Guarente’s lab—have published data pointing to the opposite conclusion: very fast uptake of NMN into cells.⁷ Sinclair said the science points clearly to the potential for NMN’s effectiveness. In 2017, he and Imai co-founded a company called MetroBiotech that is running clinical trials on drug formulations of NMN. The privately owned pharmaceutical could charge more if it’s able to sell NMN as a drug, compared to marketing it as a supplement.

Imai conducted the first clinical trial of NMN in humans, reporting in 2021 in *Science* that it improved insulin sensitivity in older, pre-diabetic women.⁸ It's printed right on the bottle that supplements aren't intended to treat diseases. Nevertheless, Imai said, "Now we have a series of clinical evidence for the efficacy of treatment in humans."

But the benefits of NR and NMN supplements for health span, let alone lifespan, are debated. "Every human clinical trial that I've seen where people claim some effect from NAD precursors, when you actually dive into the papers, they've all got major weaknesses," said Matt Kaeberlein, also a former postdoc in Guarente's lab, who went on to become a leading biogerontologist at the University of Washington.

Although the prediabetic women in Imai's research on NMN did improve their insulin sensitivity, they didn't get other expected benefits, such as better blood lipids. "It's some evidence in the right direction, but not compelling evidence that it's clinically therapeutic," said Samuel Klein, a professor of medicine and nutritional science at Washington University in St. Louis. Klein was a former partner in MetroBiotech, but he's given up all relationships with businesses related to NMN and NR. "The research was more important

to me than the potential for financial gain," he said. (Imai, too, has left MetroBiotech.) Klein told me the benefits seen from NAD boosters in some animal studies haven't translated to people because the dosing isn't right, or because "humans are simply not rodents."

IN MANY WAYS, Brenner is a much-needed skeptic. "In an area like aging, every advance gets announced like it was climbing Mount Everest," Arthur Caplan, a bioethicist at New York University, told me. "Just about every advance in the history of medicine is not really a breakthrough. It's a slow, cumulative slog. I don't care what study it is—minimally, it has to be confirmed by further research."

Brenner would agree. But sometimes Brenner's own assertions seem to verge on hype. When he declares that taking NMN for health doesn't make sense, without noting the data that support NMN, it can sound like an overstatement. When I brought up the NMN data, though, he told me it's "deeply flawed"—and referred me to his published paper on the topic, as he so often does.

Unquestionably, Brenner and Sinclair have impressive scientific credentials. They also have financial interests in NAD boosters. Does that mean the public shouldn't trust their research and perspectives?

Not necessarily, said Josephine Johnston, a bioethicist and research fellow at The Hastings Center, an independent research

Just about every advance in the history of medicine is not really a breakthrough. It's a slow, cumulative slog.

THE LONGEVITY ADVOCATE

David Sinclair insists organisms have longevity genes that can extend maximum lifespans.



WIKIMEDIA COMMONS

institute that focuses on health and science. She explained that partnering with companies is an important incentive for scientists across biomedical fields. “We don’t want inventions languishing in academic labs and not actually getting out to the public,” Johnston said. In fact, translation of academic research into commercial products has been a policy goal of the U.S. government for decades. American universities also have robust requirements for scientists to disclose financial relationships.

Brenner lists his financial interests in his published papers, noting when he’s received research funding from companies such as ChromaDex. Sinclair does the same, disclosing his position at MetroBiotech and several other private sector roles.

It’s tough to declare a winner in the standoff between Brenner and Sinclair. After all, we all have a stake in aging. Caplan said one surefire way the public can identify which scientists to trust is to determine whether they engage in debates. That speaks well for Brenner, who continues to be invited to longevity conferences, despite his “longevity skeptic” status. Another measure of trustworthiness is whether scientists with conflicting findings are willing to collaborate.

A few years ago, for example, the National Institute on Aging and the University of Wisconsin investigated whether caloric restriction extends lifespan in rhesus monkeys. Because it was an important experiment, they partnered to run the same study in parallel at two different sites, ensuring rigor and responsibility. When they got conflicting results, instead of arguing, they worked together to spot differences in their study designs.⁹ They came to a shared conclusion that caloric restriction does improve the health and survival of the monkeys.

Perhaps Sinclair and Brenner will one day run side-by-side research on sirtuins, or the benefits of NMN compared to NR. Both, at least, agree on the gap in comparative research. “We need studies directly comparing the two, and both may have unique benefits,” Sinclair said. Brenner acknowledged the need for more research in humans. Generally speaking, he said, “I don’t like to get out ahead of my skis or get ahead of where the evidence is in science.”

There are several examples of such partnerships, sometimes called “adversarial collaborations,” but

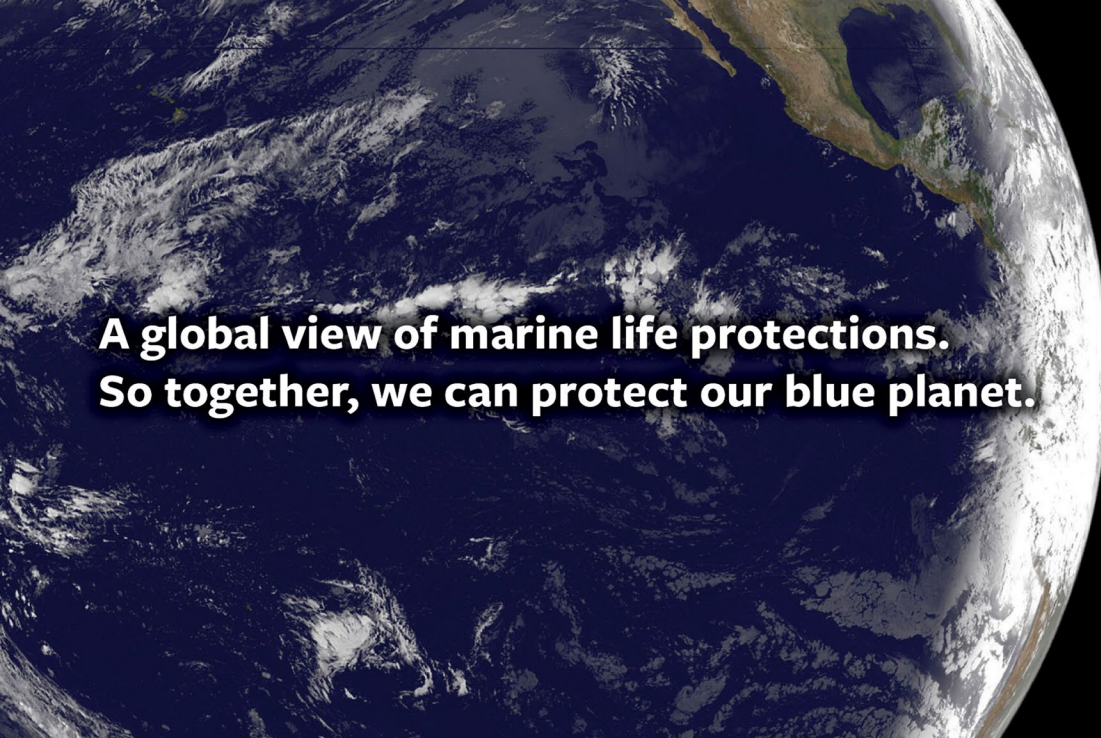
it’s easy to imagine this one ending badly. Brenner clearly takes pride in his image as the Great Debunker of extending human lifespan, while Sinclair is standing by his reputation as the biologist who said we can. Could they arrive at a shared conclusion?

Whether it’s advanced through disputes or collaboration, science will have the last word on how well and long we can live. “Charles Brenner and David Sinclair are both distinguished scientists,” Klein said. “The fact that they have opinions that are polar opposites reflects the nature of NAD science. Nothing is black and white. There’s a lot of gray.” ☺

MATT FUCHS is a freelance writer covering science and health, and editor-in-chief of Leaps.org.

REFERENCES

1. Kaeberlein, M., McVey, M., & Guarente, L. The SIR2/3/4 complex and SIR2 alone promote longevity in *Saccharomyces cerevisiae* by two different mechanisms. *Genes & Development* **13**, 2570–2580 (1999).
2. Belenky, P., *et al.* Nicotinamide riboside promotes SIR2 silencing and extends lifespan via NRK and URH1/PNP1/MEU1 pathways to NAD⁺. *Cell* **129**, 473–484 (2007).
3. Imai, S., Armstrong, C.M., Kaeberlein, M., & Guarente, L. Transcriptional silencing and longevity protein SIR2 is an NAD-dependent histone deacetylase. *Nature* **403**, 795–800 (2000).
4. Howitz, K., *et al.* Small molecule activators of sirtuins extend *Saccharomyces cerevisiae* lifespan. *Nature* **425**, 191–196 (2003).
5. Baur, J.A., *et al.* Resveratrol improves health and survival of mice on a high-calorie diet. *Nature* **444**, 337–342 (2006).
6. Digeut, N., *et al.* Nicotinamide riboside preserves cardiac function in a mouse model of dilated cardiomyopathy. *Circulation* **137**, 2256–2273 (2018).
7. Grozio, A., *et al.* SLC12A8 is a nicotinamide mononucleotide transporter. *Nature Metabolism* **1**, 47–57 (2019).
8. Yoshino, M., *et al.* Nicotinamide mononucleotide increases muscle insulin sensitivity in prediabetic women. *Science* **372**, 1224–1229 (2021).
9. Mattison, J.A., *et al.* Caloric restriction improves health and survival of rhesus monkeys. *Nature Communication* **8**, 14063 (2017).



**A global view of marine life protections.
So together, we can protect our blue planet.**



21700

PROTECTED AREAS



220

COUNTRIES & TERRITORIES



25

LANGUAGES

Navigator

Navigator is a free, interactive map of regulatory information for over 21,000 managed saltwater and coastal areas worldwide, including the high seas. As the most comprehensive database of marine protections and their boundaries, Navigator can be used to help estimate progress towards 30x30 through its Level of Fishing Protection (LFP) scoring system.

Together, we can preserve special ocean places for future generations.



protectedseas

NAVIGATOR

GUIDE TO OUR REGULATORY SEASCAPE





PRINCE ALBERT II
OF MONACO
FOUNDATION

Protecting and progressing Planetary Health

The Prince Albert II of Monaco Foundation, a global, non-profit organization, works around the world to bring humanity together to empower impactful solutions for our planet's biodiversity, climate, ocean and water resources. Through our initiatives and the hundreds of projects we support we aim to build a more conscious future.

Every one of us has an opportunity to help progress Planetary Health for present and future generations.

Join us in building our legacy, together.

Protéger et faire progresser la santé planétaire

La Fondation Prince Albert II de Monaco est une organisation internationale à but non lucratif, oeuvrant dans le monde entier afin de promouvoir des solutions efficaces pour la biodiversité, le climat, les océans et les ressources en eau de notre planète. Au travers de nos initiatives et des centaines de projets que nous soutenons, nous participons à construire un avenir plus conscient.

Chacun de nous a la possibilité de faire progresser la santé planétaire pour les générations actuelles et futures.

Ensemble, œuvrons en faveur de notre héritage commun.

MONACO

PARIS

LONDON

GENEVA

NEW YORK

MONTREAL

MUNICH

ROMA

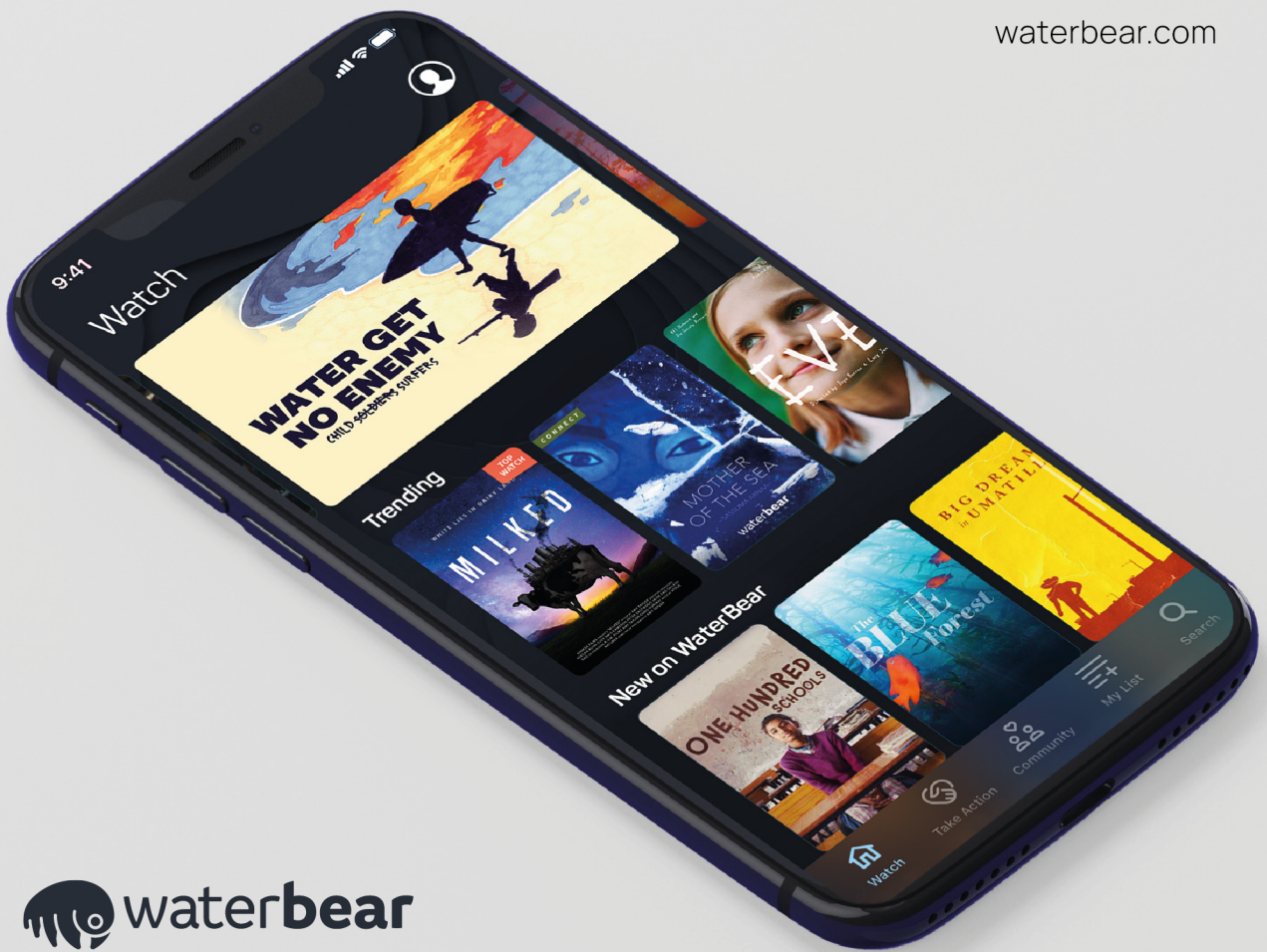
SINGAPORE

MADRID

BEIJING

www.fpa2.org

waterbear.com

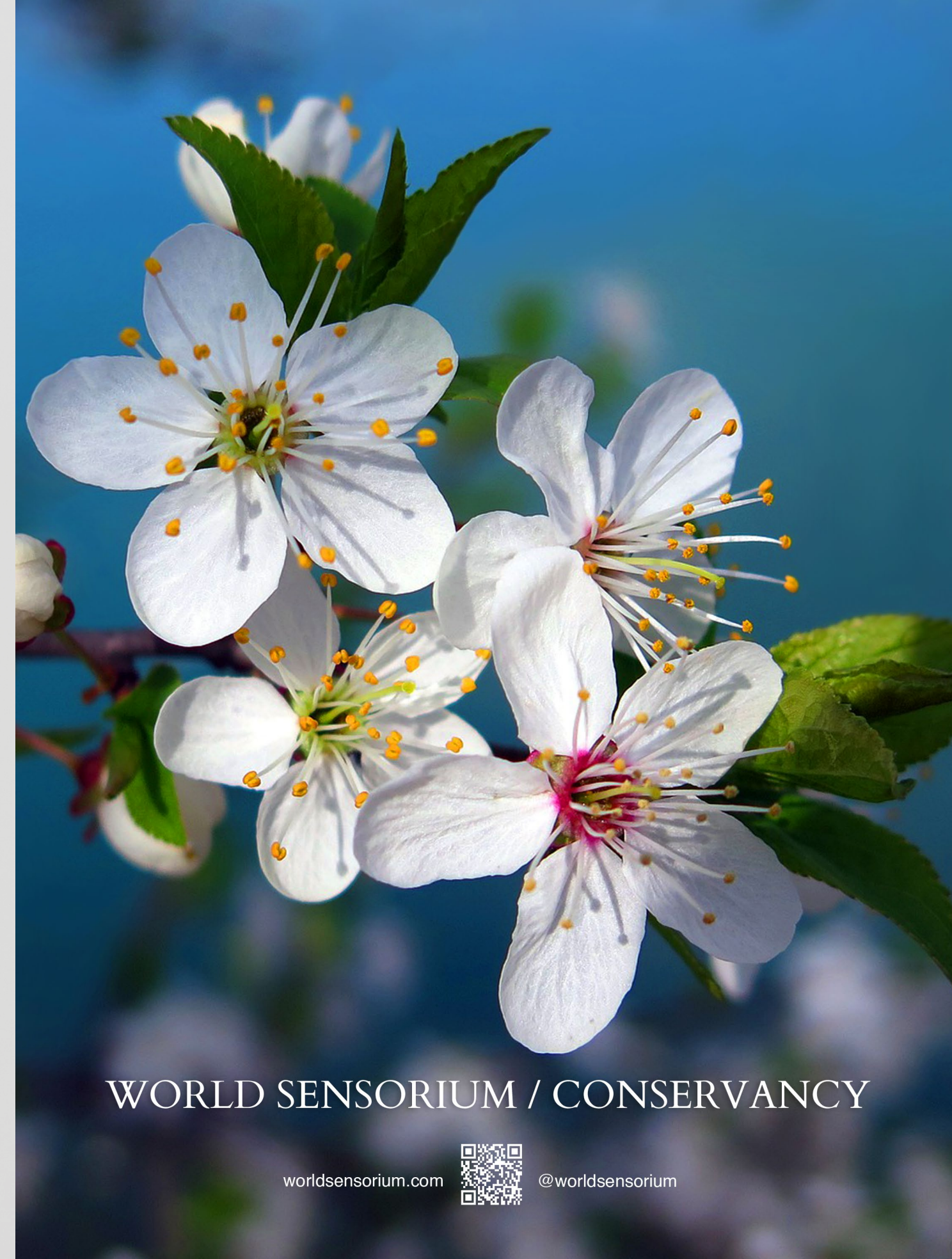


Watch hundreds of documentaries.

Anywhere. **For free.**

Download our app now



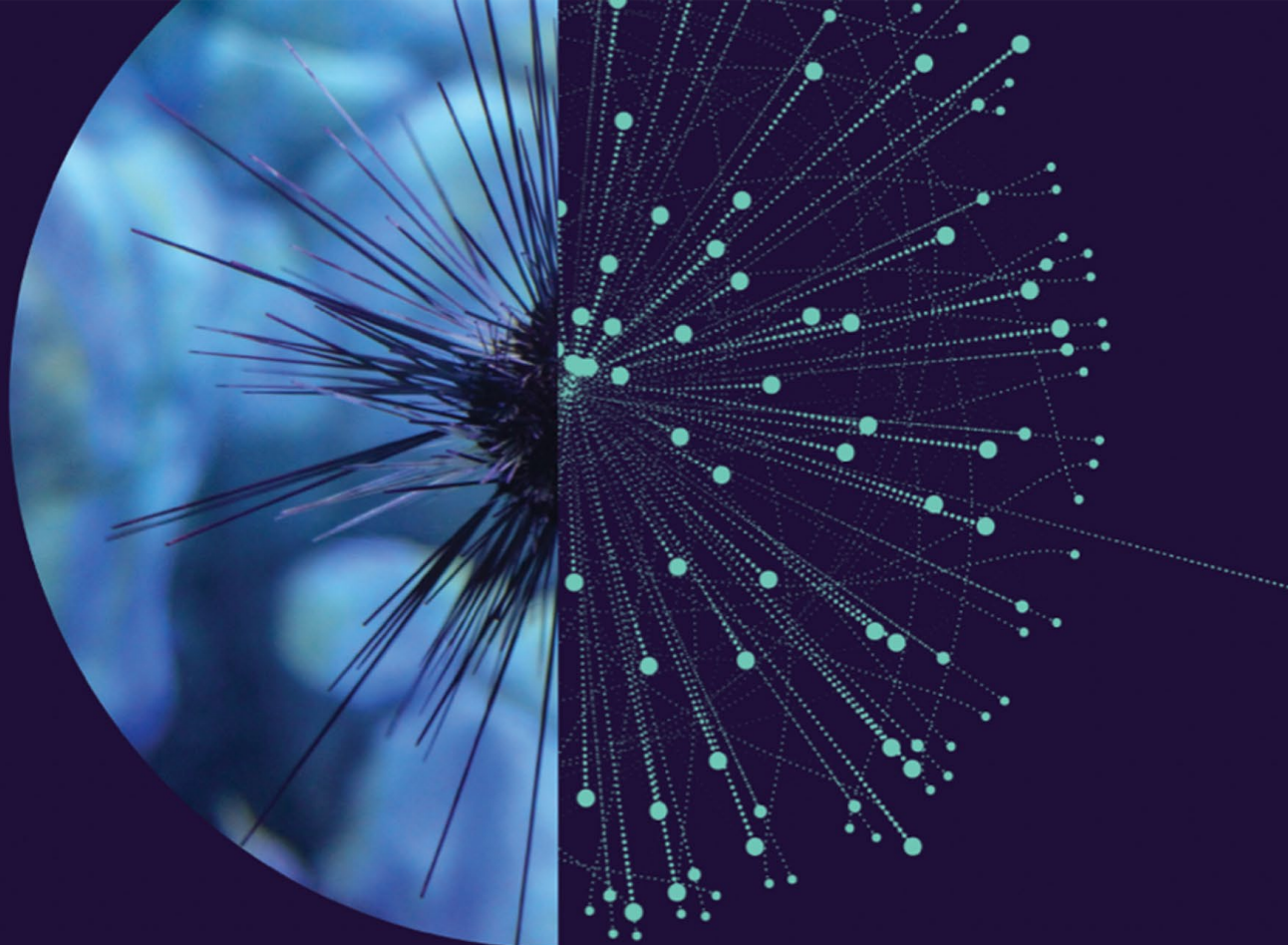


WORLD SENSORIUM / CONSERVANCY

worldsensorium.com



@worldsensorium



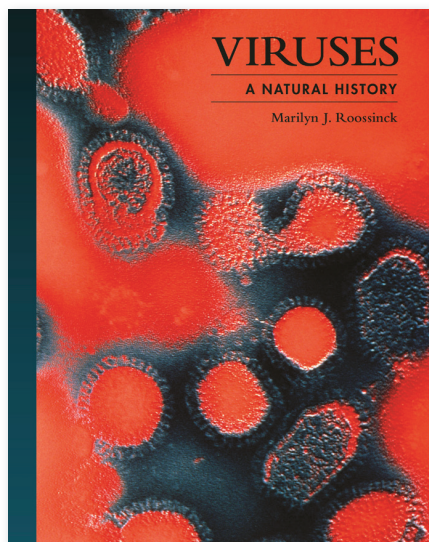
Share your data.

Enable ocean health and a thriving ocean economy.

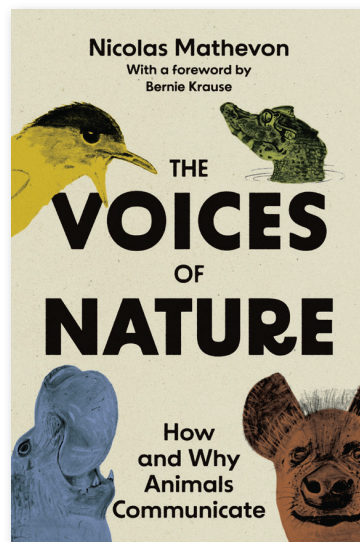
HI IR Ocean

Changing the fate of the ocean
by unleashing the power of data.

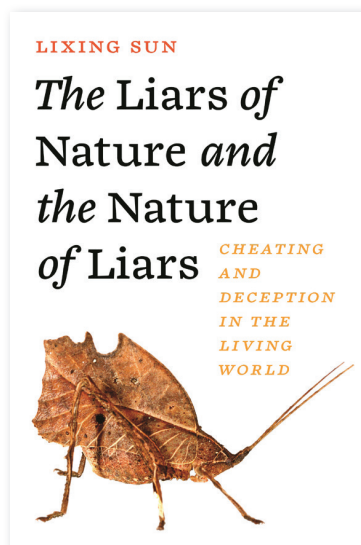
Connect with us www.hubocean.earth



"An entry-level introduction to virology that fascinated me."
—Leon Vlieger, *Inquisitive Biologist*



"The language flows easily and important scientific concepts, often complex in nature, are seamlessly woven into an entertaining story."
—David Gascoigne, *Travels with Birds*



"A tour de force of evolutionary biology....Fascinating."
—David P. Barash, *Wall Street Journal*

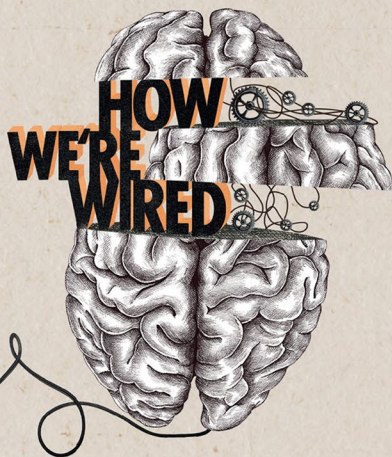


"A fascinating new perspective on why the planet's in trouble and what we can do about it."
—Elizabeth Kolbert, author of *The Sixth Extinction*

OWN YOUR MIND BUSINESS

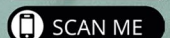
Discover what makes you tick with **How We're Wired**, a brand new podcast that looks at what happens inside your brain – from before you were born through to death.

Presented by anthropologist Dr Anna Machin, this series features real life stories, expert analysis, the latest research and at-home experiments that will open your eyes to the most fascinating organ in the human body.



fb fondation
bertarelli
fondation-bertarelli.org

Search for 'How We're Wired' and subscribe wherever you get your podcasts.



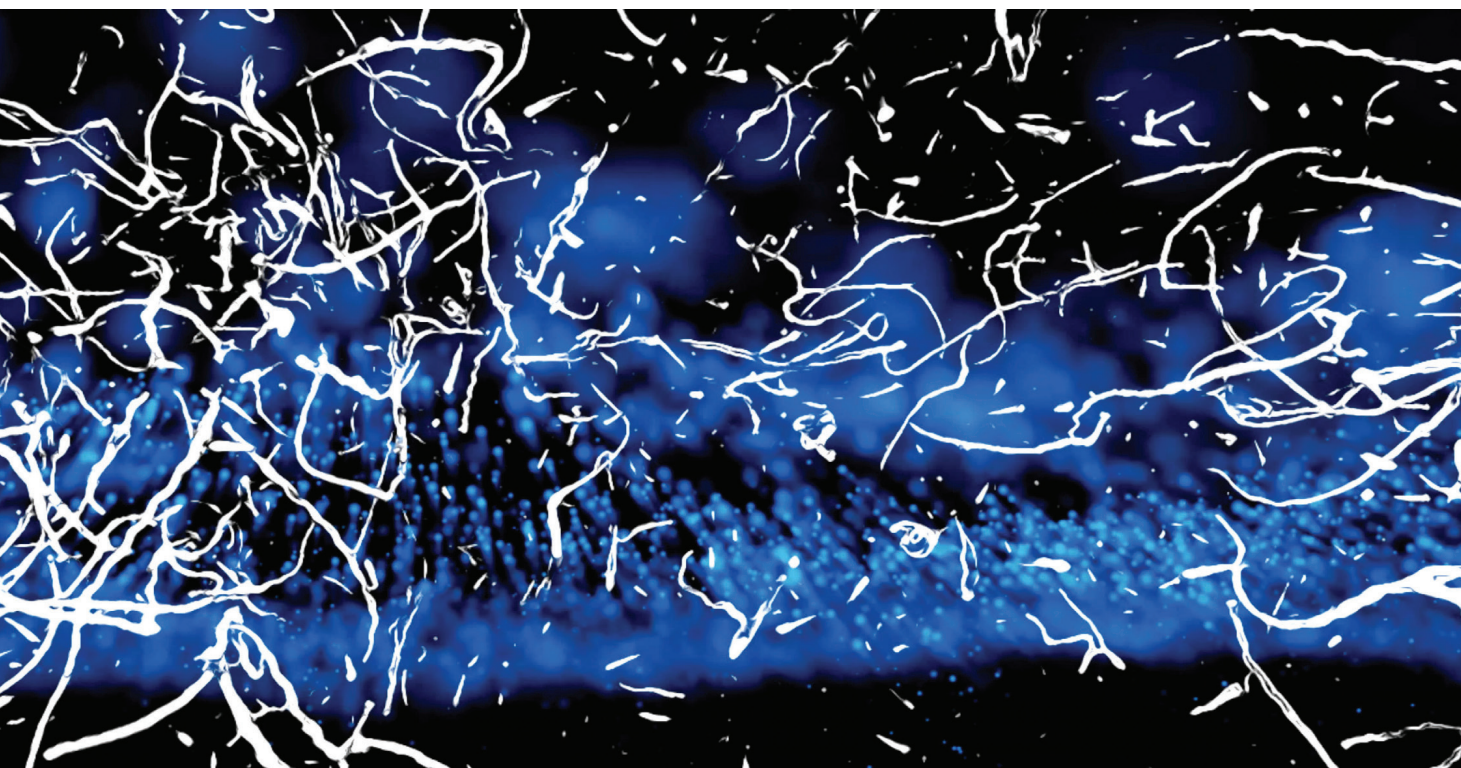


Advancing basic science—The foundation of our future

sciphil.org



**CULTURAL
PROGRAMS OF
THE NATIONAL
ACADEMY OF
SCIENCES**



Blue Dreams Rebecca Rutstein and the Ocean Memory Project

March 15, 2023 - September 15, 2023

An immersive video installation inspired by the intricate workings of microbial networks in the deep sea and beyond.

Generous support for this exhibition was provided by **Schmidt Ocean Institute**.

NAS Building, 2101 Constitution Ave., N.W.,
Washington, D.C. Upstairs Gallery.
Open 9 a.m. to 5 p.m. on weekdays

FOR MORE INFORMATION, VISIT WWW.CPNAS.ORG.

   @CPNAS



THE JOY OF

Why

WITH STEVEN STROGATZ

SUBSCRIBE AND LISTEN



Apple



Spotify



Google



Stitcher



Quanta
magazine

JOIN NAUTILUS AT

SUMMIT OF MINDS

**15-17 SEPTEMBER 2023
CHAMONIX MONT-BLANC
FRANCE**

**Immerse yourself in a 3-day ideas festival
with nature at its heart.**



**SUMMIT
OF MINDS**

Great People, Great Content & Great Outdoors

**Bonus for the adventurous: conquer the French leg
of the iconic Tour du Mont-Blanc pre-event**

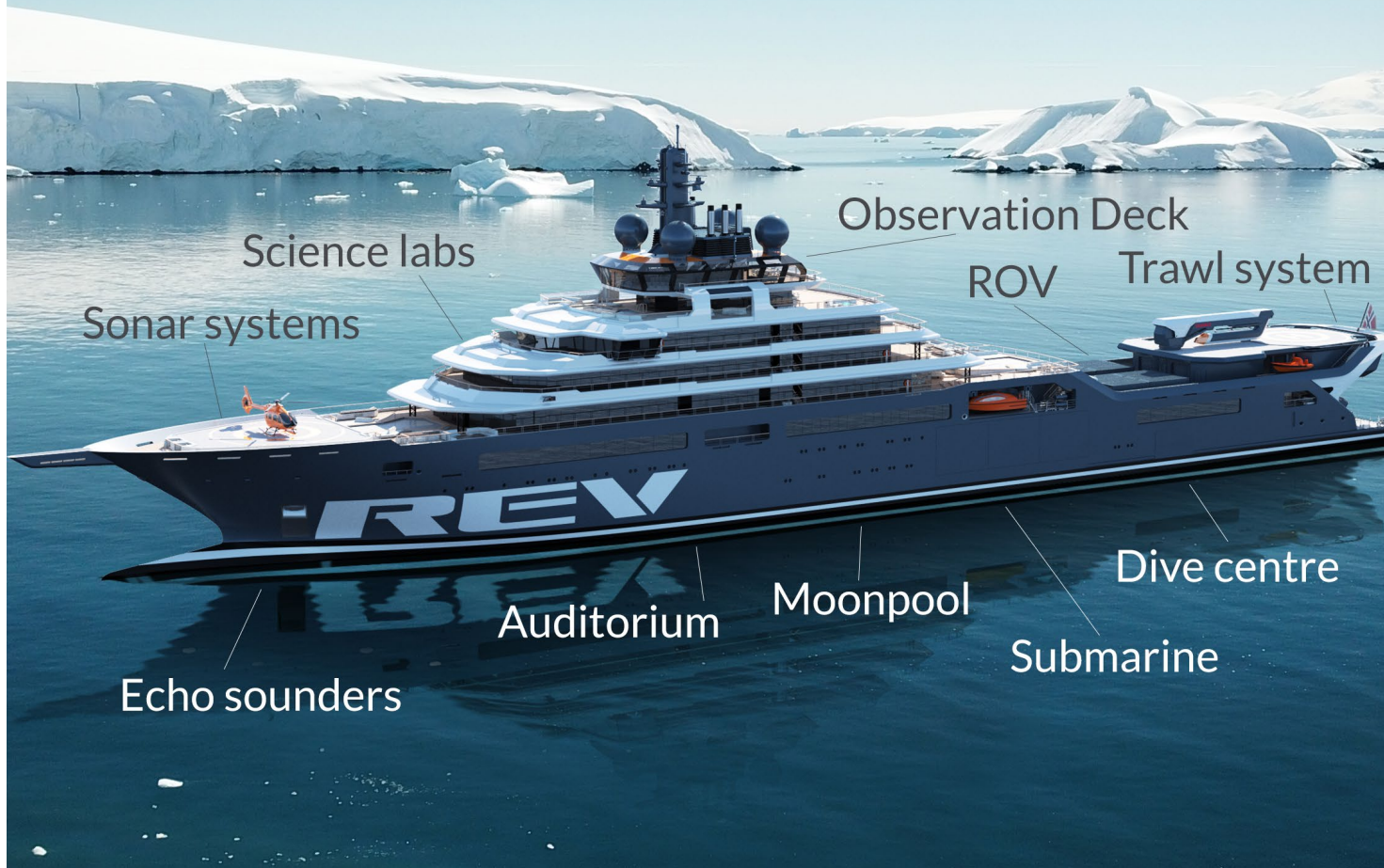
www.monthlybarometer.com

**Register
here**



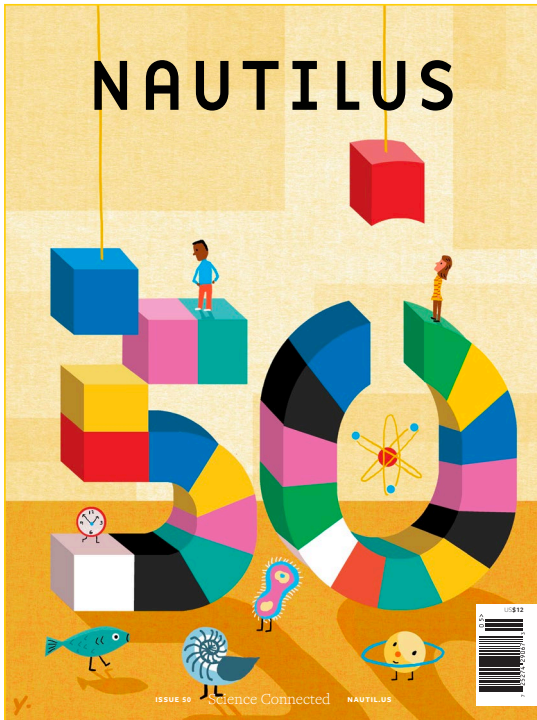
REV Ocean

From curiosity to understanding to solutions



www.revocean.org
One Healthy Ocean

Issue Index



50

2023

MAY / JUNE 2023

Science Connected.
Visit nautil.us/shop for single issues,
subscriptions, and more.

SUBSCRIPTIONS

Address subscription and address changes to:
Nautilus
360 W 36th Street, 7S
New York, NY 10018;
email: order@nautil.us

Visit nautil.us/shop for more information.

POSTMASTER

Send address changes to:
Nautilus
360 W 36th Street, 7S
New York, NY 10018

© 2023 NautilusNext, Inc.
All rights reserved





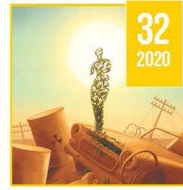
35
2020



34
2020



33
2020



32
2020



31
2020



30
2020



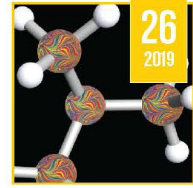
29
2020



28
2019



27
2019



26
2019



25
2018



24
2018



23
NOV/DEC
2017



22
SEP/OCT
2017



21
JUL/AUG
2017



20
MAY/JUN
2017



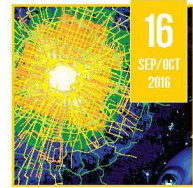
19
MAR/APR
2017



18
JAN/FEB
2017



17
NOV/DEC
2016



16
SEP/OCT
2016



15
JUL/AUG
2016



14
MAY/JUN
2016



13
MAR/APR
2016



12
JAN/FEB
2016



11
NOV/DEC
2015



10
SEP/OCT
2015



9
JUL/AUG
2015



8
MAY/JUN
2015



7
MAR/APR
2015



6
WINTER
2015



5
FALL
2014



4
SUMMER
2014



3
SPRING
2014



2
WINTER
2014



1
FALL
2013

Yo-Yo Ma & Fabiola Gianotti

The renowned cellist and director-general of CERN, the largest particle physics lab in the world, discuss art, science, and truth

YO-YO MA: One of the differences between the two of us, Fabiola, is I grew up in a musical household. I chose the cello. And I'm still trying to figure out why I chose the cello. I thought it was big when I was 4 and I wanted the biggest instrument. I'm still playing, still trying to get it right. You graduated from Milan Conservatory in piano, studied Greek, Latin, and philosophy. The funny thing is you thought you would give up philosophy because you wanted to do something more practical. And so you went into particle physics!

FABIOLA GIANOTTI: I love philosophy but philosophy turns around a question. It loops. In the end, you don't have an answer. I wanted to understand how things work. And there is nothing more fundamental than particle physics because it studies the building blocks of nature. But my music and humanities studies have contributed as much to who I am today as my physics studies. I get asked about why I abandoned humanities and music to study physics. I didn't abandon anything. Music, physics, humanities—they are all part of our creativity, our intrinsic way of being a human being, with our intelligence, our creativity, and our curiosity.

YO-YO MA: In mainstream society, people are always saying, "Science says this, science says that, this is the truth." What is your definition of truth?

FABIOLA GIANOTTI: There is no absolute truth. Of course, there is a scientific truth. The Higgs boson exists. You can do your experiment. You will find it. However, this is an evolving truth. Science is not immutable. Science progresses incrementally. I like to talk about truth as an aspiration. We are talking about scouting and a path that has no end point. I think the path of knowledge will never end. Thank goodness because if we knew everything, there would be no fun in life.



YO-YO MA: This brings to mind something I think about a lot—the idea of truth and perfection. I used to annoy Manny [Emanuel Ax], a pianist with whom I've been playing for more than 50 years. I'd come up with an idea and say, "Manny, we should do this." He'd say, "OK, but there are many ways to do it." I'd get furious because we had to come to a decision about the right thing to do. Only after a long discussion did I understand that he wanted to maintain a viewpoint that encompasses more than what we're doing. Many musicians think, "This is the score. This is perfection." But it's just the composer's intention, and the composer is dead. If the composer were alive today, what would that person say? Someone might say, "How dare you play the Bach cello suites; Pablo Casals already has. How can you be worthy of doing something with that great weight on your shoulders?" I came around to saying, "Look, I may be 27, but the recording is the best I can do during the days I'm recording." It's not permanent. What's permanent is how you grow, because if you stop growing, you're dead. ☺

It's happening.



imagine⁵

Did you know? There's a world of kick-ass green ideas already out there. Now it's time to make them fly. So jump on and join us: we are the eco-impact foundation supercharging real-world change with positive action, solutions and stories.

imagine5.com

Seamaster



PRECISION AT EVERY LEVEL

PLANET OCEAN ULTRA DEEP
Co-Axial Master Chronometer

Since 1948, the Seamaster has served every kind of ocean adventurer from solo free divers to entire racing yacht crews. Continuing this fine tradition is the 45.5 mm Seamaster Planet Ocean Ultra Deep in O-MEGASTEEL. A tribute to the concept watches that survived the deepest place on Earth. Fitting for a timepiece with a water resistance of 6000M, the dial of OMEGA's Co-Axial Master Chronometer is an exact representation of the Mariana Trench, mapped by the Five Deeps team using billions of sonar points. A special seahorse logo on the back marks the 75th anniversary of our oceangoing icon. Signifying our proud past and enduring commitment to delivering new levels of depth-defying precision.

Ω
OMEGA