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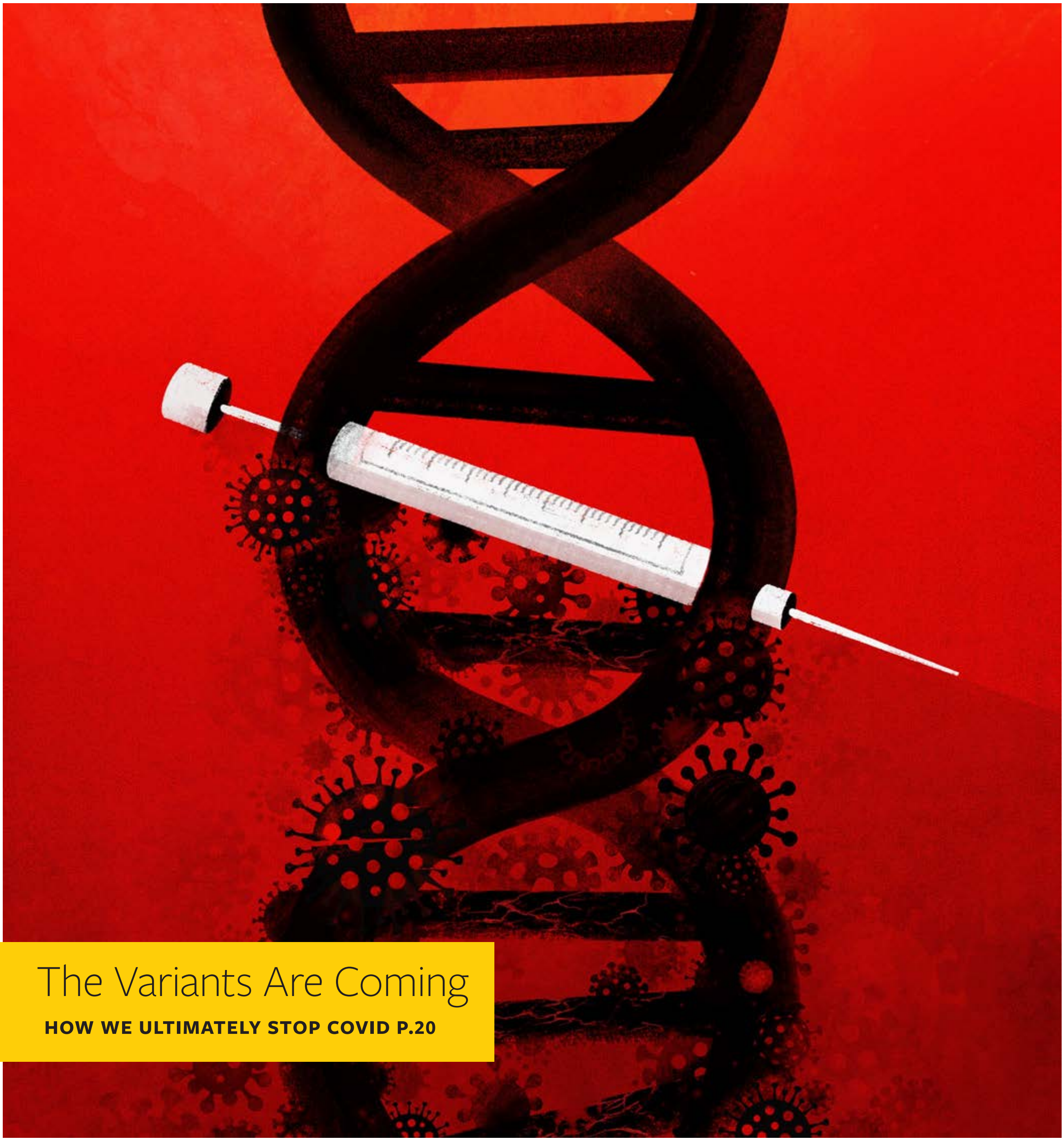
ARE THEY WATCHING US?
Earth is visible to 1,700 stars

DOUBLE HELIX HEIST
A case against Watson & Crick

THE PAIN IS REAL
Inside psychosomatic illness



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ISSUE 40

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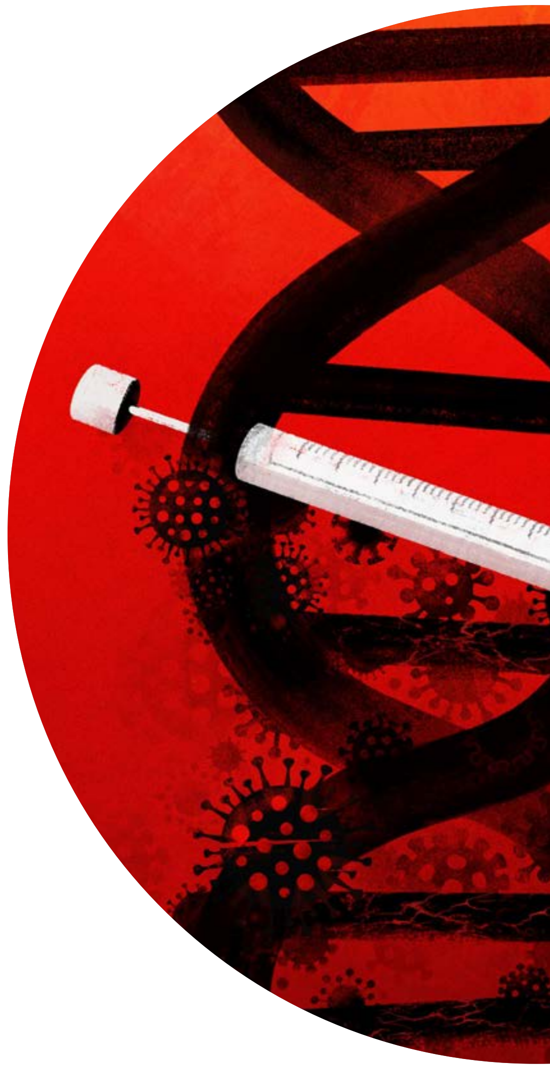

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Features

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NAUTILUS *Next*

The Alien View

BY KEVIN BERGER

ASTRONOMER LISA KALTENEGGER is the founder and director of the Carl Sagan Institute at Cornell University. She counts stars. Not just any stars. She's an expert at spotting stars that may represent the center of habitable worlds. Like our sun, the stars are orbited by planets at various distances. Some of the planets, like Earth, fall into a Goldilocks zone, not too hot and not too cold, and could support life.

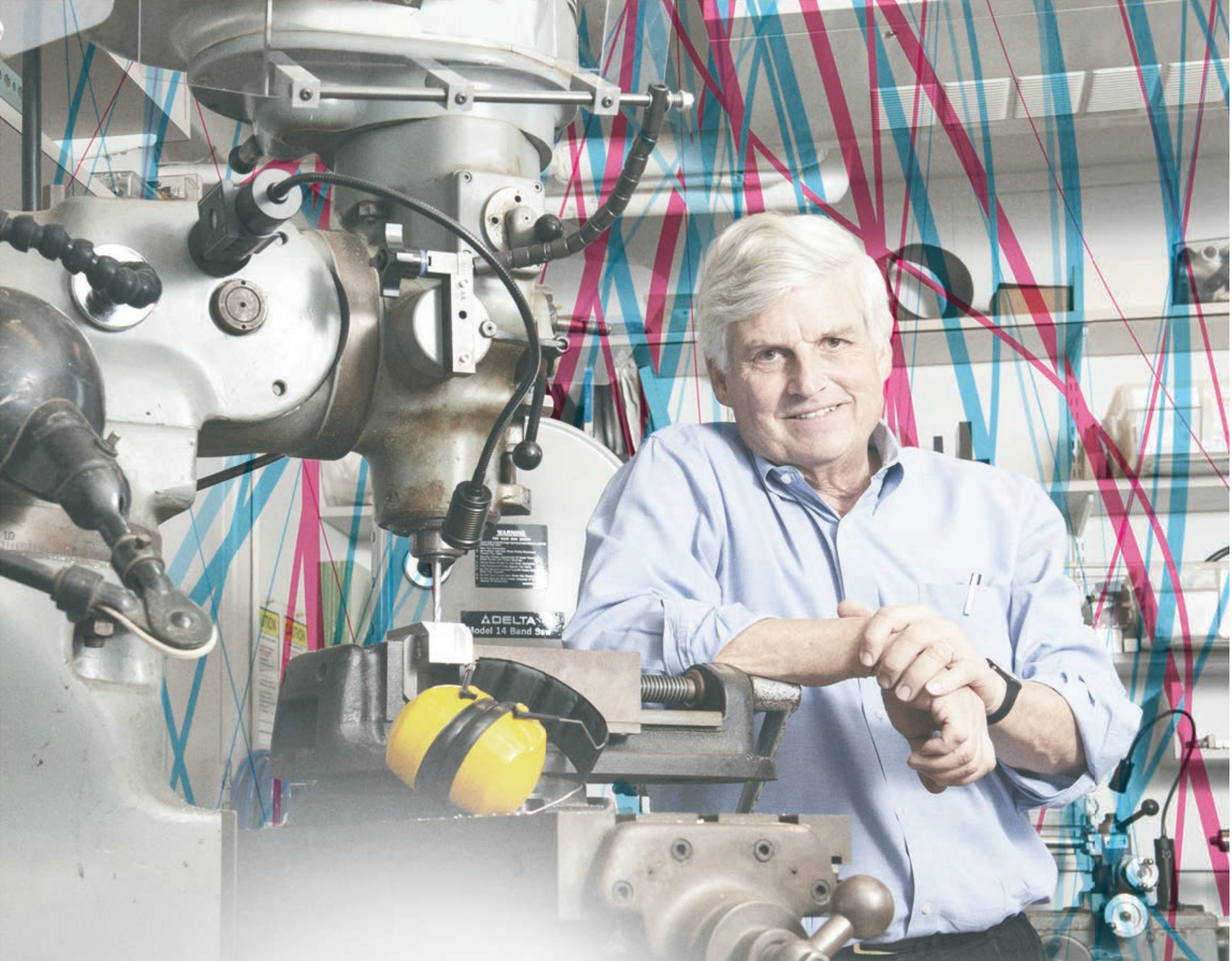
In this issue, Kaltenegger writes that over the past 5,000 years, more than 1,700 stars with orbiting planets have been in just the right place at the right time to have spotted Earth. Three dozen of those planets orbit in a Goldilocks zone, and if they were inhabited, and their beings had awesome telescopes, they could have said to their pals, on a clear night away from their city lights, "Hey, Zecky, come quick, we can see that weird blue planet again."

In fact, Kaltenegger writes, "One thing that an alien astronomer would likely see is our atmosphere. If they had been watching us for a while, they would have seen that we destroyed our ozone layer—but we also managed to fix it. So maybe we would have scored a point on their intelligence scale. Now, of course, they see our atmosphere is becoming concentrated with carbon dioxide and shows no signs of abating yet. But maybe every civilization goes through this, every civilization nearly destroys its habitat before figuring out a way to save themselves from themselves."

Kaltenegger reminds me of an indelible image penned by Lewis Thomas, whose vivid, percipient science writing is the model for every issue of *Nautilus*. "Viewed from the distance of the moon, the astonishing thing about the Earth, catching the breath, is that it is alive," Thomas wrote in the 1970s. "If you had been looking for a very long, geologic time, you could have seen the continents themselves in motion, drifting apart on their crustal plates, held afloat by the fire beneath. It has the organized, self-contained look of a live creature, full of information, marvelously skilled in handling the sun."

Over that very long, geologic time, Earth handled the sun with its atmosphere, trapping the right amount of solar energy to nourish life, releasing the rest. Thomas looked up at the atmosphere and saw a "gleaming membrane of bright blue sky." "Taken all in all," he wrote, "the sky is a miraculous achievement." Or was. We've congested the sky, Earth's membrane, with industrial gases, warming our world beyond natural controls. Is that what the aliens who are watching us are saying to one another? "The atmosphere of the weird blue planet can no longer manage its sun. It's cooked."

Maybe Kaltenegger is right and every civilization figures out how to save itself. It's certainly an optimistic way of looking at the fork in the road we now face, idling in our SUVs, carbon monoxide rising. The high-tech freeway to the right is a direct route, no thinking required, to a coastal land parched of living things; the winding road to the left, requiring thought and care, leads to a different coast, a beach, with sun umbrellas and full coolers. As writers, we're like aliens watching Earth, trying to figure out which way humanity will turn.



Readers Respond

Comments and letters about stories from print issue 39.

"TWILIGHT OF THE NAUTILUS"

Tragic, but not surprising, that this ancient iconic creature, a physical manifestation of the golden ratio, is being driven to extinction by human hunting and habitat destruction. Just one of innumerably many species, all distinct, all special. It points out the existential threat to life, including our own. We have the capacity and the knowledge to overcome this threat. Do we have the will?

—*George Gantz*

Ward's article hit home particularly hard for me. I was born and raised in the Florida Keys, spending most of my free time diving the sub-tropical reefs. One particular reef, Pacific Reef, off North Key Largo, was utterly amazing. The abundance of marine life was astonishing. It was impossible to count all the species of tropical fish and marine "fauna & flora." Such an incredible variety of vibrant colors. It was the closest thing to visiting another world. Or so it was in 1984.

Today Pacific Reef is nothing more than a crumbling fortress of bleached dead coral. A barren world colored in all grayness. The only life left is the passing schools of blue ocean fish. It took Mankind only 27 years to cause the extinction of that magnificent reef. And there is absolutely nothing Mankind can ever do to restore that dead reef.

—*Preston Mitchell*

"PLANTS FEEL PAIN AND MIGHT EVEN SEE"

Our traditional ideas about a hierarchy with humans at the top, then other animals and then plants definitely needs revision. All animals, directly or indirectly, rely on plants for their sustenance—putting plants in the driver seat. We can look upon a lot of animal evolution as adaptations in the service of plants, mostly assisting them with their reproduction. That evolution went along fine until great apes evolved with a propensity for spreading fruit seeds and then we happened—unleashing an unprecedented destructive power onto natural systems. Plants had not intended that, and we will have to learn the hard way who's the boss, in the end who really needs who—and we are slow learners.

—*John Campbell*

"MY PERSONAL QUEST TO STUDY SUPERNOVAE ON MARS"

I really hope you make it to Mars and beyond. A wonderful story, but that left me wanting to shout at all of your distractors over the years: "What is wrong with you people?" Good on you for staying true to yourself.

—*Velo Mitrovich*

"THE INCREDIBLE FIG"

Figs have long been my favorite "fruit." Now, I guess, my favorite multi-species treat! This article is wonderful. Even more wondrous is the story of saving the forest and honoring the Samoan culture with the creation of the canopy walk.

—*Diana Richardson*

Nautilus *welcomes reader responses. Please email* letters@nautil.us. *All letters are subject to editing.*

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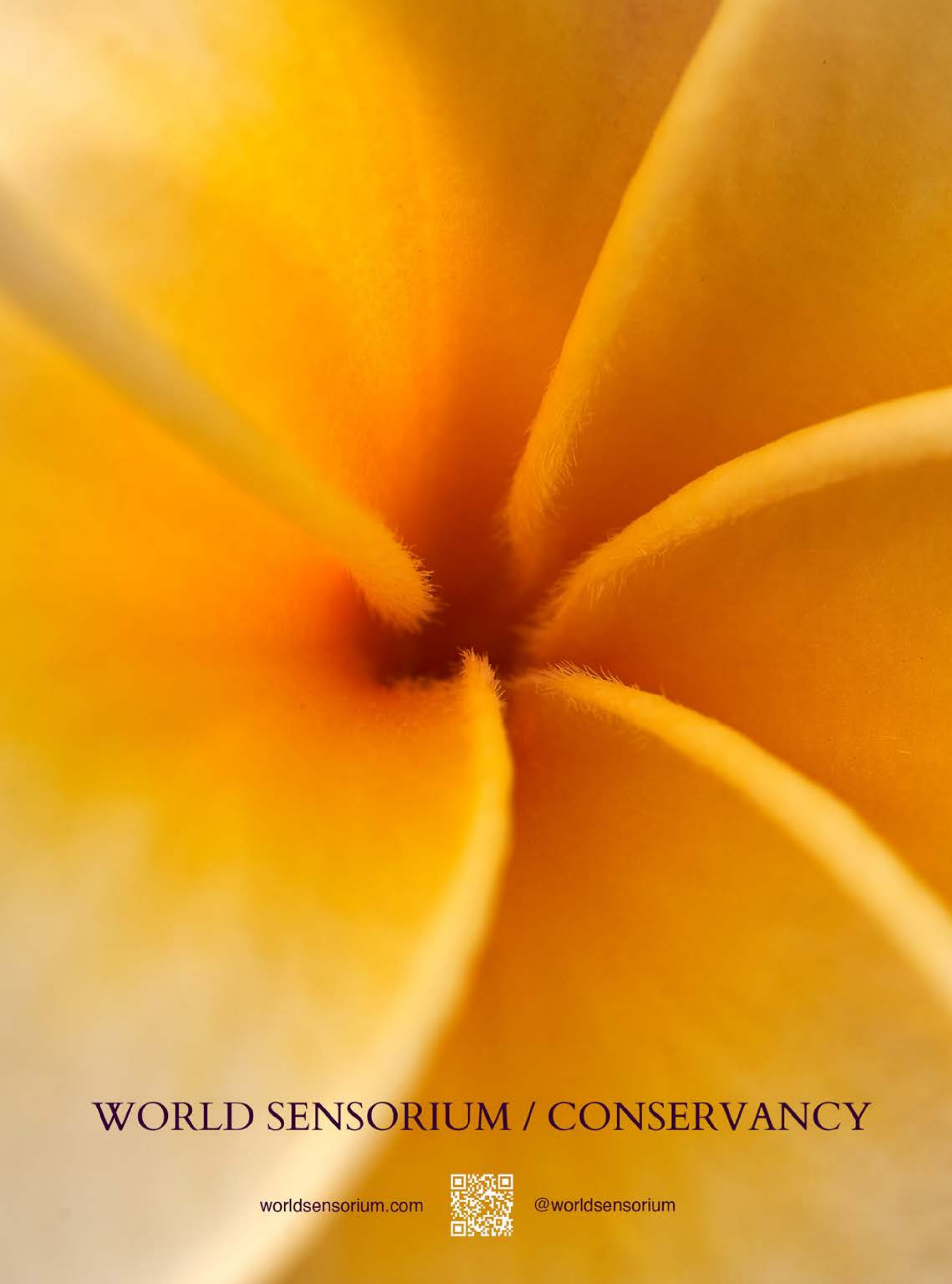

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Preludes

COGNITIVE SCIENCE

The Easy Part of the Hard Problem

HOW DOES CONSCIOUSNESS ARISE? What might its relationship to matter be? And why are some things conscious while others apparently aren't? These sorts of questions, taken together, make up what's called the "hard problem" of consciousness, coined some years ago by the philosopher David Chalmers. There is no widely accepted solution to this. But, fortunately, we can break the problem down: If we can tackle what you might call the easy part of the hard problem, then we might make some progress in solving the remaining hard part.

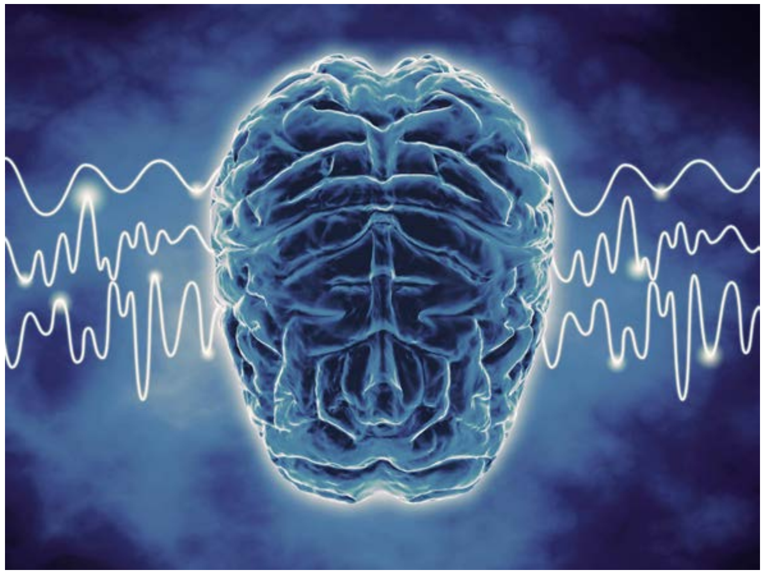

ILLUSTRATION FOREST / SHUTTERSTOCK

This is what I've been up to with Jonathan Schooler, a psychologist at UC Santa Barbara. Since I came up in philosophy, rather than neuroscience or psychology, for me the easy part was deciding the philosophical orientation. Schooler and I duked it out over whether we should adopt a materialist, idealist, panpsychist, or some other position on our way to a complete answer. I'm a card-carrying panpsychist. Panpsychism suggests that all matter has some associated mind/consciousness and vice versa. Where there is mind there is matter, where there is matter there is mind. But for Jonathan, this was far too glib. He felt strongly that this was actually the hard part of the problem. Since he's the Distinguished Professor, we decided to call this philosophical positioning the hard part of the hard problem.

In a 2019 paper, we laid out our General Resonance Theory of consciousness, a framework with a panpsychist foundation that may, at least in theory, provide more complete answers to the full array of questions the hard problem of consciousness poses. The easy part of the hard problem is the "combination problem," also known as the "boundary problem." It's a challenge not only for panpsychist approaches to consciousness, but also materialist approaches: How do parts, like neurons, combine into a whole, a single consciousness? For panpsychists, the question gets more precise: How do micro-conscious entities (whatever they are) combine into macro-conscious entities, like human or cat consciousness?

Our answer, in short, is this: Things that resonate in proximity to each other will, under certain conditions, achieve a shared physical resonance, and thereby a combined consciousness. This shared resonance refers to frequencies, or cycles per second. And it's looking more and more likely, as data comes in, that the key frequencies at issue for human and other animal consciousness is electromagnetic field resonance of various types. By achieving a shared resonance, the bandwidth and speed of information flows increase remarkably, allowing far more energy and information to flow between the constituents. This will, all else equal, result in a new higher-level consciousness. Where before there was a lack of resonance and rather chaotic energy and information flows, now there is a

How do parts, like neurons, combine into a whole, a single consciousness?

smooth transfer of energy and information. We call this "the shared resonance conjecture."

For us, this combination of consciousness, through shared resonance, does not squelch the consciousness of smaller conscious entities—they continue as parts of the new larger whole.

In the context of neural information flows, the specific shared resonance is known as neural synchrony. This kind of synchrony is a well-established phenomenon key for brain processes and human consciousness. Neural firing patterns and electromagnetic field phenomena more generally can achieve synchrony across distant parts of the brain and, thereby, form a larger and more complex consciousness—which leads to our second conjecture: the "boundary conjecture." This states that the boundaries of a consciousness like ours depends on the velocity and frequency of the resonance chains connecting its parts.

What do boundaries even mean in the context of a seemingly immaterial thing like consciousness? What we're referring to is the boundary of the physical energy and information flows that provide the content of consciousness. It's something like axiomatic that for any information (like perceptions or internally generated thoughts) to become part of consciousness, in each moment that information needs to reach the physical geography generating that consciousness. This would be the brain, in the case of humans and other animals (though not exclusively the brain, as we're learning).

If, for example, a gunshot is fired in Mississippi at noon, the sound of that gunshot is not going to be part of the consciousness of a person on the top of Mount Everest only a minute later. That information simply can't reach our person on Everest in that timeframe. Consciousness in each moment is a function of the information that reaches us. But that's only half of it. It's also a function of the processing of that information.

For example, visual information from the retina is highly processed by the retina and the brain before it becomes visual perception in our consciousness. Light falls on the retina, goes through various layers of neurons, is sent down the optic nerve across the brain, and then all the way to the back of the brain where the visual cortex resides. It's then processed further by the visual cortex and then, somehow (we still don't know the full details) that information becomes visual imagery that includes colors, lines, shadows, along with the affect that accompanies our visual perception, such as the pleasure of beholding a beautiful work of art, say.

In this view, consciousness is a snapshot of time, integrating the available information into a single conscious moment. In fact, there is good data showing that the resolution of human visual consciousness is about 1/20th of a second. That means we can perceive about 20 changes in our vision per second. That's pretty good but, of course, the universe moves much faster than this, so we miss an awful lot of what is happening around us.

This temporal resolution is a kind of edge or boundary—a temporal boundary. The "frame rate" of our visual consciousness—about 1/20th of a second—is also the limiting factor for the visual data that can reach our consciousness. If, for example, a visual image of a volcano exploding 20 miles away can't reach our retina within 1/20th of a second, then it won't be included in that snapshot of our consciousness. Light travels in a vacuum 300,000 kilometers per second, so this particular information would have no problem reaching us in 1/20th of a second. But something farther away, like an explosion of the Olympus Mons volcano on Mars, would not, if we were looking through a telescope, reach our retina in 1/20th of a second, so it would not be integrated into our next snapshot of consciousness. It would come in a later conscious moment. So the velocity of information flows, and thus their distance, also are reflected in the boundaries of our consciousness.

I'm happy to report that we are now starting to investigate our theory experimentally, so stay tuned for more on the boundaries of consciousness. It's an exciting time to be expanding these scientific frontiers.

—*Tam Hunt*

BRUCE ROLFF / SHUTTERSTOCK

PSYCHOLOGY

Why We Have Weird Dreams

FOR MANY OF US over the last year, our waking experience has, you might say, lost a bit of its variety. We spend more time with the same people, in our homes, and go to fewer places. Our stimuli these days, in other words, aren't very stimulating. At the same time, our dreams have gotten more bizarre. More transformations, more unrealistic narratives. Why might this be?

Maybe our brains are serving up weird dreams to fight the tide of monotony. To break up bland regimented experiences with novelty. This has an adaptive logic: Animals that model patterns in their environment in too stringent a manner sacrifice the ability to generalize, to make sense of new experiences, to learn. AI researchers call this "overfitting," fitting too well to a given dataset. A face-recognition algorithm, for example, trained too long on a dataset of pictures might start identifying individuals based on trees and other objects in the background. Rather than learning the general rules that it should be learning—the various contours of the face regardless of expression or background information—it simply *memorizes* its experiences in the training set. Could it be that our minds are working harder, churning out stranger dreams, to stave off overfitting?

Erik Hoel, a Tufts University neuroscientist, thinks it's plausible. "Mammals are learning all the time. There's no shut-off switch," Hoel told me. "So it becomes very natural to assume that mammals would face the problem of overlearning, or learning too well, and would need to combat that with some sort of cognitive homeostasis."

What's distinctive about Hoel's idea in the field of dream research is that it provides not only a cause of the weirdness of dreams, but a purpose, too. Other accounts of dreaming don't really address why dreams get weird, or just write them off as a kind of by-product of other processes. They get away with this by noting that truly weird dreams are rare: It's easy to overestimate how weird our dreams really are. Although we tend to remember the weird dreams better, studies show that around 80 percent of our dreams reflect normal activity, and can be downright boring.

The continuity hypothesis suggests that dreams are just replays of plausible versions of waking life. To its credit, most of our dreams, though not most of the dreams we remember, fall into this category. But the continuity hypothesis doesn't explain why we dream more about some things than others. For example, many if not most of us spend an enormous amount of time in front of screens—working, playing, watching movies, reading. Yet how often do you dream of being at a computer? The continuity hypothesis would suggest that the proportion of activities in dreams would reflect their proportions in waking life, and this clearly doesn't happen.

Another set of theories holds that dreams are there to help you practice for real-world events. These theories are generally supported by the findings that sleep, and dreams in particular, seem to be important for learning and memory. Antti Revonsuo, a cognitive neuroscientist at the University of Skövde, came up with two theories of this nature. The threat simulation theory accounts for why 70 percent of our dreams are distressing. It holds that the function of dreams is to practice for dangerous situations. Later he broadened this to suggest that dreams are for practicing social situations in general. These learning theories also provide an explanation for why we believe that what we see in dreams is really happening: If we didn't, we might not take them seriously, and our ability to learn from them would be diminished.

Hoel faces the weirdness of dreams head-on. His hypothesis suggests that weirdness helps keep the brain from doing something that plagues machine-learning researchers: overfitting. Many of the main ways to deal with overfitting introduce noise, often with distorted versions of the input. This, in effect, makes the "deep learning" neural network not so sure about the

Dreams are weird because they need to be.

importance of the idiosyncrasies of the training set, and more likely to focus on generalities that will end up working better in the real world. So, for Hoel, dreams are weird because they're serving the same function: They provide distorted input to keep the brain from overfitting to the "training set" of its waking experiences.

Interestingly, overfitting has been shown to happen in people in laboratory experiments—and sleep removes the overfitting. In short, dreams are weird because they need to be. If they were too similar to waking life they would exacerbate overfitting, not eliminate it. Even the dreams that are realistic usually don't *exactly* match the episodes that happened to us—they're different takes on the activities we do in life.

—Jim Davies

ENVIRONMENT

The Man Who Seduced the World with Whale Songs

ANTTONIART / SHUTTERSTOCK

IT'S BEEN MORE THAN 50 YEARS since biologist Roger Payne brought whale song into the lives of millions via the popular album, *Songs of the Humpback Whale*. At the time, commercial whaling had decimated global whale populations, and Payne's record helped spark the anti-whaling movement. In the late 1960s, Payne was a senior scientist at the Institute for Research in Animal Behavior, studying animal echolocation. His chance encounter with whale song and the stunning subsequent success of the album led him to found the nonprofit Ocean Alliance in 1970, an organization devoted to scientific research and preservation of life in the world's oceans.

Payne is now 86 years old, but no less invested in the plight of whales and other denizens of the seas. I recently met up with Payne at his home in Vermont to chat about his remarkable career.

Your background is in the neurophysiology and behavior of small animals. How did you get involved with whales?

I spent my life studying subjects that could be analyzed in direct and scientific ways, but which could also generate strong emotion. I always felt this was the best way to connect with people and get them to care about the natural world. In my first 10 years of research, all of my research was experimental work—as an undergraduate I studied the directional sensitivity of bats' ears under Donald Griffin; for my Ph.D., I showed that barn owls can locate a mouse in total darkness, based solely on hearing it move; and for a postdoc, I studied how moths detect the approach of a bat, even though each moth ear contains just three sense cells. However, at the same time, I could see the wild world was falling apart and I worried that the kind of work I was doing, though interesting, was not of much value for getting people to see the importance of conserving nature.

So I asked myself: If the only thing I knew about in enough detail to speak with any authority was how animals use sound, what could I do that might make a difference to the grim future of the natural world? And then I thought of whales. I knew they were in grave danger but I knew absolutely nothing about them.

Why did you start recording humpback whales?
Back during the Cold War, I'd heard about a man who'd been listening for Soviet submarines in Bermuda, and had inadvertently captured what he thought were whale sounds. My former wife, Katy Payne, and I went down to Bermuda and met this man, Frank Watlington. He played us one of his recordings, though he did so under the worst possible conditions. We were in the engine room of Frank's research vessel and there was a generator roaring away. Frank took a tape out of his pocket, threaded it across the tape recorder heads, and after listening through his headphones to adjust the sound, he took his headphones off and put them over my ears while shouting, in order to be heard over the roar of the generator: "I think these may be whales!"

In spite of the racket, what I heard blew my mind. It seemed obvious that here, finally, was a chance to get the world interested in preventing the extinction of whales.

If you can move people emotionally, you can also get them to act.

When did it occur to you that they were actually structured songs and not just random noises?
It took time for me to notice, because while the whales do repeat themselves, several minutes often pass before the same stanza comes around again. Also, there are no breaks in their songs. Unlike birds, they sing a river of sound that flows on and on, sometimes for hours. But I finally noticed these were repeat performances after maybe 40 days of using Frank's tape as an alarm clock and waking up to it every morning. I finally realized, "My God, these animals are repeating themselves." And from that point on I started listening to their sounds with far more attention.

You published an analysis of the structure of these songs in *Science*—and then you decided to produce a commercial record aimed at the general public. Why did you decide to make the record?
My idea was, if you can move people emotionally, you can also get them to act. To see if I was right, I started playing humpback whale sounds to friends and other small audiences, and soon it became very clear that these sounds moved people deeply. In fact, some friends wept when they heard them—they're that powerful.

How do you feel now about the serious problems we now face, with climate change, ocean pollution, overfishing, and so on?
I think we're headed in the right direction, but headed there so slowly that unless we can accelerate it by a couple orders of magnitude, I see no hope. However, I have noticed over the years that when humans change in some very basic way, they often change so quickly, all you can do is sit back and watch. A classic example was when the Berlin Wall fell. Nobody knew that anything could happen that fast and also completely shift the whole balance of power—and of possibility.

If we can finally get people interested enough and stimulated enough by what's happening in the world, I believe that humans *will* change, and if we do, that we will change so fast people will hardly be able to keep up with what's happening. And if that starts, then I'm filled with hope.

—*Stuart Firestein*

NEUROSCIENCE

Here's Where Our Minds Sharpen in Old Age

MANY HAVE NOTED that the big contenders in the last two American presidential elections were well into their 70s, raising questions of the mental capacity, going forward, of these potential leaders. But what actually declines—and what abilities might improve, as well as when, how, and at what speed—is a complex issue.

It turns out, according to a new study in *Nature Human Behavior*, that many things improve with age, including some cognitive aspects that had previously been thought to

There are ways we get smarter with age, even in the domain of fluid intelligence.

TRIFF / SHUTTERSTOCK

get worse. John Verssimo, of the University of Lisbon, and his colleagues, looked at a large sample of people between the ages of 58 and 98 and measured their performance on a broad range of cognitive tasks to get a more detailed picture of cognitive aging. They controlled for participants' sex and education, as well as declines in general thinking speed, motor control, and perception, and found some surprising and hopeful results.

The broad strokes of the traditional thinking on lifespan psychology is that people improve in all kinds of cognition until their early 20s. After that, "fluid" intelligence, which includes thinking about new things, thinking quickly, and abstract reasoning, gradually declines until the end of life. "Crystalized" intelligence, on the other hand, which is characterized by wisdom, knowledge, and expertise at things one practices often, continues to improve with age, but with slower returns as we get older. This continues into your 70s, after which things begin to decline.

But, as cognitive psychologists have suggested, some of the aspects of fluid intelligence, such as attention, can be broken down into component parts—like alerting, orienting, and executive control. Alerting covers one's vigilance and preparedness for responding to information coming in. This is important for driving, for example. Orienting is one's ability to select some perceptual information over others based on what's important. Executive control refers to one's ability to inhibit all the information that orienting deemed unimportant, such as the conversations at other tables in a restaurant. These abilities are somewhat independent, and even involve different neural substrates. "Given that these attention/executive functions show neurocognitive differentiation," Verssimo and his colleagues write, "we suggest that they may also show distinct susceptibilities to aging."

Does age affect fluid intelligence broadly, as has been traditionally believed? Or, given that these components are anatomically distinct, might aging affect each one differently?

To find out, Verssimo and his colleagues used a common measurement tool, the Attention Network Test, which provides individual scores for alerting, orientation, and executive function. As expected, older people are slower in general, as measured by their response time in the task. But there were differences in the components: Alerting got worse with increasing age but orienting, and the ability to inhibit irrelevant information, got better. There are ways we get smarter with age, even in the domain of fluid intelligence.

"Thus, our findings, together with other data, argue against theories positing general age-related declines in attention and executive function," the researchers write. "[E]ven though aging is widely viewed as leading to cognitive declines, it in fact yields multifaceted outcomes, including a range of benefits."

Many decisions a president has to make require careful thought, and the important decisions never need to be made so fast that milliseconds make a difference. And given that age tends to increase abilities in vocabulary, language comprehension, reading others' emotions, and knowledge, perhaps American candidates being in their 70s shouldn't worry us too much. At least as far as brain power goes.

—Jim Davies

Starlings in Flight

PHYSICIST-TURNED-PHOTOGRAPHER Kathryn Cooper has spent the past three winters at Middleton Moor in England filming starlings in flight. “Sometimes the flock is so large that it fills the horizon like a curtain of smoke,” Cooper says. Scientists say starlings flock to avoid birds of prey like hawks. Cooper spent hundreds of hours filming the starling to capture the birds’ defensive swerves in the sky, those moments when “chaos briefly changes to order.” She designed a special photographic technique to preserve and accentuate the beauty of their patterns.

KATHRYN COOPER

How the Coronavirus Stays One Step Ahead of Us

As long as there are vulnerable populations, a virus will evolve. That's nature.

BY MEGAN SCUDELLARI

AT FIRST, NO ONE LOOKED TWICE at the new variant. Detected in South Africa in January 2021, the novel coronavirus lineage, called C.1, appeared similar to other variants. It wasn't spreading much, and there was nothing unexpected about its genome.

But viruses evolve fast. Exceptionally fast. Faster than any other organism on Earth—and the new coronavirus is no exception. Ed Feil, a professor at the University of Bath, studies the evolution of pathogens and recently analyzed the coronavirus's mutation rate. "SARS-CoV-2 has experienced roughly the same amount of mutational evolutionary change during the pandemic (proportional to genome size), as humans have since *Homo habilis* first walked the Earth about 2.5 million years ago," Feil explained in *The Conversation*.

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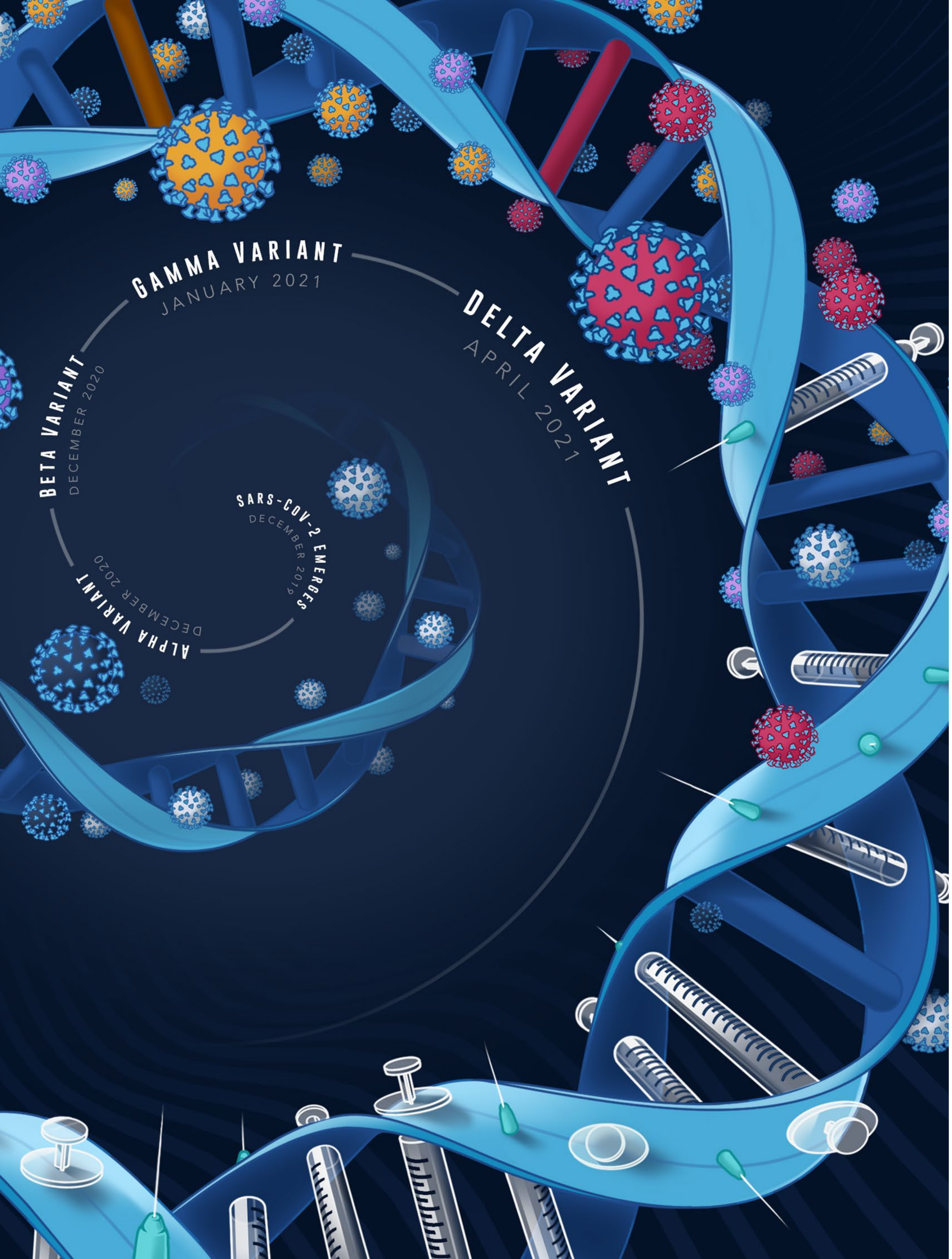

SARS-COV-2 EMERGES
DECEMBER 2019
ALPHA VARIANT
DECEMBER 2020
BETA VARIANT
DECEMBER 2020
GAMMA VARIANT
JANUARY 2021
DELTA VARIANT
APRIL 2021

The question of whether anything else happens in the evolution of this virus is moot. It will.

It's no surprise that just four months later, when South Africa was suffering through a third wave of COVID-19 caused by the highly transmissible Delta variant, a team tracking the virus began detecting a new version of C.1 with extensive changes in its genome. They soon discovered that the variant, dubbed C.1.2, is more mutated than any other major variant sweeping the world. It contains all the key changes found in Alpha, Beta, Gamma, and Delta, as well as additional worrisome changes currently under investigation, including some associated with an ability to evade the immune system.[1]

"This version has so many more mutations," says computational biologist Cathrine Scheepers at the National Institute for Communicable Diseases in Johannesburg, who was part of the team that spotted C.1.2 in May 2021. For now, thankfully, the new variant remains at low levels compared to Delta, says Scheepers, but it has been detected in 10 additional countries. "We're still monitoring it," Scheepers adds.

As a science journalist entrenched in daily COVID-19 news, I've recently noticed some public health officials forecasting Delta as the last major wave of the pandemic. They tend to qualify their remarks with something akin to "assuming nothing else happens." We can't assume that.

SARS-CoV-2 has already morphed to be 40 to 60 percent more transmissible than the Alpha strain, which was already 50 percent more contagious than the original strain, evolving into what some epidemiologists are calling the most infectious disease of our lifetime. The viruses that cause measles and chickenpox transmit slightly more easily than Delta, yet Delta has a faster cycle time, so it whips from one person to another in four days, as opposed at least 10 to 14 days for the other viruses.

The question of whether anything else happens in the evolution of this virus is moot. It will. As long as there are vulnerable populations that can be infected, the virus will transmit, replicate, and mutate, evolving as it spreads. Evolution by natural selection is a law of biology in the same way that gravity is a law of physics; it is a literal force of nature. Continued spread of this virus will lead to further mutation, new variants, more deaths, and an ongoing pandemic.

It's not that humans aren't attempting to manage the evolution of this virus. We are. Every day, vaccine makers, researchers, and governments are tracking viral changes, identifying and containing new variants, and attempting to slow the spread. Our species has undertaken the largest vaccination campaign in history, inoculating 3.9 billion people with at least one dose of a COVID-19 vaccine within two years of the initial outbreak.

Yet we've been unable to contain this pathogen. SARS-CoV-2, an epitome of evolution by natural selection, is an extraordinary opponent. As humans have countless times before and will again, we underestimate the power of nature at our peril.

EACH SARS-COV-2 GENOME is made up of 30,000 individual chemical bases, represented as letters, which store instructions for a suite of proteins used to hijack our cells and produce billions of new viral particles.

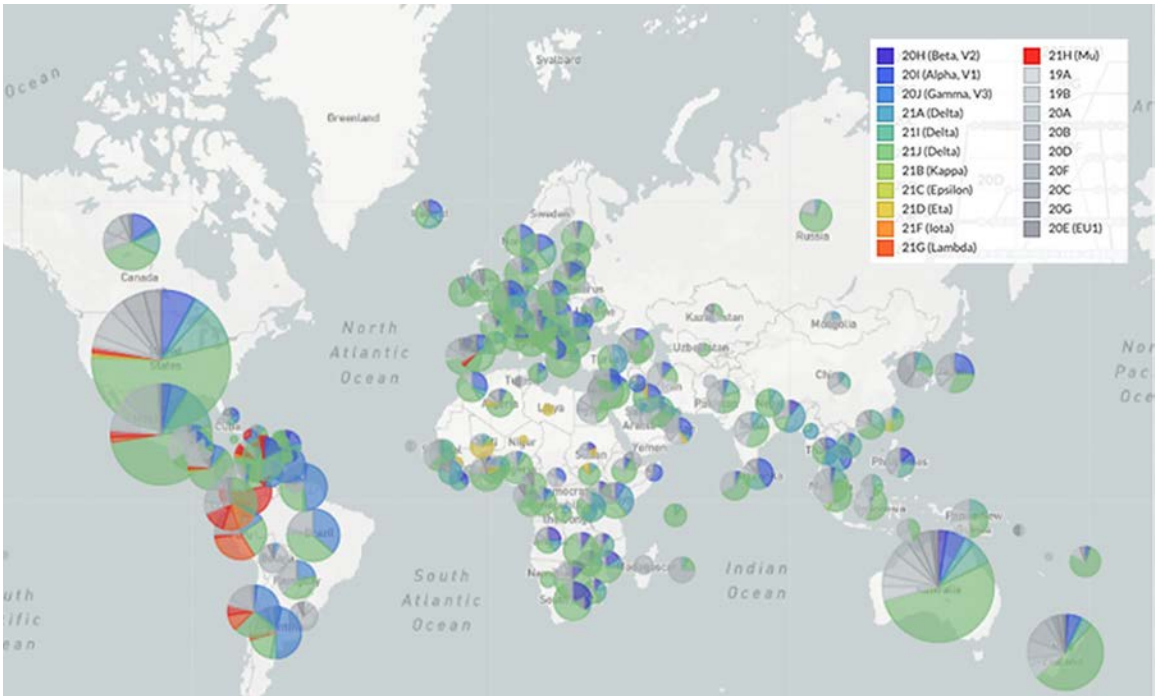
When a person breathes in the virus, the infamous spike proteins on its surface recognize and attach to proteins on human cells. Although the process of infection begins in our throats and lungs, the virus is capable of attacking cells and systems throughout the body, including the heart, blood vessels, gut, kidneys, and more.

Once attached to a cell, the virus shoots its genome—a single, coiled strand of 30,000 RNA bases—into the interior of the cell. There, viral proteins begin remodeling cellular structures to accommodate mass production of viral parts. Like a factory architect and manager rolled into one, the viral genome leads this multifaceted, coordinated effort to make more virus.

Each new viral particle carries a freshly minted copy of the viral genome and is primed and ready to infect more cells. As the particles depart the host cell, they trigger a cascade of events that kill it. As it dies, the cell releases signals to the immune system, like highway flares, alerting the body to danger. In some cases, the resulting immune response to those signals causes more harm than help, including severe lung damage and/or widespread hyperinflammation called a cytokine storm.

Now, remember those freshly minted copies of the viral genome? Mistakes occur during the process of copying RNA, such as one chemical base switched for another, or a small chunk of RNA added to or removed from the original sequence. Better known as mutations, these random changes are typically small, like altering the angle of a brushstroke on a painting, but the ramifications can be great. We commonly think of mutations as bad for an organism, such as a mutation on a hemoglobin gene that causes sickle cell disease. But a mutation can also be neutral or beneficial, such as mutations in a gene associated with insulin production that make a person 65 percent less likely to get diabetes, even when they have risk factors like obesity.[2]

The viral genome gains new mutations, both good and bad, with every infection as new copies of the virus are made. In June, a team at the Weizmann Institute of Science in Israel and collaborators calculated that every



NEXTSTRAIN.ORG

DOMINANT DELTA In most places around the world, the Delta variant (shown in pale green) causes the majority of COVID-19 cases, out-competing the other variants. That's because the variant evolved to spread more effectively than earlier strains. In every population where the virus is spreading, it continues to evolve, and this map will continue to change.

time a human is infected with SARS-CoV-2, their body produces between 1 billion and 100 billion copies of the virus. The team also estimated that 0.1 to 1 mutation is likely to occur within the virus's genome during each infection. If we conservatively agree that each infection adds 0.1 mutations to the viral genome, then among the 425,000 global daily cases, 42,500 mutations occur. That means it's possible that every one of the 30,000 bases in the coronavirus genome is mutated each day.[3]

Thankfully, few of those mutations gain a foothold in viral populations. There's a transmission bottleneck. Even if a mutation occurs within a single infection, that mutation is rarely passed onto another person. According to two recent studies,[4,5] the small amount of virus passed on to others is usually identical to the strain that started the infection. Or, as Vaughn Cooper, a microbiologist and director of the Center for Evolutionary Biology and Medicine at the University of Pittsburgh, eloquently describes to me, "The code that went in is usually the one that comes out."

There is an exception, unfortunately. If the virus spends extended time in a single body—such as in an individual with a weakened immune system, who is unable to clear the virus—it will extensively interact with the human immune system and gain useful mutations to combat it, like going through a bootcamp and coming out stronger. In the past year, for example, scientists have observed SARS-CoV-2 variants gain mutations that change the shape of the spike protein just enough so that protective antibodies—which bind like a lock-and-key to the spike to identify and neutralize it—no longer attach.[6]

As humans have before and will again, we underestimate the power of nature at our peril.

As the virus lingers in one body, new mutations replicate to a point that they are ubiquitous and can be passed to others, slipping through the transmission bottleneck. Evidence suggests the Alpha variant may have first appeared in an immune-compromised individual, and Scheepers believes it was the case for C.1.2 as well.

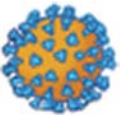
Still, most mutations that accumulate within a single infection are subject to the transmission bottleneck and will be lost. But not all. The virus has spread so exponentially that even rare events occur, so mutations are gained and passed on. Any mutation that gives the virus a competitive edge to survive and reproduce in its environment—known as its "fitness"—is more likely to be passed on and become a permanent part of the genome. That's natural selection in action.

Today, SARS-CoV-2 gains about 2 permanent mutations per month in the global population. This virus is not out of tricks yet.

ON JAN. 5, 2020, virologist Zhang Yongzhen at the Shanghai Public Health Clinical Center in China uploaded the first genome SARS-CoV-2 sequence onto a public database, despite an order from the Chinese government forbidding the publication of any information about the disease. Zhang's example initiated a torrent of sharing worldwide. As of late October 2021, the GISAID Initiative, a free genome-sharing platform launched in 2008 for influenza, has accumulated over 4.7 million shared SARS-CoV-2 sequences.

Those millions of shared genome sequences enable scientists to track viral mutations in near real-time, a first in human history. After establishing a system for detecting mutations, scientists began determining, in excruciating molecular detail, what the mutations do. One of the first major SARS-CoV-2 mutations—and the one that accelerated the spread of the virus around the globe—is D614G, sometimes referred to as "Doug."

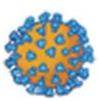
In early April 2020, Doug climbed the charts in the United Kingdom, then began a worldwide tour. Researchers found that as soon as this mutation was introduced into a region, it quickly became the most common form of the virus. The mutation itself is an A to G base change at position 23,403 in the viral genome. That change switches out one amino acid (aspartic acid) in the virus's spike protein for another (glycine). That single swap causes the virus' receptor binding domains—the bits of the virus that hook onto human cells—to stick more often in an up position and latch onto passing cells.



Trying to guess the next mutation is a fool's errand. Trying to prevent it is a worthwhile goal.

Doug was a harbinger of things to come. Today's list of fitness-altering mutations reads like alphabet soup: P681R, L452R, D950N, del144Y, K417N, T1027I, A701V, N501Y, L18F, del242-244, and on. Based on studies conducted around the globe, SARS-CoV-2 mutations are resulting in increased transmissibility of the virus, increased resistance to antibodies (those generated by natural infection and vaccines), and increased severity of disease symptoms.

While some single mutations, like Doug, have clear effects on viral fitness, scientists believe it is primarily combinations of mutations that transform the variants into the juggernauts that they are—especially Delta, which accumulated nine mutations in the spike protein that together enable its wildly increased transmissibility.



Plus, RNA viruses have another method to quickly evolve: They are known for recombination events, in which multiple viruses within a single cell exchange entire sections of RNA, resulting in Frankenstein-like genomes. Now that multiple variants are in circulation, it is possible—even likely, according to some epidemiologists—variants could swap and combine parts into a so-called "super" variant. While recombination events have been detected, they've so far been restricted to small clusters of people, and surveillance efforts tracking them are ongoing.

But bear with me, as it's not all bad news. Over the last 22 months, scientists have identified a silver lining to the virus's evolution. Yes, natural selection is pushing the virus toward increased viral transmission and immune evasion, but *not* toward more severe disease in humans. Severe disease, such as a cytokine storm, is a by-product of infection, and does not appear to help the virus transmit or reproduce any better, so evolution does not select for that trait, says Cooper.

Another bit of good evolution news: Viral populations around the globe appear to be settling on similar mutations. At Fred Hutchinson Cancer Research Center in Seattle, Trevor Bedford, Katie Kistler, and colleagues recently used GISAID's data trove to show that the most successful lineages of the virus gained spike protein mutations associated with improved cell entry, as well as mutations in two other proteins, Nsp6 and ORF7a, implicated in viral replication and evading the innate immune system.[7] In many cases, they found that identical mutations appeared independently around the globe, a process called convergent evolution.

If the virus is converging on certain key adaptations, it is becoming more predictable, which may allow scientists to track and combat it with more confidence. "The good news is we're not seeing entirely new combinations," says Cooper. "That, hopefully, is calming."

TRYING TO GUESS the next dominant mutation is a fool's errand, but trying to prevent it is a worthwhile goal being undertaken by vaccine makers and governments around the world.

The only way to slow the evolution of the virus—and prevent additional mutations and new variants—is to slow viral transmission, says Kistler, a molecular biology graduate student at the University of Washington. "Each infection is a chance for more evolution of the virus," she notes. Whatever we can do to reduce the number of infections—and to take particular care of chronically infected individuals—can help us manage the evolution of SARS-CoV-2.

Our most powerful weapon to slow transmission is vaccination. Different vaccines work in different ways to protect the body against an invader, but the general gist is that a vaccine presents an inactivated form or piece of a virus—something non-infectious—to the body to simulate the immune system against it, like training an army to fight a specific foe.

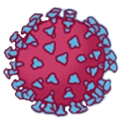
Pfizer and Moderna's mRNA vaccines, for example, contain instructions for our cells to produce the virus's spike protein. After our cells make a bunch of harmless spikes, the body's immune system notices and attacks those foreign proteins and produces T cells and B cells that stick around to fight that virus if it ever enters the body again.

Besides preventing infection, another perk of vaccination is that if a vaccinated person does become infected, they tend to produce a lower amount of virus in their body and they clear the infection more quickly than an unvaccinated person, giving the virus less time to mutate.

It will only be through widespread vaccination that we will slow the evolution of this virus.

When doctors or scientists mention "escape" variants of the virus, they're referring to variants with mutations that can avoid (escape) the protection gained from vaccination or previous infection. The Beta variant, for example, carries mutations—including E484K or "Eek"—that enable it to partially dodge the immune system because antibodies are less likely to bind to the spikes. Back in February 2021, South Africa even stopped using the AstraZeneca vaccine after clinical trials showed it did not provide protection against mild-to-moderate COVID-19 caused by the Beta variant.[8] The spread of the Delta variant also appears to be partially driven by mutations in the spike protein that allow it to evade the immune system better than the original spike.[9]

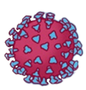
For now, vaccine companies say their approved vaccines are the best protection against all known variants, and most are encouraging booster shots for at-risk groups, as recently approved by the FDA. Further, Pfizer, Moderna, and AstraZeneca are practicing what it would take to quickly produce a vaccine for an escape variant by doing dress rehearsals. They're making vaccines based on current variants, then running through the workflow of getting them tested and approved. "We want to practice all aspects of executing a strain change … so that if we do see a variant out there that truly escapes vaccine immunity, we're ready to go fast," Philip Dormitzer, vice president and chief scientific officer of viral vaccines and mRNA at Pfizer, told *Nature* in October.



For any new variant that crops up, Pfizer and partner BioNTech expect to be able to "develop and produce a tailor-made vaccine against that variant in approximately 100 days after a decision to do so," Kit Longley, a spokesperson for Pfizer, told me.

HUMANITY IS IN A RACE with the virus to vaccinate as many people as possible before the virus can evolve new variants. Most estimates suggest we need 60 to 70 percent immunity across populations to slow or stop transmission. As of late October 2021, 48.7 percent of the world population has received at least one dose of a COVID-19 vaccine, according to vaccination rates estimated by the Our World in Data project at the University of Oxford. That sounds good, right? Pretty close to 60 percent?

Unfortunately, the world is not uniformly vaccinated at that high rate. There is a yawning gap between countries. Wealthier countries have high vaccination rates, and less wealthy countries do not. Overall, only 3 percent of people in low-income countries have received at least one dose, meaning those groups of people are still highly susceptible to infection, and the virus has extensive breathing room to continue to transmit and evolve. PATH, a U.S.-based nonprofit global health organization, calls the rollout



of COVID vaccines "a global emergency," stating that vaccinations for many around the world could be months, even years away.

There are also uneven vaccination rates within single communities, as we've seen in the United States. A patchwork network of vaccination—highly vaccinated populations side-by-side with unvaccinated populations—creates a melting pot for the virus to simmer into something stronger, something worse. Here's the scenario: In unvaccinated pockets of people, high quantities of virus spread. The abundant virus manages to infect a vaccinated person, where it interacts with vaccine-induced antibodies. Novel antibody-evading mutants emerge, then are passed back into an unvaccinated population to increase in number and spread again, this time infecting both vaccinated and unvaccinated populations.

As infections continue, evolution continues. I'm as tired as the next person of wearing a mask, sanitizing, and maintaining distance from others. But it will only be through vaccination and these safety measures—which work against *all* variants of the coronavirus—that we will slow the evolution of this virus.

MEGAN SCUDELLARI is a science journalist for national magazines and newspapers. She has been covering the COVID-19 pandemic since March 2020. Follow her on Twitter @Scudellari.

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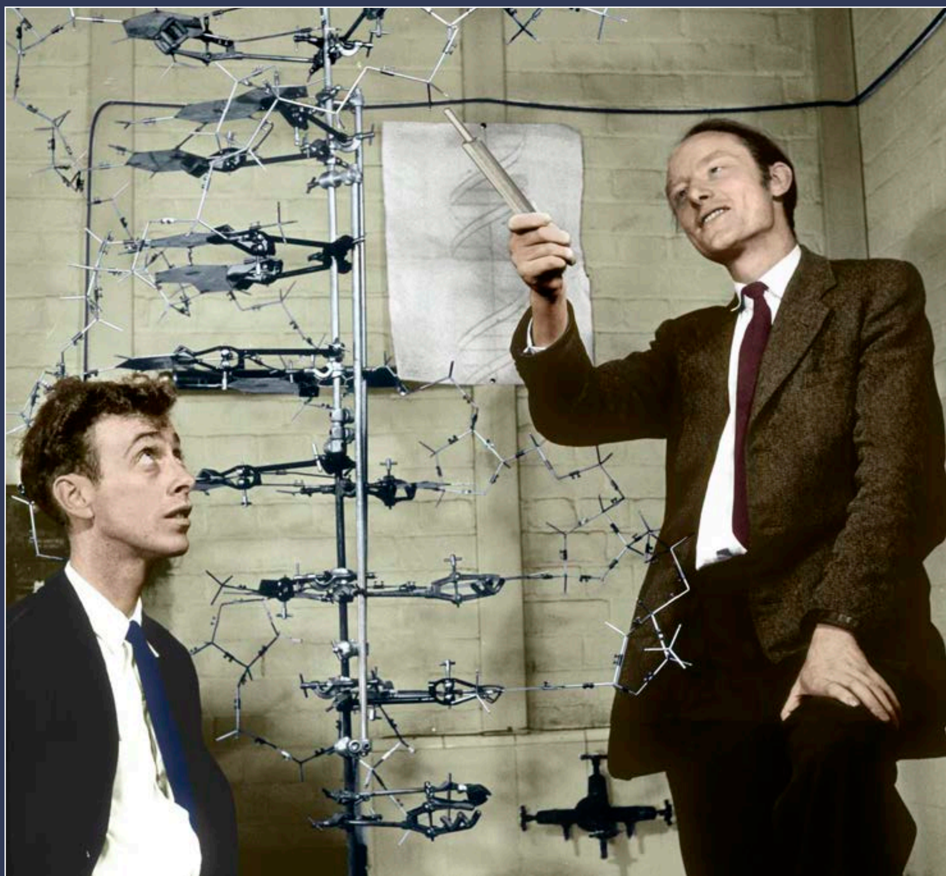

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One of the Most Egregious Ripoffs in the History of Science

A new history of the race to decipher DNA reveals Shakespearean plots of scheming

BY KEVIN BERGER

J**AMES WATSON ONCE SAID** his road to the 1962 Nobel Prize began in Naples, Italy. At a conference in 1951, he met Maurice Wilkins, the biophysicist with whom he and Francis Crick shared the Nobel for discovering the double-helix structure of DNA. Meeting Wilkins was when he "first realized that DNA might be soluble," Watson said. "So my life was changed."

That's a nice anecdote for the science textbooks. But there's "a tawdry first act to this operetta," writes Howard Markel in his new book, *The Secret of Life*, about the drama behind the scenes of the famous discovery.

At the time, Watson was an arrogant, gawky 22-year-old, working as a postdoctoral fellow at the University of Copenhagen. His biology lab director, Herman Kalckar, invited Watson and another fellow in the lab, Barbara Wright, to accompany him to the Naples conference. The confident and competitive Watson didn't think much of Wright's work. It was "rather inexact," he sniped. But Watson was pleased to be invited on the trip. "It should be quite exciting," he wrote his parents.

Watson was bored with most of the presentations at the conference. But he perked up when Wilkins projected images of DNA, captured with X-ray crystallography. The novel image showed the molecule arose from a crystalline structure. Watson later tried to buddy up to Wilkins at a cocktail party, but the socially awkward Wilkins did his best to avoid the bumptious American. Watson thought he had another opening when he spotted Wilkins chatting with his sister, who had joined Watson in Naples. But when Watson approached them, Wilkins slipped away.

DAY IN COURT Howard Markel explains what motivated him to write a new history of the race to crack the DNA code. "For a trained historian of science and medicine to look through all the details, laboratory results, X-rays, and manuscripts, to see who really did what, it was clear to me Rosalind Franklin deserved her day in court."

Nonetheless, Watson's encounter with Wilkins cemented his future. He was determined to discover the precise molecular structure of DNA. He knew he had little chance to join Wilkins at his lab at King's College at the University of London, mainly because Wilkins didn't like him. Watson set his sights on joining the other prominent biology lab probing molecular structures. At Cavendish Laboratory Biophysics Unit at Cambridge, Watson met the intellectually unstoppable Crick, and in two years, the duo built the first sound model of DNA's structure. Their model showed the world how DNA did its thing and shaped the course of biological life.

In *The Secret of Life*, Markel, a distinguished professor in the history of medicine at the University of Michigan, and author of nonfiction books that roll along like novels, relishes explaining the backstory to Watson's and Wilkins' first encounter. Turns out Kalckar was having an affair with Wright and wanted to keep their trysts secret. Watson was invited to Naples "to act as a beard for his boss, to provide cover for his affair with Wright," Markel told me in a recent interview. In *The Secret of Life*, Markel writes, "one cannot help but smile at the paradox that the unraveling of the double helix of DNA began with the coupling of Kalckar and Wright."

That flair of fun wit helps define the tone of *The Secret of Life*. Markel has mounted on his book's stage all the players at King's College and Cavendish Lab who schemed to win favor for their research. Watson is clearly the Iago of the cast. Although Watson doesn't beguile his boss into killing his wife, he does commit character-assassination of Rosalind Franklin. In particular,

CLEISA THOMPSON

Markel told me, Watson's 1968 book, *The Double Helix*, "really did a number on her." Watson's portrayal of Franklin as a raging termagant who one day "in her hot anger" was going to strike Watson for interrupting her, constituted one scene that lived in infamy for years.

The London-born Franklin, a chemist and mathematician, drove herself to perfect X-ray crystallography. The process to determine the atoms that constitute a molecule is painstakingly slow. Crystallographers take hundreds of photographic images of a molecule and apply complex mathematical formulas to determine its final shape and size, informing them which atoms are involved. After the preternaturally meticulous and patient Franklin made a name for herself in crystallography, she was hired to deconstruct DNA at King's College. Wilkins felt DNA was his dominion and Franklin was being hired as his assistant, not an independent scientist with her own mind and methods.

Wilkins and Franklin never got along. Markel amplifies a chorus of their colleagues on why. Watson blamed Franklin for refusing to accept her role as Wilkins' assistant. In *The Double Helix*, he wrote, condescension dripping from his pen, the real problem was "Rosy." Others say Wilkins was jealous of Franklin, intimidated by her, resentful of her for correcting his science in public, or, as Crick wrote, Wilkins "was in love with Franklin," adding, "And Rosalind really hated him … either because he was stupid, which was a thing which always annoyed her, or else something else happened between them." In any event, Crick said, it was a "big love-hate thing between them."

James Watson is clearly the Iago of the cast. He commits character-assassination of Rosalind Franklin.

Markel offers a multifaceted portrait of Franklin. He quotes a letter from Mary Fraser, a biophysicist at King's College, who wrote Franklin didn't want to mix with anybody in the lab. Wilkins was "tall, quiet, gentle, a brilliant experimentalist who normally would never quarrel although he could be stubborn," Fraser wrote. Meanwhile, Franklin's "manner was rather brusque and everyone automatically switched-off, clammed-up and obviously never got to know her. She couldn't be bothered with social chit-chat—it was a bore and a waste of time." Franklin "was too obsessive and took everything too personally—if she had suggested to Wilkins that help was needed with the problem it would have been alright but she didn't want any help."

The incident has been interpreted so often it provides a lesson in history, how the truth of an event can be fractured into many viewpoints.

Markel told me a big part of his inspiration for writing *The Secret of Life* were his two daughters, Samantha, 16, and Bess, 21, who had long been after him to write about Franklin. "They aren't science-y kids," Markel said, but were aware of Franklin. As they understood her story, Franklin was never taken seriously by her male lab mates, was constantly the subject of their sexist gossip, and had her work stolen by them. "I kept saying to them, 'Well, wait kids. You've got to look at the data. You've got to look at the facts. You can't assume. That's not the way we do things,' " Markel said. "And then when I got deep into the research, it was startling. I was like, 'Whoa, this is far worse than I thought in terms of the evidence.' "

Markel is not the first to report one of the worst episodes in the double helix drama—that Wilkins, without Franklin's knowledge, went into a file room and retrieved a photographic print, created by experiments designed by Franklin, and showed it to Watson. The print, "Photograph No. 51," revealed that DNA had a three-dimensional form in the shape of a double helix. "The instant I saw the picture my mouth fell open and my pulse began to race," Watson wrote in *The Double Helix*.

The famous incident was reported by Horace Judson in his 1979 book, *The Eighth Day of Creation*, and presented with rich context by the late biographer, Brenda Maddox, in her 2002 book, *Rosalind Franklin: The Dark Lady of DNA*. It has been discussed in interviews and books by most of the star and supporting characters, including Wilkins and Watson, and Raymond Gosling, a Ph.D. student who worked with Franklin. It provided a key dramatic turn in the 2015 play, *Photograph 51*, which starred Nicole Kidman as Franklin in its London premiere. The incident has been interpreted so often it provides a lesson in history, how the truth of an event can be fractured into many viewpoints.

Markel acknowledges the Rashomon effect of the incident, and the many sources for it (his footnotes throughout the book are thorough), but he himself doesn't see any moral ambiguity in it. "Quite simply, it was *not* all right," he writes. "There exists no ethical standard whereby Franklin's permission did not need to be expressly asked, and because permission was not requested, Wilkins' showing Watson Photograph No. 51 remains one of the most egregious ripoffs in the history of science."

The purloined photograph was the first offense against Franklin. Max Perutz, director of a Cambridge biophysics research unit, which brought together labs working on similar projects, showed an analytical report on DNA by Franklin and Gosling to Watson and Crick, again without Franklin's permission. The paper set off a chain reaction in Crick's brain, Markel writes, and allowed him to comprehend the structure of DNA, with two backbone chains that spiraled around the molecule's inner core, the paired nucleotides. In *The Double Helix*, Watson wrote the rationale for the double helix arose from the notion that biological things came in pairs. "That's just nonsense," Crick later said in an interview. Crick admitted he and Watson "needed a clue to get to that point, and the clue was Rosalind Franklin's data."

Watson and Crick had a vested interest, while they were alive, of burnishing the story of the double helix.

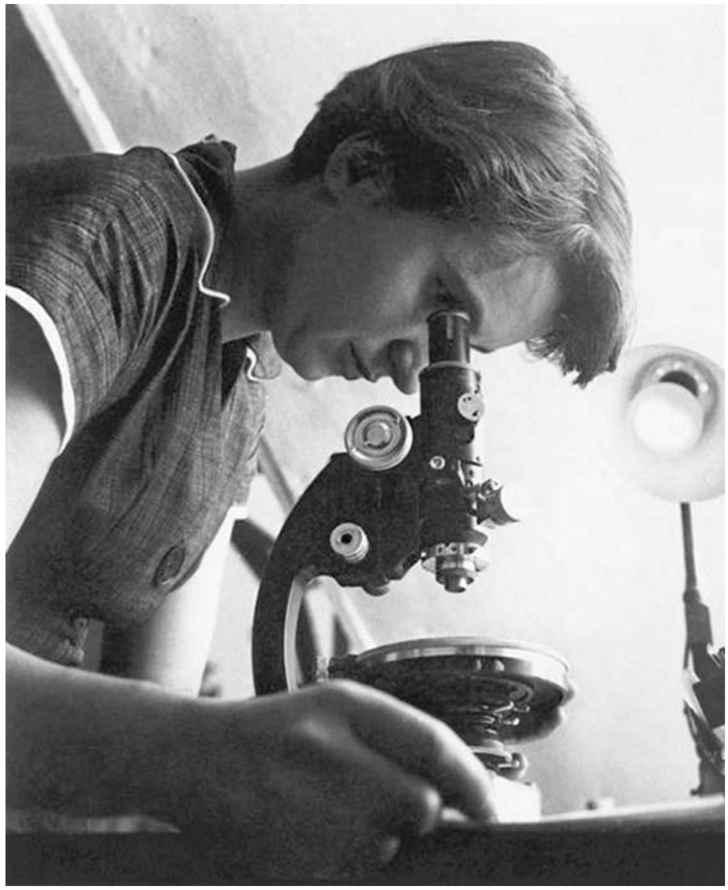
Crick, in Markel's telling, is the more sympathetic of the DNA duo. Franklin, in her 30s, developed ovarian cancer, "which may have been the result of the massive radiation exposure she experienced during her laboratory work," writes Markel, who is a physician. Markel remarks cancer treatment in the 1950s was "akin to medieval medicine," and details the effects of the procedures on Franklin with unflinching clarity, exposing the depths of her suffering. During some of her direst times, Franklin convalesced with Crick and his wife Odile at their house in Cambridge. Franklin's sister, Jenifer Glynn, whom Markel interviewed, said Franklin held no resentment against Crick and Watson. She died in 1958 at age 37. Crick later told Anne Sayre, a friend and biographer of Franklin, that Franklin would have solved the structure of DNA; "with Rosalind it was only a matter of time."

Given Crick's respect for Franklin, his and Watson's final crime against her is exasperating. With "sinister manipulations," Markel writes, Crick and Watson maneuvered to omit a formal citation of Franklin's data in their 1953 *Nature* paper, spelling out their construction of the double-helix model. When they and Wilkins won the Nobel Prize in Chemistry in 1962, neither Crick nor Watson mentioned Franklin in their Nobel Prize lectures; Wilkins mentioned only that she "made valuable contributions to the X-ray analysis."

Markel reviewed the nominations for the 1962 Nobel in Chemistry at the Royal Swedish Academy of Sciences by "some of the most accomplished and well-informed scientists of the day." Not one of them mentioned Franklin. In fact, she was not eligible for the prize, which is not awarded posthumously. Markel, however, did unearth a 14-page report for the 1960 Nobel in Chemistry by Arne Westgren, a professor of chemistry who was well versed in crystallographic studies of DNA and protein. Westgren wrote that Crick and Watson produced an ingenious hypothesis, but those who deserve the most credit for deciphering the DNA molecule are Wilkins, Franklin, and Gosling. A reward for Crick and Watson that bypassed those three "would not be worthy of consideration," Westgren wrote, adding that if Franklin survived "she could well have had claims to receive her part of the prize." Clearly, the Nobel Prize committee wasn't moved. And neither, to this day, is Watson.

In 2018, Markel interviewed Watson. The glow of Watson's public reputation had been extinguished by the racism in his repeated comments that Blacks possessed an inferior intelligence to whites because of genetics. In *The Secret of Life*, Markel shows Watson's racism was always part of his character. When Watson was in Naples in 1951, he wrote to his parents, "The entire city can be described as a slum and the people are wretchedly poor, living in slums which make the Negro section of Chicago look almost pleasant in comparison."

Markel asked the 90-year-old Watson if, in a perfect world, and Franklin were alive in 1962, she didn't deserve to have shared the Nobel Prize with him? "He slowly rose from his chair and, with one finger pointing directly at me pronounced from on high, 'You don't usually win the Nobel Prize for data you can't interpret,' " Markel writes. Markel pushed Watson on the question, saying that Wilkins in 1953 couldn't interpret the data either. Watson, chuckling, replied, "We *wanted* Maurice to get the Nobel, too, because we all *liked* him ...."



THE LONELY SCIENTIST James Watson and Francis Crick chided Rosalind Franklin, here at a microscope, for working alone. "In real time, however, neither Watson nor Crick," writes Howard Markel, "lent Rosalind Franklin anything resembling a helping hand."

MRC LABORATORY OF MOLECULAR BIOLOGY / WIKIMEDIA

Markel told me he was familiar with egos and jealousies running rampant in the production of science. The process was practically always steeped in politics. “There is always competition, in-fighting, and bad behavior, and I could talk your ear off about my own career, where I’ve seen it happen,” Markel said. He offered one example. In the 2000s, he was working on analyzing infectious diseases, notably the H5N1 avian flu virus, with CDC officials. In a 2007 paper, he coined a term for how infections could be curtailed by implementing actions for people to keep a safe distance from one another, the now ubiquitous “flatten the curve.” As Markel was amassing the data, and helping design social measures, he told me, “Everybody was saying, ‘Hurry up, hurry up, we’ve got to get the data, we’ve got to do this, do that.’ I understand the dynamic at play.”

Still, I wondered, how did Markel explain how Watson and the more likable Crick committed the egregious sin of burying Franklin’s role in cracking life’s biological code? “They had a vested interest of burnishing the story of the double helix,” Markel said. “They wanted to control history by telling their story.”

In the beginning of *The Secret of Life*, Markel writes, “Buried under layers of interpretation, explanations, and obfuscation, the discovery of DNA’s molecular structure is one of the most misunderstood whodunnits in the history of science.” At the end of the book, I was pleased to feel that I understood who had done it.

KEVIN BERGER is the editor of *Nautilus*.

Nature’s Fear Factor

Ecologists argue balance is maintained by predators on the prowl

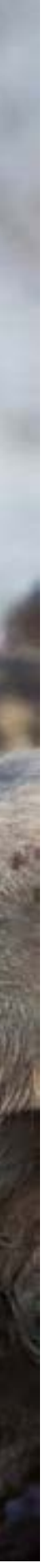
BY BRANDON KEIM

W**HEN MOZAMBIQUE’S CIVIL WAR** ended in 1992, more than 1 million people had lost their lives. Another 5 million were displaced. And the carnage was not restricted to humans: Gorongosa National Park, a 1,500-square-mile mosaic of habitats that was home to a richness of life almost unparalleled on Earth, had become a battlefield. Almost every large animal had been killed by soldiers and either eaten or sold. The destruction was so complete that many people doubted whether recovery was even possible.

Just a generation later, it's a conservation success story, teeming once again with wildlife—but something vitally important is still missing. Apart from lions, other big predators have yet to return. Ecologists studying Gorongosa say that's created an imbalance, and not only because predators regulate populations of their prey by eating them. "The really interesting idea," says Sean B. Carroll, "is that predators can shape behavior."

Carroll is the author, most recently, of *A Series of Fortunate Events: Chance and the Making of the Planet, Life, and You*. He leads the Department of Science Education of the Howard Hughes Medical Institute and is chair of biology at the University of Maryland. Carroll is executive producer of *Nature's Fear Factor*, which tells the story of how ecologists are trying to bring endangered African painted dogs back to Gorongosa. The title refers to how their presence creates what is known as a "landscape of fear"—an ominous-sounding term, but those dynamics may be vital to restoring Gorongosa to its former glory. *Nature's Fear Factor* has been nominated for best long-form film in the "Science in Nature" category at the 2021 Jackson Wild film festival.

I recently caught up with Carroll to talk about the film, the science behind it, and his own life.



STILL FROM *NATURE'S FEAR FACTOR*, A NOVA PRODUCTION BY HHMI TANGLED BANK STUDIOS FOR WGBH BOSTON.

How did you come to be interested in science and in Gorongosa National Park?

I'm an indoor biologist. I made my living studying genes involved in making animal bodies and the evolution of animal body form. But I was a log-flipper as a kid. I liked to flip things over to see if I could find a snake or a salamander, or scamper into ponds to find frogs.

But a weird thing is that the indoor world of biology, the world of cells and genes, doesn't meet the world of ecologists and paleontologists. We're generally housed in different departments. We publish in different journals. We go to different meetings. And as the conversation about the fate of the biosphere grew more intense, I really felt ignorant.

I don't care if people understand the basis of DNA. I'd rather they understand what species do in their communities.

As I started to meet more ecologists, and I learned that even some of the most protected parts of the world were showing major stress, I really wanted to understand more. I was interested in the science; I was interested in first principles. And when I came across work on trophic cascades and keystone species—the fact that predators, or lack of them, have many dramatic and indirect effects on ecosystems—at first I was somewhat embarrassed that I didn't know about it. But then I realized that many other biologists didn't know about it, either. In 2015 I visited Gorongosa for the first time. That wound up in my book, *The Serengeti Rules*, which highlighted those discoveries. I am an enthusiast for the people who are undertaking the hard work of restoring and protecting what we've got left.

You were saying how the principles of ecology are not well-disseminated through the scientific world. Isn't that crazy?

One hundred percent.

Here's a discipline of science devoted to understanding how life on Earth works—and it's off in the corner somewhere.
You can look at a syllabi of general biology courses from high school and college, and often ecology gets short shrift. It just doesn't make any sense. I don't care if people understand the basis of DNA. I'd rather they understand what species do in their communities and start addressing their energies to figuring out how we're going to reverse the tide.

Was there any crosstalk between the world of ecology and your own field?
There was. I learned the story of sea otters in kelp forests on the Pacific coast: Sea otters, by consuming sea urchins, allow kelp forests to flourish. It's what we refer to as double-negative logic. I've seen so much of that inside cells and in molecular circuitry.

I don't think that we're trying to recreate the past as much as reestablish some kind of stable present.

That example captures in a nutshell what people need to know about trophic cascades, but could you elaborate a bit more on the science?
There's a great phrase from a physicist in the early 20th century that the purpose of science is to explain the visible with simple invisibles. I've always loved that.

When you look out your window at nature, or go to a true wilderness, it's overwhelming. It seems chaotic. What are the rules? But if you can discover some of those hidden connections between creatures in the system—if you understand that the otters, by that simple act of consuming urchins, allow the kelp forest to flourish, which is then habitat for fish and invertebrates, and that they're food for birds and seals—then you recognize all the knock-on effects.

What are ecologists trying to accomplish by reintroducing painted dogs to Gorongosa?
Because of the extermination of large predators in Gorongosa, herbivore populations were numerically out of balance. Behaviorally they were doing things that were odd. The film shows how bushbuck—which are named bushbuck because they're often hiding behind termite mounds in little patches of foliage—were wandering out onto the floodplain and eating different food. And then waterbuck, another ungulate, were at least tenfold higher in number than they had ever been.

While lions made a comeback in Gorongosa, other predators were missing. Historically wild dogs had been there, so the thought was to introduce wild dogs. There would be two benefits: One, restoring some of the balance between predators and herbivores. The other, because Gorongosa is a relatively secure place, was that it would be a stronghold for this species in Africa. There are only six or seven thousand painted dogs left. They need some well-protected habitat.

The dogs would be doing something by consuming prey. But the really interesting idea of this landscape of fear is that predators can shape behavior, too. If you have to be aware of danger, you behave differently. In the case of grazing animals, they spend less time grazing. They must have their heads up a lot. They have to think about camouflage or cover. They may not be able to eat some of the foods that would otherwise be available. Evolutionary biologist Rob Pringle describes it as staying in their lane. In Gorongosa, the idea was that a lot of herbivores had gone out of their lanes, and that the presence of predators might knock things back into balance.

Just to push back a little, I can imagine someone saying, "Well, maybe balance is in the eye of the beholder." When we talk about bushbuck doing something unnatural, it just means something we haven't seen them do before. Is it necessarily bad? Is it something that needs to be corrected?
Those are great, tough questions. The perturbations to Gorongosa have happened in the last 50 years and were certainly human caused. Really, Gorongosa was broken. By the year 2000 wildlife was very scarce, and many doubted whether Gorongosa could come back at all. So in many ways, people are thrilled that Gorongosa now abounds with wildlife. But now, you look around and say, "OK, what's going on?"

There's no hyenas where there used to be. There's only one transient leopard that's been seen from time to time. And the sense was that the huge over-proliferation of waterbuck and lack of fear among other antelope were not normal. There was a case for bringing back painted dogs, which we knew were there before, and seeing whether that was both good for the system and good for the dogs.

There's always a risk that we are tinkering too much or trying to get things back to something that may no longer exist and may not be able to exist again. But this experiment was not done in a void. Probably the most famous reintroduction experiment is Yellowstone, where wolves were introduced after a 70-year absence.

Wolves influenced the number of elk and also their behavior. And there are knock-on effects on vegetation and on other creatures like beavers, which have their own influence on the ecosystem. And from both small-scale experiments that have looked at the ecology of fear with spiders and grasshoppers, to various reintroductions of predators in Africa, the sense was that this was something worth trying.

It does seem that our ancestors didn't necessarily try to wipe out all the large predators that might give them trouble from time to time.

Yellowstone is the archetypal example of trophic cascades and landscapes of fear. But it's also been a subject of contention. The criticism is that it's not entirely clear whether changes in elk and beaver populations were consequences of the wolves or other factors. I want to believe in that beautiful, straightforward cascade—but how confident are we that it will happen?
There's lots of moving parts. I don't know that there's any kind of trophic cascade expected from the dogs where the change in bushbuck diet is going to yield a major change in Gorongosa vegetation. It's going to change bushbuck diet, which might change the way bushbuck compete with some other browsers and grazers, which might influence the ability of some other things to get better established.

PREDATOR PILE
Ecologists are trying to bring endangered African painted dogs, seen here as a pile of puppies, back to Gorongosa National Park.

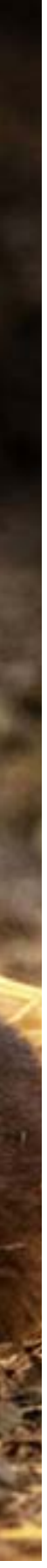
HHMI TANGLED BANK STUDIOS

I don't know what they expect to see in terms of major vegetative or hydrology changes in Gorongosa, the way that's alleged to have happened in Yellowstone. But you certainly now have another predator. And these are coursing predators, which are different than ambush predators like lions. Painted dogs and lions are divvying up territory because they are natural enemies.

I would imagine that as lions and painted dogs apportion the landscape to themselves, then you would get different kinds of vegetation depending on their different predation influences. And even if it's not this big dramatic Yellowstone-of-our-dreams cascade, it can still be a good thing, right? It doesn't need to be all that complicated to be positive.

I think that's a good outlook on it. I don't think that we're trying to recreate the past as much as reestablish some kind of stable present. In the film, we also wanted to bring attention to the whole body of thought around the landscape of fear. Fear has been a part of ecosystems for very long periods of time. It may be an even stronger factor than consumption in terms of regulating animal numbers and the balance between various populations. Hopefully that's a revelation people take away from the film.

I wanted to ask about that. There has been debate among researchers studying landscapes of fear over how to define the term. Some people



emphasize the felt experience of fear by prey. Others say it's not so much about living in fear, but rather a mental map of risk perception. Like, there's some neighborhoods I don't go to because bad things would happen to me—but I'm not in constant fear of them. How do you think about what a landscape of fear is?
Creatures have to be aware of their surroundings. And how vigilant they are may depend on their encounters with predators. If they're in a herd, obviously there's lots of mechanisms that animals use to warn other animals that there may be danger afoot. So it's not necessarily fear where cortisol is at the maximum and they're just living stressed-out lives. I don't know that we know if it's physiologically a constant state of fear as much as it is a state of awareness. Awareness that may be shared, for example, among all the members in a herd. And it's just woven into the fabric of their daily lives. It could just be a landscape of awareness—but that's not a compelling movie title.

Going in the other direction with fear: What about the human fear of big, scary dogs? Wherever people talk about reintroducing or protecting large predators, there's always ecological and logistical challenges, but ultimately the greatest challenge may be sociological.
The dogs apparently don't have a lot of interest in human habitats. That's not where their prey is. The hope is that dog conflict will be relatively minimal. Unless there's a lot of livestock there's not a big attraction, and the livestock densities are not that great. There's more pickings inside the park. I'm under the impression that the dogs are not interested in humans. But if that were to change, we could have a crisis.

I've got a folder on my computer of stories involving cultures of coexistence between humans and big predators. Do you think something like that could emerge to help people and painted dogs live alongside one another?
As I understand, in Mozambican culture, people do identify with animals. There may be a better word for it, but the idea is that there's a strong connection with certain animals. I would love to know how deep that goes in human history. It does seem that our ancestors didn't necessarily try to wipe out all the large predators that might give them trouble from time to time. Perhaps the understanding was that they were a part of the world, and you just didn't do that. But as we as a species moved across the world, we found wolves and bears and lions and tigers and everything inconvenient—and we nearly didn't understand their place in these ecosystems. There's been a huge rethink of the place of apex predators in ecosystems. Hopefully that rethinking is in time to reverse the tide.

BRANDON KEIM is a science and nature journalist. He is presently working on *Meet the Neighbors*, a book about what understanding animals as fellow persons means for human relations to wild animals and to nature.

Why These Children Fell into Endless Sleep

A neurologist makes an emotional visit to understand "resignation syndrome"

BY SUZANNE O'SULLIVAN

BERNHARD KEIL, *YOUNG GIRL SLEEPING*

I HAD BARELY STEPPED FOOT over the threshold and I already felt claustrophobic. I wanted to turn back. People shuffled into the room in front of me, while somebody else stood directly behind me, a little too close. It felt hard to escape.

I could see Nola lying in a bed to my right. She was about 10 years old, I guessed. This was her bedroom. She was wearing a pink dress and black and white harlequin tights. Her hair was thick and glossy, but her skin was pale. Her lips were an insipid pink, almost colorless. Her hands were folded across her stomach. She looked serene, like the princess who had eaten the poisoned apple.

When this started happening, it was unprecedented. Nobody knew what to call it. Was it a coma?

I had come knowing what to expect, but somehow I still wasn't prepared. Five people and one dog had just walked into the room, but Nola didn't have so much as a flicker of acknowledgement for any of us. She just lay perfectly still, her eyes closed, apparently peaceful. The only certain sign of illness was a nasogastric feeding tube threaded through her nose, secured to her cheek with tape. The only sign of life, the gentle up and down of her chest.

"She's been like this for over a year and a half," Dr. Olssen said, as she bent to stroke Nola gently on the cheek.

I was in Horndal, Sweden, a small municipality a hundred miles north of Stockholm. Dr. Olssen was my guide. She was a slim, deeply tanned woman in her 60s, with a distinctive triangular white patch in the fringe of her light brown hair. She had been caring for Nola since the child had first fallen ill, so she knew the family well. Dr. Olssen's husband, Sam, and their dog had also come with us. All three were regular visitors to Nola's home—a small but spacious apartment that overlooked a leafy playground—and knew their way around it.

From the front door, they had led me promptly and directly to Nola's room. One moment I was outside in the midday sunshine, then suddenly I was in the twilight of a sleeping child's room. I had an impulse to open the curtains. Dr. Olssen must have felt the same, because she walked to the window, drew the curtains aside and let the light in. She turned to Nola's parents and said, "The girls have to know it's daytime. They need sun on their skin."

"They know it's day," her mother answered defensively. "We sit them outside in the morning. They're in bed because you're visiting."

This wasn't just Nola's room. Her sister, Helan, who was roughly a year older, lay quietly on the bottom of a set of bunk beds to my left. From where I stood, I could only see the soles of her feet. The upper bunk—their brother's bed—was empty. He was healthy; I had seen him peeping out from around a corner as I walked to the girls' room.

Dr. Olssen turned and called to me: "Suzanne, where are you? Aren't you coming to say hello? Isn't this why you're here?"

She was hunkered down by Nola's bed, brushing the child's black hair to one side with her fingers. I stood wavering near the threshold, struggling to take the final few steps of a long journey. I was pretty sure I was going to cry, and I didn't want the others to see. I wasn't ashamed; I am human and upsetting things upset me. Sick children in particular upset me. But this family had been through so much and I didn't want to put them in the position of having to comfort me. I fixed a smile on my face and approached Nola's bed. As I did, I glanced over my shoulder at Helan, and was surprised to see her eyes open for a second to look at me and then close again.

"She's awake," I said to Dr. Olssen.

"Yes, Helan's only in the early stages," she replied.

The lucky ones were sick for a few months, but many didn't wake for years. Some still haven't woken.

NOLA AND HELAN are two of the hundreds of sleeping children who have appeared sporadically in Sweden over a span of 20 years. The first official medical reports of the epidemic appeared in the early 2000s. Typically, the sleeping sickness had an insidious onset. Children initially became anxious and depressed. Their behavior changed: They stopped playing with other children and, over time, stopped playing altogether. They slowly withdrew into themselves, and soon they couldn't go to school. They spoke less and less, until they didn't speak at all. Eventually, they took to bed. If they entered the deepest stage, they could no longer eat or open their eyes. They became completely immobile, showing no response to encouragement from family or friends, and no longer acknowledging pain or hunger or discomfort. They ceased having any active participation in the world.

The first children affected were admitted to hospital. They underwent extensive medical investigations, including CAT scans, blood tests, EEGs (electroencephalograms, or brainwave recordings), and lumbar punctures to look at spinal fluid. The results invariably came back as normal, with the brainwave recordings contradicting the children's apparent unconscious state. Even when the children appeared to be deeply unresponsive, their brainwaves showed the cycles of waking and sleep that one would expect in a healthy person. Some of the most severely affected children spent time under close observation in intensive-care units, yet still nobody could wake them. Because no disease was found, the help doctors and nurses could offer was limited. They fed the children through feeding tubes, while physiotherapists kept their joints mobile and their lungs clear and nurses made sure they didn't develop pressure sores through inactivity. Ultimately, being in hospital didn't make much difference, so many children were sent home to be cared for by their parents. The children's ages ranged from 7 to 19. The lucky ones were sick for a few months, but many didn't wake for years. Some still haven't woken.

When this started happening, it was unprecedented. Nobody knew what to call it. Was it a coma? That word wasn't quite right; it implied deep unconsciousness, but some of the children seemed to have awareness of their surroundings. Tests showed that their brains responded to external stimuli. Sleep certainly wasn't the right word either. Sleep is natural, but what was happening to the children was not—it was impenetrable. In the end, Swedish doctors settled for "apathy." The Swiss psychiatrist Karl Jaspers described apathy as an absence of feeling with no incentive to act. It is a total indifference to pain and to pleasure, a complete freedom from emotion of any kind. That description fitted with what the doctors were seeing. After a few years, apathy was converted to an official medical designation—*Uppgivenhetssyndrom*—literally meaning "to give up." In English, this became "resignation syndrome."

DR. OLSSEN ROLLED UP Nola's dress, exposing her bare stomach and revealing that she was wearing a nappy under her tights. Nola didn't resist the intrusion. Her hand lolled over the side of the bed, the dog nudged it with his nose, but she didn't respond to that either. Dr. Olssen pressed on her stomach and listened to it with a stethoscope, and then listened to her heart and lungs.

Dr. Olssen rolled up Nola's sleeve and tested her blood pressure. The child didn't flinch. "One hundred over seventy-one," Dr. Olssen told me, which is normal for a relaxed child. She lifted Nola's arm to show me how limp it was. The arm dropped unceremoniously onto the bed when let go. She turned to me and asked me to carry out an examination.

I hesitated. I am a doctor, but I wasn't Nola's doctor. I looked at her mother, who was still standing at the end of her bed. We had no shared language. What brief conversation we had went through Dr. Olssen. She seemed happy for me to be there, but I longed to talk to her directly, without a go-between. There were so many languages, and such varied dynamics between the people around the bed, that I found it hard to read the room.

Dr. Olssen raised her eyebrows as she waited for me to answer. "What did you come here to do?"

Good question. Suddenly, I didn't know why I was there. I saw patients a little like those girls all the time in my job. What made them special enough for me to feel the need to visit, and what did I hope to gain?

"Come on." Dr. Olssen coaxed me forward. "You're a neurologist, aren't you?"

I remembered why I was there. Dr. Olssen was a retired ear, nose, and throat doctor, desperate to help the children and support the families. She'd welcomed me because I was a neurologist. She hoped that I could find an explanation for what had so far been inexplicable; that I would interpret the clinical signs and, by doing so, legitimize the girls' suffering and convince someone to help them. That Nola had been lying in bed for a year and half without eating or moving had not been deemed impressive enough to get her the help she needed. A neurologist, a specialist in brain disease, would add weight to the diagnosis, or so Dr. Olssen hoped.

That's how modern medicine works: Disease impresses people; illness with no evidence of disease does not. Psychological illness, psychosomatic and functional symptoms are the least respected of medical problems.

"Examine her," Dr. Olssen said again.

Reluctantly, I took Nola's legs in my hands and felt the muscle bulk. I moved her limbs to assess mobility and tone. Her muscles felt healthy, not wasted. Her reflexes were normal. Apart from her unresponsiveness, there was nothing abnormal.

I tried to open Nola's eyes, as Dr. Olssen had, and felt her resist. Dr. Olssen asked me to palpate the muscles in her cheeks. In contrast to every other muscle in her small body, these were rigid. Her teeth were clenched shut—another piece of evidence against passive, apathetic restfulness.

I looked behind me, at Helan. The dog was staring at her; Sam, Dr. Olssen's husband, was holding him by the collar to keep him in check. Helan looked past the dog, at me. I smiled at her again, but she just stared back blankly.

Dr. Olssen followed my gaze. "Nola was the first to get sick. Helan only got symptoms after the third asylum refusal, when the family were told they had to leave Sweden."

RESIGNATION SYNDROME is not indiscriminate. It is a disorder that exclusively affects children of asylum-seeking families. These children were traumatized long before they fell ill. Some were already showing very early signs of illness when they arrived in Sweden, but most only began to withdraw when their families were faced with the long process of asylum application. Nola had come to Sweden when she was two and half—at least, that was the official age she was given on arrival, by a man she had never met before. Nola's family fled the Turkey-Syria border when she was a toddler, and their journey to Sweden had been uncharted. Somewhere in transit, their papers were destroyed. Arriving at the Swedish border, they had no proof of who they were or where they came from, so the authorities estimated their ages. They determined Nola to be two and a half, Helan to be three and a half, and their younger brother to be one.

Nola's family are Yazidi, an ethnic-minority people indigenous to Iraq, Syria, and Turkey. The worldwide number of Yazidi is estimated to be fewer than 700,000. Walking through the house to Nola's room, I had seen a picture of a peacock hanging on the wall, dark blue with his open tail feathers displayed behind him. Nola's father had a peacock tattoo on his arm. The Peacock Angel is central to the Yazidi religion. They believe he was created by the supreme deity and that he governs Earth. The stories told about

TRAUMATIZED Before Nola and her sister Helan succumbed to sleeping sickness, their family, like many Syrians who passed through refugee camps, fled their war-torn country. The girls' mother had been assaulted and shamed. "These children were traumatized long before they fell ill," writes Suzanne O'Sullivan.

SLAWOMIR KOWALEWSKI / SHUTTERSTOCK

the Peacock Angel have links to the beliefs of other religions. He is said to have taught Adam and Eve. He is also the reason that the Yazidi have been referred to as devil worshippers. Some say that, because the Peacock Angel rebelled against God and was cast into hell, he therefore represents Satan. It is this sort of interpretation of their beliefs that has seen the group subjected to centuries of persecution. In the 19th and 20th centuries alone, they were subjected to 72 genocidal massacres, while in the 21st century they have been the victims of many bloody attacks, first in Iraq and more recently in Syria. Women and children have been gang-raped and taken as sex slaves. In the region of 70,000 Yazidi people are said to have sought asylum in Europe.

Nobody can prove what Nola and her family suffered before they came to Sweden—I can only tell you the story I was told. The family used to live in an underdeveloped rural village in Syria, near the border with Turkey. Most of the people had no running water, but they had a communal well to which Nola's mother made daily trips. One morning, when she went to get water, she was grabbed by a group of four men, who dragged her into the woods and assaulted her. When she came home and told her family what had happened, her father was furious with her for bringing shame on

That's how modern medicine works: Disease impresses people; illness with no evidence of disease does not.

them. Over the next weeks, there were heated arguments between Nola's grandfather and her parents. In one of them, Nola and her siblings were in the room when their grandfather threatened to kill their mother. At the time of the assault, Nola's mother had been pregnant with her fourth child, but she soon miscarried.

With threats to the family from inside and outside the home, staying in Syria was untenable and the family were forced to flee. Arriving in Sweden with no papers, unable to speak Swedish and unable to read a Latin-script alphabet, they struggled to communicate and had no way of verifying where they'd come from or who they were. They immediately applied for asylum, but asylum depended on them proving they had been persecuted in their country of origin and convincing the authorities that it was unsafe for them to return.

At the time, Sweden took a generous stance on asylum seekers, and Nola's family were given temporary permission to stay. The subsequent process of applying for permanent asylum was very slow. Before it was properly underway, Nola and Helan were already in school. After several years, the family's application for asylum was processed—and then refused, although they had the right to appeal the decision, not once but twice. By that time, the Syrian war had started, making their birthplace even more dangerous. It was at this point that Nola showed the first signs of withdrawal.

The children had lived in Sweden for longer than they had lived anywhere else. All their friends were here, both children spoke fluent Swedish and Helan also had a good understanding of English. I don't know what Nola and Helan knew of the place they were born, but, even if it was never explicitly discussed, they must have felt the fear associated with returning there. The family had placed themselves in great danger fleeing Syria, and—whether they were believed or not—they had done so for a reason.

PEOPLE WHO HAVE psychologically mediated physical symptoms always fear being accused of feigning illness. I knew that one of the reasons Dr. Olssen was desperate for me to provide a brain-related explanation for the children's condition was to help them escape such an accusation. She also knew that a brain disorder had a better chance of being respected than a psychological disorder. To refer to resignation syndrome as stress induced would lessen the seriousness of the children's condition in people's minds. It is the way of the world that the length of time a person spends as sick, immobile, and unresponsive is less impressive if it doesn't come with a corresponding change on a brain scan.

Not all the medical interest in this disorder has focused on blood tests and brain scans. More psychologically minded explanations have compared resignation syndrome to pervasive refusal syndrome (also called pervasive arousal withdrawal syndrome—PAWS), a psychiatric disorder of children and teens in which they resolutely refuse to eat, talk, walk, or engage with their surroundings. The cause is unknown, but PAWS has been linked to stress and trauma. The withdrawal in PAWS is an active one, as the word "refusal" suggests; it is not apathetic. Still, as a condition associated with hopelessness, it does seem to have more in common with resignation syndrome than other suggestions.

The resignation-syndrome children became ill while living in Sweden, but most had experienced trauma in their country of birth. It seems likely, then, that this past trauma would play a significant role in the illness. Perhaps it is a form of post-traumatic stress disorder? Or could the ordeals suffered by the parents have affected their ability to parent, which in turn impacted on the emotional development of the child? One psychodynamically minded theory is that the traumatized mothers are projecting their fatalistic anguish onto their children, in what one doctor described as an act of "lethal mothering."

There is clearly much of value in investigating the biological and psychological explanations for resignation syndrome, but even when taken together they fall short. Psychological explanations focus too much on the stressor and on the mental state of the individual affected, without adequately paying attention to the bigger picture. They also come with the inevitable need to apportion blame, passing judgment on the child and the child's family. They risk diminishing the family's plight in the eyes of others. Psychological distress simply doesn't elicit the same urgent need for help that physical suffering does.

But the biomedical theories are even more problematic. The search for a biological mechanism is in part an attempt to ensure that the children's condition is taken seriously, but it also threatens to neglect all the external factors that have propelled the children into chronic disability. MRI scans that try to unpick the brain mechanism of resignation syndrome are useful research tools and might offer general insights into how the brain controls consciousness and motivation, but there is something faintly ludicrous about expecting scans done on individuals to explain or solve a group phenomenon.

As a neurologist, people expect me to be especially interested in the brain mechanisms that cause disability. But, standing in the bedroom shared by Nola and Helan, the confused neural networks keeping these small children in bed seemed only to be an end point and, therefore, the least important part of what created their situation. A whole lifetime had led Nola and Helan to this place, where they lay in the confines of a Swedish bedroom, the curtains pulled on a sunny day.

SUZANNE O'SULLIVAN is the author of *The Sleeping Beauties: And Other Stories of Mystery Illness*. She is an Irish neurologist working in Britain. Her first book, *Is It All in Your Head?: True Stories of Imaginary Illness*, won the 2016 Wellcome Book Prize and the Royal Society of Biology General Book Prize. She lives in London.

Where Aliens Could Be Watching Us

More than 1,700 stars could have seen Earth in the past 5,000 years

BY LISA KALTENEGGER

DO YOU EVER FEEL LIKE someone is watching you? They could be. And I'm not talking about the odd neighbors at the end of your street.

This summer, at the Carl Sagan Institute at Cornell University and the American Museum of Natural History in NYC, my colleague Jacky Faherty and I identified 1,715 stars in our solar neighborhood that could have seen Earth in the past 5,000 years.[1] In the mesmerizing gravitational dance of the stars, those stars found themselves at just the right place to spot Earth. That's because our pale blue dot blocks out part of the sun's light from their view. This is how we find most exoplanets circling other stars. We spot the temporary dimming of their star's light.

HELLO OUT THERE A view of the Earth and sun from thousands of miles above our planet, with the stars in position to see Earth transiting around the sun brightened and the Milky Way visible on the left.

OPEN SPACE/ © AMNH

The perfect cosmic front seat to Earth with its curious beings is quite rare. But with about the same technology as we have, any nominal, curious aliens on planets circling one of the 1,715 stars could have spotted us. Would they have identified us as intelligent life?

All of us observe the dynamics of the cosmos every night. Stars rise and set—including our sun—because Earth rotates among the rich stellar tapestry. Our night sky changes throughout the year because Earth moves in orbit around the sun. We only see stars at night when the sun doesn't outshine them. While circling the sun, we glimpse the brightest stars in the anti-sun direction only. Thus, we see different stars in different seasons.

If we could watch for thousands of years, we could watch the dynamic dance of the cosmos unfold in our night sky. But alternatively, we can use the newest data from the European Space Agency's GAIA mission and computers to fast-forward the time before our eyes, with decades unfolding in mere minutes. While we can only see the light of the stars, we already know that more than 4,500 of these stars are not alone. They host extrasolar planets. Several thousand additional signals indicate even more new worlds on our cosmic horizon.

Astronomers found most of these exoplanets in the last two decades because of a temporary dimming of their stars when a planet, by chance, crossed our line of sight on its journey around its star. The planet temporarily blocks out part of the hot star—and its light—from our view. Telescopes on the ground and from space, including NASA's Kepler and TESS (Transiting Exoplanet Survey Satellite) mission, found thousands of exoplanets by spotting this dimming, which repeats like clockwork.

The time between dimming tells us how long the planet needs to circle its star. That allows us to figure out how far away an exoplanet wanders from its hot central star. Most known exoplanets are scorching hot gas balls. We can tell when planets orbit closer to a

The discussion rolls around to: "Does life on Earth qualify as advanced?"

central star than others because they need less time to circle it—we also find those faster than the cooler ones farther away. But about three dozen of these exoplanets are already cool enough. They orbit at the right distance from their stars, where it is not too hot and not too cold. Surface temperatures could allow rivers and oceans to glisten on the surfaces of these planets in this so-called Habitable Zone.

This vantage point—to see a planet block part of the hot stellar surface from view—is special. The alignment of us and the planet must be just right. Thus, these thousands of known exoplanets are only the tip of the figurative exoplanet iceberg. The ones we can most easily spot hint at the majority waiting to be discovered.

But what if we change that vantage point? If anyone out there were looking, which stars are just in the right place to spot us?

Our powers of observation have been boosted by the European Space Agency's Gaia mission. Launched in 2013, the Gaia spacecraft is mapping the motion stars around the center of our galaxy, the Milky Way. The agency aims to survey 1 percent of the galaxy's 100 billion stars. It has generated the best catalog of stars in our neighborhood within 326 light-years from the sun. Less than 1 percent of the 331,312 catalogued objects —stars, brown dwarfs, and stellar corpses—are at the right place to see Earth as a transiting exoplanet. This special vantage point is held by only those objects in a position close to the plane of Earth's orbit. Roughly 1,400 stars are at the right place right now to see Earth as a transiting exoplanet.

But this special vantage point is not forever. It is gained and lost in the precise gravitational dance in our dynamic cosmos. How long does that cosmic front-row seat to Earth transit last? Because the Gaia mission records the motion of the stars, we can spin their movement into the future and trace it back into the past on a computer. It shows us the night sky over thousands of years since civilizations bloomed on Earth and gives us a glimpse of a night sky of the far future, millennia away.

If we had observed the sky for transiting planets thousands of years earlier or later, we would see different ones. And different ones could find us. We calculated that 1,715 objects in our solar neighborhood could have seen Earth transit since human civilizations started to bloom about 5,000 years ago and kept that special vantage point for hundreds of years. Three hundred and nineteen objects will enter the Earth transit zone in the next 5,000 years.

Among these 2,034 stars, seven harbor known exoplanets, with three stars' exoplanets circling in this temperate Habitable Zone. However, the small region around the plane of the Earth's orbit, where all these stars lie, is crowded. Astronomers usually don't look for planets there. Generally, it is easier to find exoplanets around stars in non-crowded fields. But now we have a reason: to discover the planets that could also discover us.

NASA's Kepler mission stared for more than three years at about 150,000 stars about 1,000 light-years away. These 150,000 stars fit in a small fraction of the sky. Its goal was to estimate how many stars harbor exoplanets. The answer is exciting. Every second star has at least one planet, big or small, and about every fourth star hosts a planet in the Goldilocks Zone. These results provide cautious optimism about our chances of not being the only life in the cosmos. It also means that about 500 exoplanets in the Habitable Zone should be on our list, waiting to be discovered.

THE THREE SYSTEMS that host planets in the Habitable Zone in the Earth transit zone are close enough to detect radio waves from Earth. Because radio waves travel at light speed, they have only washed over 75 of the stars on our list so far. These stars are within 100 light-years from Earth—because light had 100 years to travel since Earth first started to leak radio signals.

Ross 128b, an exoplanet a mere 11 light-years away from us, could have seen Earth block the sun's light about 3,000 years ago. But it lost this bull's-eye view about 900 years ago. Another exoplanet, Teegarden's Star b, which is a bit heavier than Earth, and circles a red sun, is about 12.5 light-years away, and will start to

The perfect cosmic front seat to Earth, with its curious beings, is quite rare.

see Earth transit in 29 years. And the fascinating Trappist-1 system, with seven Earth-size planets at 40 light-years distance, will be able to see Earth as a transiting planet but only in about 1,600 years.

With the launch of the James Webb Space Telescope (JWST) later this year, we will have a big enough telescope to collect light from small, close-by exoplanets that could be like ours. A particular combination of oxygen and methane has identified Earth as a living planet for about 2 billion years. That combination of gases is what we will be looking for in the atmosphere of other worlds. This exoplanet exploration will be on the edge of our technological possibility, but it will be possible for the first time. Future technology should be able to characterize exoplanets, not just in transit. But for now, telescopes like the JWST collect only enough light from the atmosphere of close-by transiting worlds to explore them, allowing us to wonder whether nominal curious astronomers on alien worlds might be watching us, too.

Of course, no aliens have visited us yet, and we haven't found any cosmic messages from them. Is that because we're unique? Have other civilizations destroyed themselves? Or are they just not interested in us?

In my Introduction to Astronomy class at Cornell, I ask students whether they would contact or visit an exoplanet that is 5,000 years younger than Earth or 5,000 years older. Without fail, they pick the older planet and its potentially more advanced life. More "advanced" than us. During our discussions, the concept of advanced life invariably rolls back around to us. Would life on Earth qualify as intelligent for anyone watching?

After all, we've been using radio waves for only about 100 years, and so those waves would only have traveled 100 light-years so far. We have set foot on the moon but not farther yet and are only starting to think about interstellar travel. So our interstellar travel resume is awfully thin.

One thing that an alien astronomer would likely see is our atmosphere. If they had been watching us for a while, they would have seen that we destroyed our ozone layer—but we also managed to fix it. So maybe we would have scored a point on their intelligence scale. Now, of course, they see our atmosphere is becoming concentrated with carbon dioxide and shows no signs of abating yet. But maybe every civilization goes through this, every civilization nearly destroys its habitat before figuring out a way to save themselves from themselves.

If any aliens are out there watching us from those 2,034 stars in our solar neighborhood, I hope they're also rooting for us.

LISA KALTENEGGER is the founder and director of the Carl Sagan Institute at Cornell University, and an associate professor in astronomy. She is a leading expert in modeling potential habitable worlds and their detectable spectral fingerprint, which can be detected with the next generation of telescopes. She has served among others on the National Science Foundation's Astronomy and Astrophysics Advisory Committee (AAAC), and on NASA senior review of operating missions. She is a Science Team Member of NASA's TESS Mission as well as the NIRISS instrument on the James Webb Space Telescope. Asteroid Kaltenegger7734 is named after her. Twitter: @KalteneggerLisa and @CSInst.

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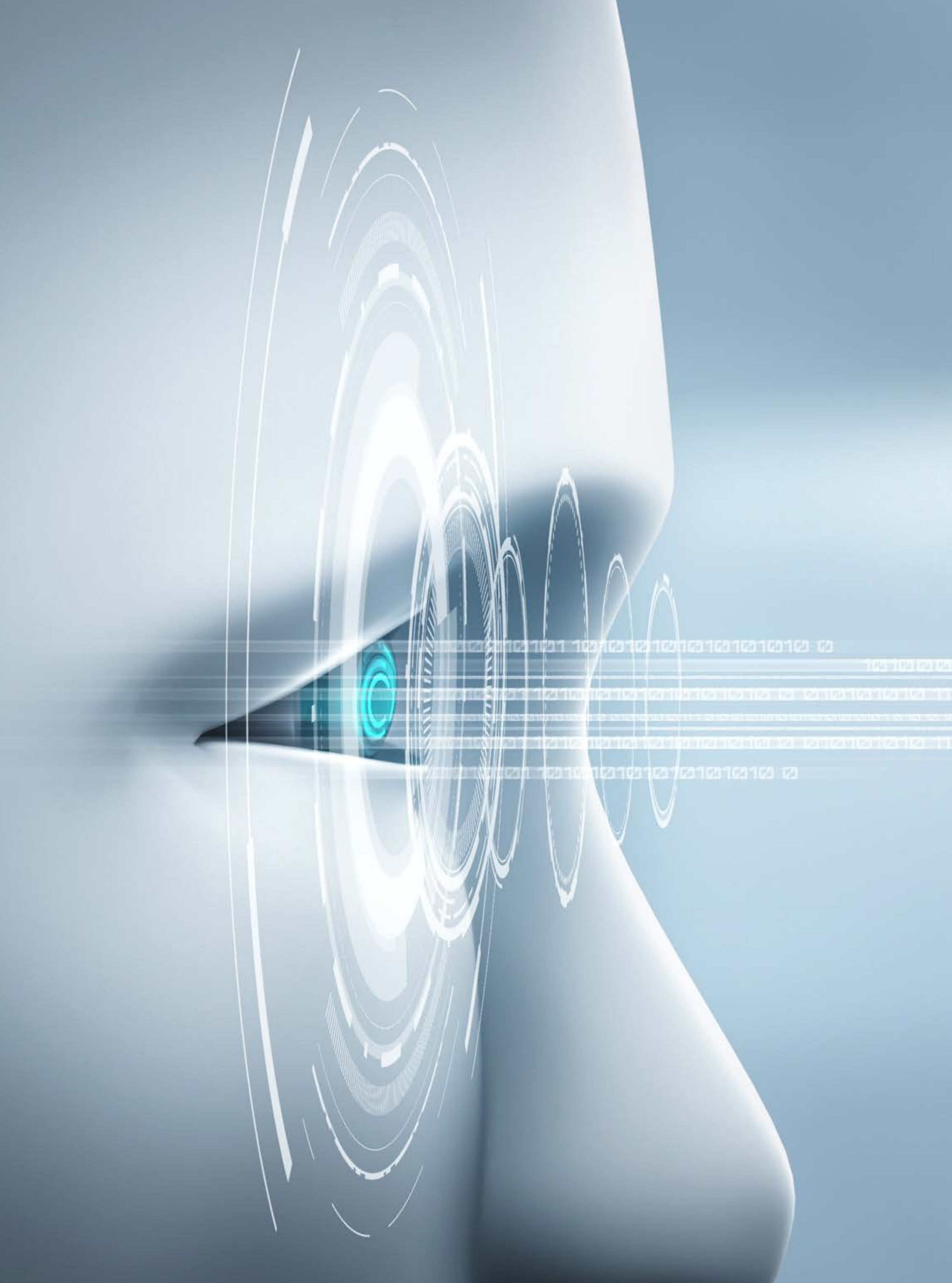


The Accident That Led to Machines That Can See

The beauty of this breakthrough is serendipity

BY PHIL JAEKL

BLUE PLANET STUDIO / SHUTTERSTOCK

F**OR SOMETHING SO EFFORTLESS** and automatic, vision is a tough job for the brain. It's remarkable that we can transform electromagnetic radiation—light—into a meaningful world of objects and scenes. After all, light focused into an eye is merely a stream of photons with different wave properties, projecting continuously on our retinas, a layer of cells on the backside of our eyes. Before it's transduced by our eyes, light has no brightness or color, which are properties of animal perception. It's basically a mess of energy. Our retinas transform this energy into electrical impulses that propagate within our nervous system. Somehow this comes out as a world: skies, children, art, auroras, and occasionally ghosts and UFOs.

Each new cell-type seemed like finding a new piece of a jigsaw puzzle.

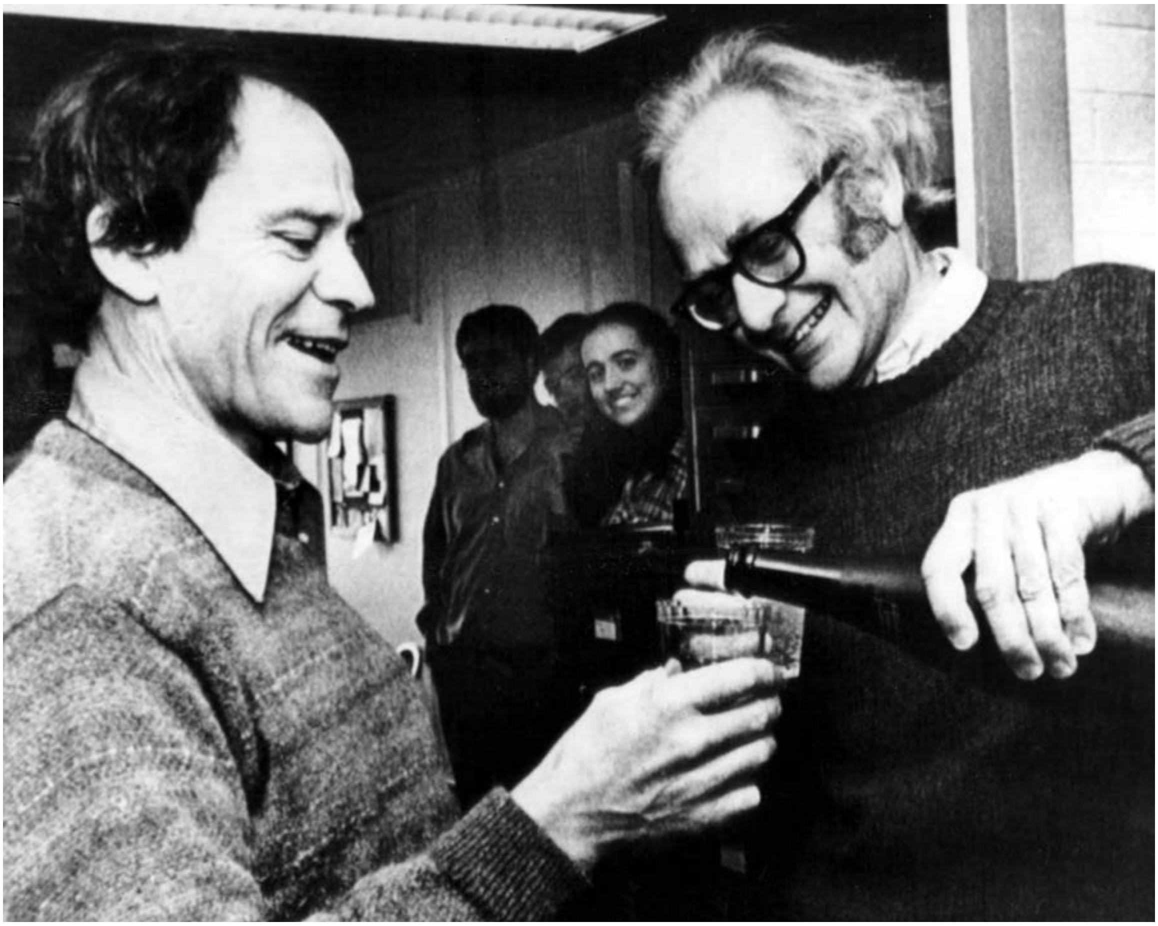
It's even more amazing when you take a closer look. The image projected in each eye is upside down, having a slightly different perspective than the image in the other eye. Our nervous system reorients them, matches each point in the projection, and uses the difference in geometry between the images to create the appearance of depth—stereopsis—in a unified scene. It processes basic features like shape and motion. It separates the objects from each other and the background, and distinguishes visual motion caused by our own movement or the movement of objects. Estimates of the percentage of the human brain devoted to seeing range from 30 percent to over 50 percent.

Today, mapping the human brain is one of the great projects in science. Scientists have a long way to go before they understand the brain's architecture and interaction of billions of neurons behind our every action and perception. Visual processing, though, is one of the most well understood aspects of brain activity. Scientists are now modeling the brain's visual system with ever-more powerful computers, gaining new insights into how vision works, and in turn transforming those insights into new technologies.

Computers can now detect the presence of specific objects and identify people; they can reconstruct three-dimensional scenes from two-dimensional images, find tumors, help forensic scientists identify evidence, and navigate vehicles autonomously through busy streets. They are being developed to explore the bottom of the ocean and defuse dangerous minefields. In the future, computer vision is projected to play a key role in proactive safety systems, identifying, *Minority Report*-style, criminal suspects, or patterns of criminal behavior, before they happen.

How has vision technology come so far? It arose from an aspect of science that leads to many breakthroughs: serendipity. Vision science wouldn't be where it is today without an accident that took place in a physiology lab in Baltimore over half a century ago.

IN 1958, STUDYING THE RESPONSES of nerve cells in living animals was difficult. To study vision, it was typical of physiologists to use anaesthetized cats. But the examination setups that carefully held them in place were extremely sensitive to movement; even a pulsation from a heartbeat could throw everything off.



ASSOCIATED PRESS

CHEERS TO THAT David Hubel (right) and Torsten Wiesel celebrate upon learning they, along with Roger Sperry, had won the 1981 Nobel Prize in Medicine for their research which showed that vision was constructed through a cascade of firing cells.

This changed when David Hubel, a 32-year-old scientist from Canada, through careful machining methods, invented a tungsten electrode and a hydraulic positioning system, as part of his postdoctoral research at Johns Hopkins University.

Armed with the advanced tech, Hubel and a new colleague, Torsten Wiesel—a budding Swedish researcher around the same age—set out to explore the visual cortex of living cats. It was brave new territory for physiology and they were optimistic because, with the fancy electrode, it was now possible to record the activity of individual neurons. They wanted to figure out exactly what these cells might be doing to contribute to vision. Would they, for example, find cells that responded to different, identifiable objects—forks, mountains, kitchens? They were going in blind, if you can excuse the pun.

Building on knowledge dating back to Santiago Ramón y Cajal's 19th-century discoveries in neuroscience, they knew a thing or two about the wiring and response patterns of the nerve cells in the retina and in the brainstem that feed into cells in the visual cortex.

They knew how to trigger these retinal and brainstem neurons to pass electrical impulses—information, essentially—by projecting spots of light. These spots had to be focused within the area of the cat's visual field that a given cell was sensitive to.

Recording sessions took many hours—it was a victory in and of itself if you could find a cell that you could reliably stimulate even just a bit, and sometimes you didn't "get lucky" until searching into nightfall. That meant you'd be spending all night in the lab trying, through trial and error, to find a pattern in a cell's responses by playing with the location, size, or luminance of the spot. It was tedious work. Once Hubel and Wiesel even tried using pictures of women from magazines to stimulate the cat's neurons. But after a month of the experiments, they simply weren't getting anywhere.

Somehow this comes out as a world: skies, children, art, auroras, ghosts, and UFOs.

Then, what started out as another uneventful recording session turned into an adventure that won them a Nobel Prize. After a few hours of trying again with spots, they finally located a cortical cell in a cat that gave them a small response. Then, while swapping out the projector slide, while there was no spot on their screen, the cell suddenly went off like a machine gun! It was unlike any response they'd heard before. What caused it? Their hearts were racing.

After calming down, they tried reinserting the slide again. But to their dismay, it didn't work. They realized they had to do exactly what they had just done. But what did they do? If only they could remember. I asked Wiesel, who is now 97, to recount what happened next. Excitedly, over Zoom, Wiesel told me, "We got the bright idea to change the orientation of the slide edge, and that's how we discovered it! We rushed down the halls and called in everybody because we realized that this was amazing. Really amazing." What they discovered was that the only thing that could have triggered so much activity in the cell was the thin dark line on the projector screen resulting from the edge of the glass slide with the dot on it. The key to getting the cell to fire was to project that slide edge at the right orientation.

IN THE FOLLOWING WEEKS, Hubel and Wiesel discovered a response pattern in the cortical cells. Projected lines triggered each of them, but only when shown at specific angles. When you went away from

We got the bright idea to change the orientation of the slide edge. That's how we discovered it!

a cell's "preferred" angle, there was a graded decrease in the number of electrical impulses they churned out, reaching a minimum of firing with the line at about a 90-degree angle, relative to whatever its maximum response orientation was. Meanwhile, almost as if to intentionally confuse them, the two scientists also discovered other cortical cells that strangely had no preferred orientation. These cells didn't care about the line's angle, just that there was a line. They called the former simple cells and the latter complex cells because they attributed differences in the response patterns to simple wiring and complex wiring, relatively speaking. Nonetheless, each new cell-type seemed like finding a new piece of a jigsaw puzzle. But was there a unifying principle here? Did these pieces fit together?

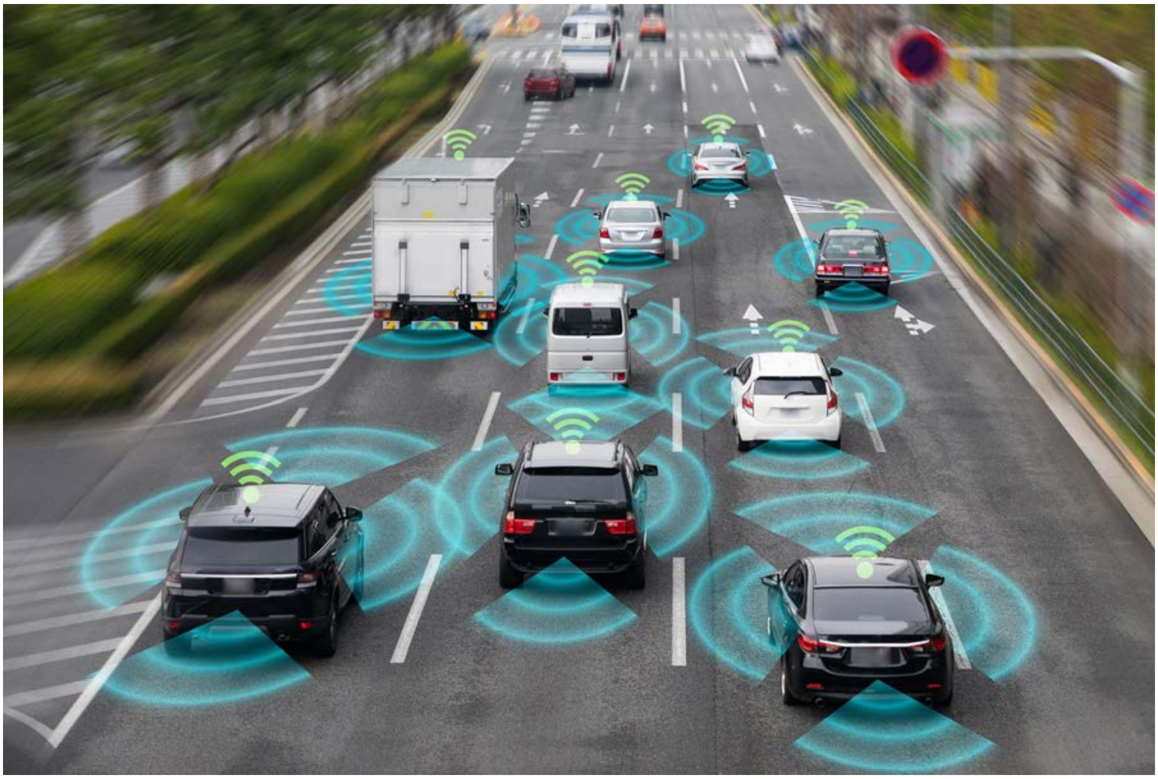
They did. The upshot of their exploration was that each type of cell they found had a response pattern that could be generated from the cells that fed into it, and the cells that fed into those cells. It seemed there was a network composed of nodes and layers in a hierarchy that began at the retina. It was a revelation of how these cells function together to create a neural representation of something in the cat's visual field; a physical instantiation corresponding exactly to what the cat could be seeing at that very moment. It was a profound connection between mind and brain.

Hubel and Wiesel showed that vision was constructed through a cascade of firing cells. Each bit of visual information stimulated a particular cell that triggered others. This expanding network constituted a hierarchical system in the brain that resulted in the identity of an image—an object, or face. The idea, taken to an extreme, forms the basis for what's become known as the Grandmother Cell hypothesis—that at the highest level, there could be cells so abstract, they only activate when stimulated by a conceptual entity, like a grandmother. Although the idea remains controversial, in 2005, researchers at UCLA came eerily close to proving it when they found cells that fired when subjects viewed specific celebrity faces, like Jennifer Aniston, or Bill Clinton.

I asked Margaret Livingstone, a student and longtime colleague of David Hubel who's now a visual neuroscientist at Harvard, about the importance of Hubel and Weisel's early discoveries. Without hesitation, she explained that the significance is "that our brains are arranged in a hierarchical series of areas that each perform similar computations on their inputs, like a neural network."

IN THE LATE 1950S, alongside Hubel and Wiesel's discoveries, the United States Navy funded the development of a computer with a sci-fi B-movie name: Perceptron. Large, clunky, and nightmarish, really, it contained a camera with an array of 400 photocells connected, rat's-nest style, to a layer of artificial "neurons" that could process image information and identify patterns after training. Although *The New York Times* touted it as "the embryo of an electronic computer that ... will be able to walk, talk, see, write, reproduce itself and be conscious of its existence," once in use it was soon revealed that even its basic pattern recognition capability was disappointingly limited to the types of patterns it was trained on, relative to such outrageously expanded expectations.

Success in computer vision required inspiration from Hubel and Wiesel's discoveries. In 1980, it came in the form of the Neocognitron (see a pattern here?), a neural network invented by the Japanese computer scientist, Kunihiko Fukushima. Paralleling biological visual architecture, the neocognitron had elementary units called s-cells that fed into c-cells, modeled after simple and complex cells, respectively. They were networked in a cascading, hierarchical fashion, just like in a brain. After training, it could recognize typed



DRIVE ON, ROBOT Cutting-edge algorithms that train computer vision systems, like those in self-driving cars, rely on the same neural network structure as vision models. Some Teslas already have a feature that allows them to park autonomously and maneuver themselves out of a parking spot. Future plans include camera-based neural net technology for full guidance during autopilot.

METAMORWORKS / SHUTTERSTOCK

and even handwritten characters. It was the first of its kind that could learn to create information from unique spatial patterns drawn by anyone and use that information to essentially make decisions about abstract categories to identify meaningful, understandable symbols.

In the late 1990s, the Neocognitron was followed up by another biologically inspired model dubbed HMAX for "Hierarchical Model and X," which was more flexible in terms of the kinds of objects it could recognize. It could identify them from different viewpoints and at different sizes. Leading this project was Tomaso Poggio, originally trained in theoretical physics, and now regarded as a pioneering computational neuroscientist at MIT. He, along with the late David Marr, are credited with using a physiologically inspired approach to modeling neural processes computationally to create vision in computer systems.

Poggio's HMAX also included simple and complex processing nodes where the simple nodes fed into the complex nodes. The output of the highest processing nodes in the hierarchy approximated a neural representation of the object in view—the outputs were even termed "neurons"—such that their model firing rates peaked when the images they were shown contained objects they were trained to identify. In a 1999 publication about HMAX, published in *Nature*, Poggio and his colleagues remark that their model was an extension of Hubel and Wiesel's hierarchical model of visual processing.

Neocognitron "was the first computer model that really followed this hierarchy," Poggio told me in a recent interview. "In my group, we did something similar, which was more faithful to the physiology that Hubel and Wiesel found. You could think of it as a sequence with layers of logical operations that correspond to simple and complex cells and their combinations to get the selectivity properties of neurons high up in the visual pathway." Basically, with HMAX, Poggio was able to mimic neurons that receive input from not only simple and complex cells, but many others further along in the processing sequence. In cat and human brains, these "high-up" neurons are activated not by oriented lines, but by complex figures like 3-D shapes, no matter what viewpoint. To do this, these neurons must learn the features they become tuned to identify.

Incredibly, the connective structure or architecture of these models is seen today in cutting-edge algorithms that train computer vision systems to identify objects on the fly. The most widely known example involves autonomous driving. Tesla's smart-summon feature allows its vehicles to park autonomously and maneuver themselves out of a parking spot. Newer models will have camera-based neural net technology for full guidance during autopilot.

Computers with visual intelligence are currently employed in security, agriculture, and medicine, where they're used to spot, with varying degrees of efficiency, the bad apples—suspects, weeds, and tumors. The breakthroughs have come along with huge increases in information processing power and massive sets of training images, in what's known as Deep Learning, a system-architecture with multiple layers of processing nodes between input and output. In a manner similar to simple and complex cells, the layers of these models are networked in a feed-forward manner as they are in mammalian brains. Indeed, Poggio said, "The architecture of Deep Learning models were originally inspired by the biological data of Hubel and Wiesel."

While Deep Learning's architecture is inspired by the human brain, its methods of visual recognition are not a perfect parallel. For example, AI systems that learn to recognize objects or people often rely on a process called backpropagation, which involves re-weighting the connection strength between artificial neurons according to error rates, in ways that are agreed upon by neuroscientists to be anatomically and physiologically unlikely or even impossible. Poggio said that " 'backprop' doesn't correspond accurately with what we know about how the brain processes visual information." He also describes it as a remarkably clunky, inefficient process. "In some AI systems it requires megawatts of power, yet our brains do it while running only on the energy from the food we eat," Poggio said.

Still, he pointed out, scientists are recapitulating the brain's visual processing power with computations in more detail, potentially leading to better visual processing in AI. Already artificial neural networks that show direct correspondence with actual brain architecture can accurately predict neural responses to images. In a 2019 experiment, a group of scientists at MIT designed a computer model to stimulate neural activity in the brain's visual system, based on neuroscientific findings. They had the computer generate an image that triggered the desired pattern of neural activity. When the scientists showed the synthesized images to monkeys, with electrodes implanted in their brains to record their neural activity, the monkeys' visual system fired just as the scientists predicted. The potential to stimulate neural activity, notably in people who have suffered a brain injury, is, scientists say, exciting. It's something out of science fiction.

Wiesel told me that he and Hubel felt that kind of excitement when they made their first discoveries. "We felt more like explorers than scientists," Wiesel said. Their explorations are still charting new courses in science today.

PHIL JAEKL is a freelance science writer and author with an academic background in cognitive neuroscience. His latest book is *Out Cold: A Chilling Descent into the Macabre, Controversial, Lifesaving History of Hypothermia*. He lives in the Norwegian Arctic in Tromsø.

How to Build a Society for All to Enjoy

To make social structures more equal, we can't blind ourselves to genetics

BY KATHRYN PAIGE HARDEN

Structure:

(*noun*)

The arrangement of or relation between the parts of something complex; the organization of interrelated elements.

1.

My partner trained as an architect, and now he is cursed. His curse is not just working like an architect works, with grueling hours and implacable clients, although that's true. His curse is seeing like an architect sees. Every structure is, to him, a palimpsest of the structure that *could have* been, if the people who built things—other architects, of course, and also building-code writers and contractors and construction workers and landscapers and interior designers—had made different choices. If they had made *better* choices.

Sometimes, the "what-if" structure is only a minor variation on the structure that actually exists: If the cabinet maker were more expert, for instance, the custom wine rack would have fitted perfectly. Other times, the "what-if" structure is more consequential: If better insulation had been installed, then some Texans might not have frozen to death in their homes during this year's winter storm. Much of the built environment in American cities, if you stop and look at it, really *look*, is ugly. Even worse—it's hostile to humans doing basic human things, like walking, or breathing. Not being able to ignore that ugliness and hostility, not being able to *un*see how structures could be different, is the architect's curse.

Structure derives from the Latin, "*struere*," which means "to build." The infinitive form of the verb allows the subject—the builders doing the building—to lurk in the shadows, but they are always there. Sociologists use the term "social structures" to describe how we, as individuals and as a collective, have built our social lives, the patterned ways we relate to each other. Using the term "structure" to refer to our social arrangements conveys something about their solidity, their reality, their power. Like physical structures, social structures can facilitate individual action in one direction but constrain it in another. In Texas, I can zip up I-35 in my car but would struggle to cross over I-35 on my bike; I can buy a gun this afternoon but would have to wait three days to get married; and it might take me a year or more to enroll a toddler in center-based daycare. But "structure" also conveys how social arrangements are the result of choices—our choices. We are the builders of our social world. Like architects, sociologists have a second sight about structures: They are trained not only to describe what is, but also to imagine what could be, if we made different choices.

The Americans with Disabilities Act (ADA) is a piece of social structure that affects architectural structures. First signed into law in 1990 by President George H.W. Bush, the ADA prohibits discrimination against people on the basis of disability, including in their "full and equal enjoyment of ... any place of public accommodation." Architectural barriers to "full and equal enjoyment" must be removed. Complying with federal legislation, the Texas Government Code on the elimination of architectural barriers lists building requirements for drinking fountains, bathrooms, pools, bus stops, change machines, miniature golf facilities, and—this is Texas, after all—"shooting facilities with firing positions." Reading the accessibility requirements, I am astonished at how many micro-level choices ("openings in floor or ground surfaces shall not allow passage of a sphere more than ½ inch (13 mm) diameter") are governed by one macro-level choice: We will change structures to include people.

MELITAS / SHUTTERSTOCK

Or, rather, sometimes we will. We will also change structures to exclude people. Jackson, Mississippi, drained its swimming pools rather than include Black swimmers. Prince Edward County, Virginia, closed its entire public school system rather than include Black students. Austin, Texas, created a "Negro" district, which was the only part of the city where Black families could access schools or public services, and which had weakened zoning restrictions to allow "slightly objectionable industrial uses" that were prohibited in white neighborhoods.

In a twin biography of Malcolm X and Martin Luther King, Jr., historian Peniel Joseph described how the segregation of physical space on the basis of race was an affront to what he termed "radical Black citizenship" and "radical Black dignity." Citizenship and dignity—these are the lodestars of civil rights legislation prohibiting discrimination on the basis of race or disability or other human difference. Whether a structure upholds the citizenship and dignity of people who have to live their lives within and around it, in my view, is very close to the heart of whether a structure is "good." Citizenship is more than voting rights, although voting is obviously critical and getting harder by the day. Citizenship is the ability to participate in the political and social and economic life of a country.

A fundamental problem is the idea that society should be structured as a race we all compete in, rather than a building we all have to live in.

As King said, just weeks before his murder, "What does it profit a man to be able to eat at an integrated lunch counter if he doesn't earn enough money to buy a hamburger and a cup of coffee?" The affirmation of dignity is equally important: There's a difference between inclusion and pity. The sinners damned to eternal torment in Dante's *Inferno* thank the narrator for his pity. He swoons at their agony, but his intensity of feeling does nothing to change their position, which is structurally inferior. They are trapped in hell and he can leave for heaven. A demand for inclusion, on the other hand, is a claim to joint ownership on the basis of equal dignity: I am just as worthy of heaven as you.

2.

Up to this point, I have said nothing about whether disabilities that are protected by the ADA are caused by genes or the environment. Nor have I weighed in on the relationship between socially constructed racial groupings and genetic ancestry. I could enumerate other such "nature vs. nurture" issues for other dimensions of human difference protected, to varying degrees, by civil rights legislation. The narrative that queer and trans people are "born this way" was certainly ascendant for a time. But, some in the LGBT+ community have pushed back against that narrative, articulating how, for them, their sexual experiences and gender identities feel chosen or fluid rather than fixed and "innate"—and chosen experiences and identities are no less worthy of legal protection against discrimination. As the writer Andrew Solomon pointed out: "Surely, when we defend the rights of Jews or Muslims, we don't imply that they can't help being that way; rather, we confer dignity on a chosen way of life."

The reason for my lack of attention, thus far, to these "nature vs. nurture" questions is simple: The answers to them are irrelevant to what I've been considering about what makes structures good. As a college professor, I most commonly encounter ADA accessibility requirements not in the form of building codes but in the need to caption videos and lectures for my hearing-impaired students. It would be bizarre—not to mention illegal—if I only accommodated the needs of students who were hearing-impaired because of an environmental cause (like maternal rubella infection) but not a genetic one.

INVISIBLE STRUCTURE The way some social structures operate is hard to see. Things like family and educational systems, and labor and dating markets—they are "the IKEA stores of our lives," Kathryn Paige Harden writes. "We appear to meander along organically but are actually being steered deliberately along predictable routes."

ZIKG / SHUTTERSTOCK

I am certainly not the first person to point out that empirical questions about whether human differences are "genetic" or "biological" can be irrelevant to the moral question of how we should relate to each across those differences. The psychologist Leon Kamin made this point decades ago: "Are 'genetically' produced differences more just, good, or true than 'environmentally' produced differences?" Similarly, the political philosopher John Rawls suggested that, "Once we are troubled by the influence of either social contingencies or natural chance on the determination of distributive shares, we are bound, on reflection, to be bothered by the influence of the other. From a moral standpoint the two seem equally arbitrary." The ADA makes this abstract philosophical idea concrete, sometimes literally. Knowing *why* my students are different does not tell me whether I *should* structure my class to accommodate those differences.

Nevertheless, people conflate these questions constantly. In fact, I think most of the public attention paid to my scientific discipline of behavioral genetics is driven by the deeply mistaken belief that discovering whether or not there are genetic or biological causes of human differences will reveal something deeply important about whether social structures *should* be inclusive of those differences. The question of cause—and, specifically, the question of biological causes—keeps creeping into our conversations. Why?

I can buy a gun this afternoon but would have to wait three days to get married.

3.

There is one particular instance where the question of *why* people differ is essential to the question of whether that event has been structured appropriately—a race. ("Race" in the sense of track-and-field, i.e., "a competition to see which is fastest.") Unlike an ADA-compliant building, which is structured so that different people can experience something similarly, races are structured to produce differences in outcome among otherwise similar people. Races are structured so that these differences in outcomes can be rewarded differently. Races are structured to produce winners and losers. Races *discriminate* between people.

In a race, the question of cause—why did someone finish the race first?—is, as I said, essential to the question of whether the race was set up properly. If differences in how fast people run are caused by some types of environments (e.g., some people had a different starting line), then the win is illegitimate. We have to revise the rules of the race; we have to change the structure. But, if differences in how fast people run are caused by something "genetic," then the winners are entitled to their win. They own their own bodies. To the victors go the spoils.

If differences are caused by something genetic, then the winners in society are entitled to their win. Nearly all of our public discourse about genetics follows from this (deeply flawed) premise. What is often called the "hereditarian" position answers in the affirmative: Yes, differences in people's life outcomes are caused by genetic differences between them, so, yes, the "winners" in society's rat races are entitled to their win. In this way, genetic differences are invoked to "naturalize" inequality.

A tempting, but ineffective, response to the hereditarian attempt to naturalize inequality is to deny or minimize the influence of nature. *No, absolutely not, it could not possibly be true* that genetic differences between people matter for their outcomes in the "meritocratic" competitions (for grades, for places at university, for jobs, for promotions) that are ubiquitous in our modern lives.

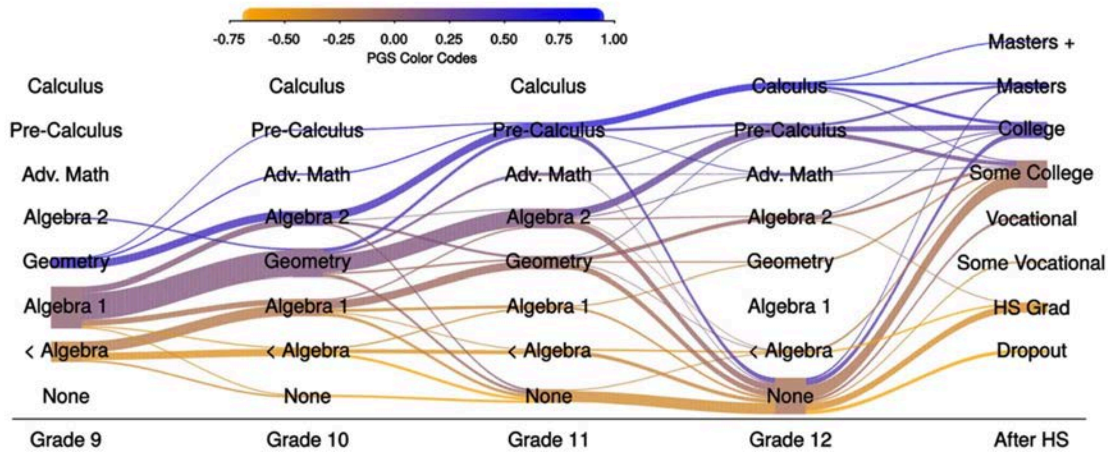
Such a position is ineffective, because it is empirically wrong, and because few people actually believe it. As the psychologist Eric Turkheimer recognized almost 25 years ago, "assertions like these strain credulity, and play into the hands of a radical right that stigmatizes its opponents as gullible or dishonest fools whose political doctrines blind them to obvious scientific facts."

A more effective response to hereditarianism, which also has the benefit of being accurate, is to point out all the ways that a race could have turned out differently, or could turn out differently in the future. After all, the existence of genetic influences does not pose any hard boundaries to the possibility of improving functioning: People run faster in response to training; children who are given better environments early in life perform better in school. At the same time, impoverished environmental contexts can impede people from fulfilling their maximum potential level of functioning. It's therefore impossible to know, in retrospect, what any one person's maximum level of functioning might have been, given a different environment.

Social structures are the IKEA stores of our lives. They steer us along predictable routes.

All of the points I've summarized in the previous paragraph are important, but none is radical enough. None of these ideas, important as they are, addresses the flawed premise of the conversation, the idea that all of the goods of a society should be dangled as prizes in a single, high-stakes race. Improving human functioning *is* possible! More than possible—it is, in my view, a *good* thing to do. But, even if we gave everyone on Earth the most ideal training regimen we could possibly imagine, we will still observe differences between people in how fast they run, because *that is what races are structured to do*. Races are high-stakes competitions designed to discriminate between people on the basis of a single domain of human functioning.

The fundamental problem with hereditarianism isn't that genetics matters for human difference. The fundamental problem with hereditarianism is the idea that society should be structured as a race we all compete in, rather than a building we all have to live in. A building built for our full and equal enjoyment. A building where we are joint owners. A building we build for each other.



Columns represent year of secondary school; rows represent mathematics course sequence ranging from least to most advanced. Width of the rivers connecting columns proportional to number of students. Shading of rivers represents the average education polygenic score for students in a particular course in a particular year, ranging from low (orange) to high (blue).

STRUCTURED BY GENES Student DNA can be used to visualize the flow of students through the high school math curriculum.

HARDEN, D., ET AL. GENETIC ASSOCIATIONS WITH MATHEMATICS TRACKING AND PERSISTENCE IN SECONDARY SCHOOL. *NPJ SCIENCE OF LEARNING*, 5, 1 (2020).

4.

The results of genetic research will not be an arbiter of whether structures are good. The latest twin study or genome-wide association study will not tell us whether we need to take responsibility for building new structures that better accommodate human difference. What, then, is genetics for? After all, I have written a book that is subtitled, "Why DNA Matters for Social Equality," so clearly I think genetics is good for something.

Genetics will not judge whether structures are good. Much more modestly, genetics is a tool for seeing structures *as they are*.

Some structures are obviously ugly and hostile. Drained swimming pools, shuttered public schools—we don't need genetics to see how these structures harm. But some structures operate more invisibly. They are the IKEA stores of our lives: We appear to meander along organically but are actually being steered deliberately along predictable routes. Family systems can work like this, as can educational systems. Labor markets. Dating markets. As an individual person, you begin college or work or marriage or parenthood with the expectation that you're going to destination A, but then you end up at destination B instead. "How did I end up here?" we wonder.

Social scientists are used to interrogating structures in terms of critical dimensions of human difference—gender, race, social class, disability. And, to be absolutely clear, I think studying how these differences play out in human lives is vitally important work; they are worthy of study and worthy of being the focus of policy agendas. But, *they are not the whole story of inequality*. In the case of education, even if children of different genders, children from different socioeconomic backgrounds, children from different schools were *exactly equal*, on average, in their academic achievement, we would have eliminated only half of the total inequality in educational outcomes among secondary school students (and even less among primary school students). The majority of educational inequality in the United States and in other high-income nations exists *within families*—including inequalities associated with genetic differences between family members. Is the genome not a dimension of human difference that merits our attention?

As an example of how genetic tools can help us see, consider students' progress through the high school math curriculum—a structure that is being hotly debated in school districts around the country. A student's DNA sequence cannot change as he winds his way through high school, so that genetic sequence can be used as an inert molecular tracer that lights up how they move from algebra to geometry, illuminating the pathways and choke points that might be otherwise invisible even to the students themselves. Among U.S. high school students of European genetic ancestry, student genetics predicts being tracked to better math classes and persisting in math classes for longer—and this association persists even above and beyond information that is more visible, such as family socioeconomic status, school-level socioeconomic status, and even students' GPA in their math class the previous year.

Again, studying the association between genetic differences and an outcome like mathematics course taking will not tell me if that curriculum is good or bad, whether high school math should be de-tracked, whether the differences in labor market outcomes between students who took calculus and those who didn't are fair or unfair. Genetics is simply a tool for seeing what the structure is. It is up to us to imagine what the structure should be.

It's harder to imagine what structures should be, if we deny ourselves tools for seeing what they are right now. Yet this is exactly what much psychological and sociological research does. Too many of my colleagues pay lip service to a "biopsychosocial" model of human development, while in actuality failing to pay attention to any genetic differences between people in their research designs. I understand why that is: They've been convinced that the existence of genetic influences on human differences would "naturalize" inequalities between people, and they fear giving any rhetorical ammunition to people opposed to social change. However, ignoring genetics in social science research in order to preserve the possibility of social change is a fundamentally counterproductive strategy. If we actually want to change social structures to be more equal, more inclusive, more accommodating of human differences, we can't blind ourselves to a major source of those differences. We need to be able to see.

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Ian and the Limits of Rationality

A student at the edge of reason

BY SIMON DEDEO

SETTING: CHESTERFIELD HIGH, AN UNUSUAL SCHOOL IN THE SUBURBS OF OHIO.

The teacher writes on the board:

2, 3, 5, 7, ...

How, he asks, do we complete this pattern?

Now a student might say that the next term is 12. When the teacher asks him why, he says, "I looked out the window and saw the number 12 bus go by."

What's wrong with this answer?

One thing you might say is that there's a metarule, a rule about rules, and the metarule is: The only valid rules are ones that don't involve anything specific about the classroom in which the question is asked. There aren't any "indexical" rules, in the philosopher's terminology.

So then the student says, fine, the next number in the series is 5. And this time, when you ask him why, he says it's because it's the fifth term in the series.

So then you come back at him and say, but the fourth term is 7; according to your rule, shouldn't it be 4?

And he replies, no, no, the rule is only that *some* of the terms correspond to the order in which they appear. One of those special terms is the fifth one.

So what about the others? Well (he says), the fourth term is 7, because you're counting upward from the fifth in units of two. After that, we start counting down again and that's why the third term is five, and the second term is three. The first term is 2 because that's where we start, and that sets the size of those backwards steps.

You're understandably frustrated, because the correct answer is that the next term is 11, and the reason is that this is the list of prime numbers, and the student is clearly intelligent enough to know.

"Ian,"—call him Ian—"Ian, look, you *know* that the correct answer is that they're primes, and the next number in the series is 11. This is 10th-grade mathematics, it's end-of-term review, and we did the whole unit on the prime numbers."

Ian objects. I thought the rule couldn't be indexical! What's the difference between my first answer and yours—mine was about the bus, yours is about where Honors Math is at the end of March? Why is your context bigger, or more important, than my lived experience of the number 12 bus? Is it just that you're more powerful than me? Is this something to do with standardized tests and the post-War meritocracy?

Let's begin there.

SERGEY NIVENS / SHUTTERSTOCK

DIALOGUE

Teacher: I don't doubt, Ian, that you're clever enough to come up with any extension of the pattern you like. And I admit that we do have a list of things we want you to know, that the prime number sequence is on that list, and you and I both agree it's the best match from that list.

Practically, we need to evaluate your ability to remember what we want, and we like to make things a bit tricky because one day your boss will want you to read his mind in roughly the same way. Welcome to the real world.

But the real reason, if we were to get into it—and, honestly, I'd rather not—is that my rule is better than your rule because my rule is *simpler*. It's short, it's easy to tell someone. It's elegant. And so if you were to somehow encounter the first few terms of this sequence in the real world—say, in the crash log for a computer program you wrote, or a list of cicada generation times—you'd do far better to think about whether it's to do with primes, than with your elaborate construction.

Ian: Thanks for leveling with me. I appreciate your concern for my future employment. And it's really useful to know that prime numbers might be a good heuristic one day.

I even agree with you that elegance is a good metarule. I know you don't mean what's fashionable, or pretty, that you mean something that's sort of beyond any particular culture—beauty in the abstract, that's just as good here as it will be when I'm 80 (god forbid), and as it will be when me or my descendants meet aliens on their voyage to the stars. I don't doubt that you, or whoever will teach me next, will have a whole list of elegant things for me to learn.

But how do I *know* what's elegant? I'm not saying elegance isn't real. What I want to know is how to know "they're all primes" is high in elegance. It can't be that it's only three words—I mean, it took me 12 years to learn enough to appreciate the rule, but I explained mine to you in a few seconds.

Why is your context bigger, or more important, than my lived experience of the number 12 bus?

Teacher: If you really want to get into it, we can. The stakes are high, however. If you're asking questions about completing a pattern, you're looking under the hood at reason itself.

When we look out into the world, it's natural to say that we see patterns: patterns in how people behave, or how nature works, even patterns that we reflect on in our own minds.

But that's not quite the case. What we see is a field of possible patterns, possible ways to complete the series.

Imagine, and this is the standard example from the theory of rational explanation, a doctor. On the surface, it looks like a doctor is in the business of translating a patient's symptoms into a diagnosis.

A good doctor, however, inverts the process: He plays out each disease in turn, seeing how well the symptoms match the story. If a patient had a respiratory virus, for example, it might make some of his symptoms very likely indeed, but others he sees would require an unlikely coincidence. A different disease would easily produce all of the symptoms—but given who the patient is, he would be far much less likely to contract it at all.

The doctor contemplates two different ways to complete the pattern. In one case, the respiratory virus, he completes the pattern

Ancestors with the wrong priors die out; our priors get better; we become more rational.

in a natural fashion—he counts off symptoms, although not all of them match very well. In the other case, he matches reality perfectly—but the pattern is an unusual one, more like your jumbled rule from before. The rational doctor's job is to weigh the benefits of matching with the plausibility of the underlying template.

Ian: This all seems pretty contrived. You have your doctor imagining different diseases, but there are plenty of places where that doesn't work. When I'm doing translations in Honors Latin, I don't try a whole bunch of sentences in English, translate them to Latin, and see which one fits the best. I don't reverse the natural direction. We haven't even tried English-to-Latin translation yet, it's much harder.

Teacher: Bear with me. In the doctor's case, the two possible patterns are pretty easy to weigh against each other: He has a sense of how common the two diseases are, and it turns out that there's an optimal procedure for how to combine these facts with the relative match to the symptoms at hand.

Even in your case, the case that started this whole discussion, the answer is pretty easy. Given "2, 3, 5, 7," and the fact that I'm the one presenting it, and the context you're in, if your goal is to figure out what's in my head, the prime number pattern is far more likely than the rules you gave, or any other people have found.

Ian: We've been over this. That's not what I'm after.

Teacher: Yes. You're not interested in reverse-engineering the system. You want to know the truth—you want these methods to give you true answers, not useful ones.

Ian: Exactly.

Teacher: So I'll give you a new word: "prior." A prior is a rule for how to judge a pattern before the evidence comes in. What you're really asking about is how we get the right priors.

Having good priors is why Latin-to-English is easier than English-to-Latin. You know a lot about what English sentences look like, because of how you grew up—subjects and verbs and objects in familiar orders. You can spot a few key vocabulary words in the Latin, crossing off sentences before you even entertain them. It's iterative, subconscious, and you don't make the leap all at once.

Ian: Fair enough. If I think about it, I may even do a little conscious diagnosis, too, at the end. If I have two translations I'm deciding between, I might ask how they'd look in Latin.

Where do these priors come from?

Teacher: Practically speaking, the answer is that we learn them. If you spend enough time in high school, you learn to prefer patterns that are in the curriculum, and if a doctor spends enough time in practice he learns the right preconceptions—

Ian: No, no, I'm sorry to interrupt, but I can see where this is going and I don't agree. If I need priors to choose between patterns, I can't learn the priors themselves in the same way! It's just regress; how can I learn the high school testing pattern without having certain preferences that prefer that pattern over, say, the Illuminati Conspiracy Pattern that tells me you and the rest of the faculty are lizard people who pass messages to me through the bus lines. If you contradict me, I can just say you're wrong —I've done that to other teachers, you know.

Obeying my biology might make me happy, but it won't tell me the truth, and it won't get me to the stars.

Teacher: I do. If you trace the regress back far enough, our priors come from evolution. Ancestors with the wrong priors die out; our priors get better; we become more rational.

Ian: What does death have to do with rationality? Evolution doesn't want you to know the truth. It wants you to believe the thing that will bring you more children. If evolution can get you to have more children by thinking beautiful women are actually shadows of a divine order, then a lot of people are going to walk around completely convinced of that, with these kinds of lizard-people priors that are constantly confirmed.

Obeying my biology might make me happy, but it won't tell me the truth, and it won't get me to the stars. Changing my biology is no better: drugs, brain hacking, it's just more priors, and how can I judge between them?

Tell me about beauty. Beauty is a way out.

Teacher: That's correct. It's a value, but it's a universal one—we call it beauty here in Chesterfield High, but other cultures might have called it something else, and that beauty, or elegance, or whatever it is, is "a thing." It's a real, measurable quantity, something that can guide us beyond our biological priors. It's Occam's Razor, preferring the simple, avoiding unnecessary complications. Some people even call it the "Universal Prior."

Ian: It sounds a little religious. At least it's not indexical. I'll take a universal principle over a specific one. And I confess it has a rather attractive, esoteric feel.

This prior, it has to do with succinctness, like a poem—how swiftly the rule can be conveyed. My rule is complicated, yours is not, so yours is more likely.

Teacher: Yes. We do as the great physicists did: equate beauty and simplicity, and judge the latter. When we ask which rule is simpler in the most general and abstract fashion possible, we're talking about something called Kolmogorov Complexity. Every rule has a Kolmogorov Complexity, the length of the rule stated in the most efficient fashion possible. The smaller the complexity, the more beautiful and preferable the rule.

Ian: — but —

Teacher: And I know where you're going; you're going to give all sorts of objections to why your rule is actually simpler than mine.

Ian: Yes. And unless you can show me why, I'll have to assume that this Kolmogorov Complexity is just another ideology, something that's made up to tilt me in one direction over another. Maybe it's beauty, but it's basically the same as getting hot for girls. Or boys.

Teacher: Don't get personal. It's not a trick. Kolmogorov Complexity—let me put a lot of mathematics aside for a moment—is absolutely real. Every pattern has a simplicity, which corresponds to its Kolmogorov Complexity.

Ian: So let's settle the original question. Is there an app that tells us the Kolmogorov Complexity of our rules?

Teacher: No, there's no app.

Ian: Why not?

Teacher: Because even though Kolmogorov Complexity is real, and every rule has one, it's not knowable. It's not measurable.

Ian: That's nonsense. It might be hard to calculate, but how can it be impossible? Why can't I just work it out?

Teacher: We usually show that with a proof by contradiction. If you tell me that you have a calculation method, I'll show you how it must—for an unknowable set of patterns —give the wrong answer. And I'll even show you that you can't get close. If you think you have a way to approximate it, I'll show you how that method must be wrong as well.

Ian: So there's a universal prior, but we'll never know it? You're using reason to tell me that rationality is unfounded, that there are these unknowable edges. That's insane.

Teacher: A lot of things have edges. In the case of reason, it's a very crinkly one, hard to spot, and easy to wander back and forth across. It's quite beautiful, really.

Ian: You don't understand. I'm 16 years old. I'm in high school. Half the people around me are morons, half of them are sex-crazed, and half sold out for status. A plurality are all three. We haven't even gotten into how I feel about my body. The whole System has traumatized me, and I'm full of harmful—irrational—beliefs.

Rationality is my ticket out. The only reason I can trust you is that you seem rational enough to talk to. But now you're telling me that rationality is just a layer on top of the System—it's just as irrational as the people I'm trying to escape. I don't know which is worse: being duped by someone else's priors, or being a biological machine.

Teacher: Don't go too far. You're a smart kid—you can iterate faster than most. You can match patterns better. Evolution set you up well. You'll get better at predicting the consequences of your actions, and better at adapting your environment to your will. Rationality is systematized winning.

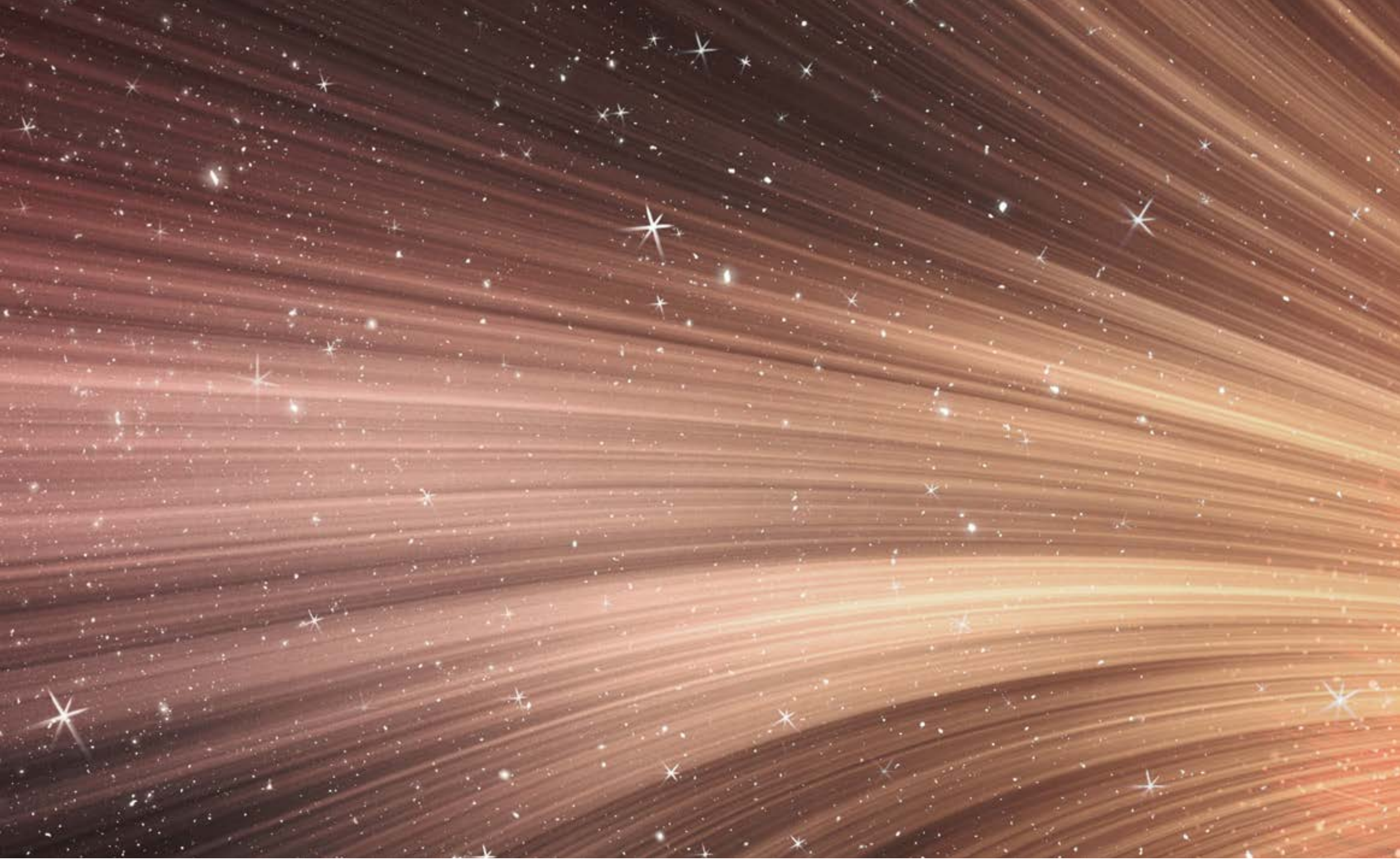
Ian: It's not winning I'm worried about. It's my mind. Maybe it's silly, maybe it's a fetish, but I want to know the truth. It's the principle of the thing. Wanting to know the truth got me this far, but now the only option you've given me is believing in something I can't see. If I know it at all, it can't be through rational, scientific calculation. There's some kind of extra-rational process I have to engage in—but what's beyond the edge of reason?

Teacher: Many things. Dreams, intuition, transcendence, love, ascending the ladder, repetition and the leap of faith, philosophy itself …

Ian: … delusion, fairy tales, fascism!

Teacher: Childhood's end.

SIMON DEDEO is a professor of social and decision science at Carnegie Mellon University, and external faculty at the Santa Fe Institute. In November, he'll be leading a public seminar on the future of intelligence through the New Centre for Research and Practice.



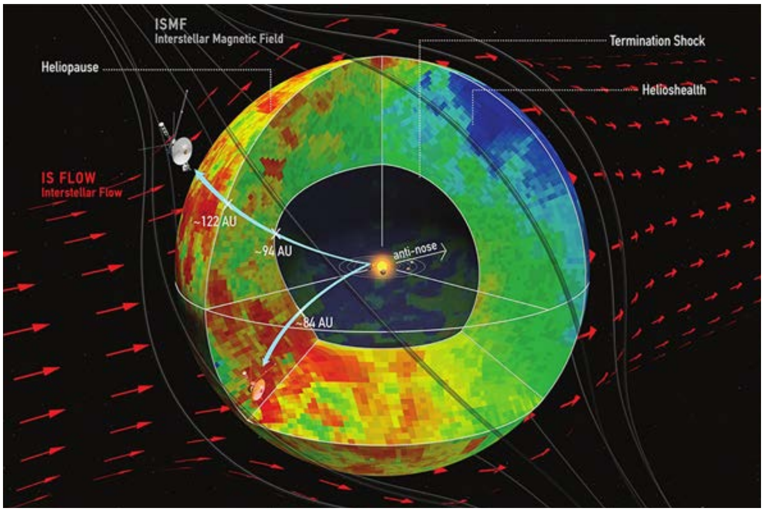
The Safety Belt of Our Solar System

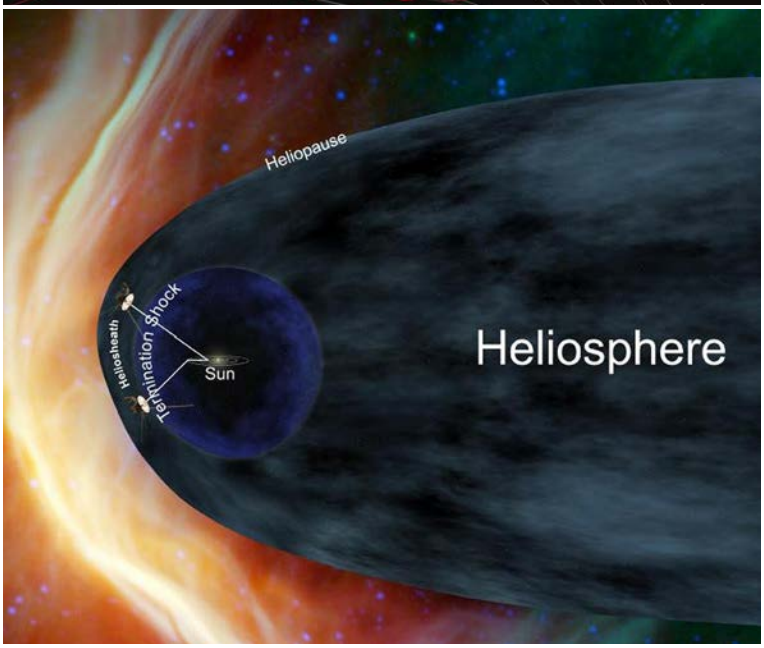
Mapping the heliosphere, which shields us from harmful cosmic rays

BY VIRAT MARKANDEYA

OOBQOO / SHUTTERSTOCK

DAVID MCCOMAS HAS a favorite "astrosphere," the environment created by a star's stellar wind as it buffets the surrounding interstellar medium. It belongs to a star named Mira. In an image from 2006, Mira is heading to the right, at 291,000 miles an hour, five times the speed our sun ambles through its local interstellar cloud in the Milky Way. You can make out a "bow shock" forming ahead of the star, like one would ahead of a boat sailing through water. Gas there heats and mixes with the wind of the cooler hydrogen gas blowing off Mira, and then flows to the star's rear, forming a wake. Mira's astrosphere, trailing behind the star to the left, looks turbulent, fragmented, and stretched. "How clearly you can see it sort of fall apart from this single structure to these turbulent smaller structures," McComas, a professor of astrophysical sciences at Princeton, said in a recent video interview. "I think it is very beautiful."





DOES IT HAVE A TAIL?

Recent data from satellites and space probes suggest our heliosphere, butting up against the interstellar medium, might be more compact and rounded (top) than scientists thought (bottom). We might be missing a comet-like tail, a feature which has been spotted in the astrospheres of other stars.

When McComas isn't admiring Mira's astrosphere, he's spearheading efforts to understand our own, the "heliosphere," a bubble canonically comet-shaped. He's eager to learn about the functions it might serve. Since 2008, McComas has been the principal investigator of the Interstellar Boundary Explorer (IBEX) mission. He oversees the data the IBEX satellite collects to disclose the nature of our solar system's edge. He'll also be in charge of IBEX's successor, the Interstellar Mapping and Acceleration Probe (IMAP), which is set to launch in 2024.

What might count as our solar system's boundary? There is no definite point at which light from our sun completely fades, or where its gravity stops being felt, so neither of those could mark it. But the heliosphere can. It "moves through the galaxy, keeping our home safe," McComas says. The sun's solar wind, an outflow of ionized gas, or plasma, pushes out against the galactic material between stars, also called the "interstellar medium." The interstellar medium in our very local region is a mixture of plasma, helium, and neutral hydrogen. It is formed by warm, partially ionized clouds found in the local bubble, a large cavity filled with plasma that was likely produced by multiple supernova explosions, along with interstellar dust and other stellar winds. The barrier separating us from this occupies a region far beyond the orbit of Pluto, one you can define and measure.

"In some ways," McComas says, "it is like our ship traveling through interstellar space." Without it—as data from the Voyager probes,

NASA

launched in the 1970s, indicated—we would be bombarded on Earth by four times the amount of cosmic rays that come at us, which would be damaging to both the Earth's ozone layer and our DNA. This year, using data from IBEX, McComas and his colleagues were able to create a 3-D map of the heliosphere—from the inside. Scientists have only had quite a limited sense of things from the outside. In the last decade, both Voyager 1 and Voyager 2 crossed the heliosphere's threshold, a layer called the heliopause, and offered some data on the shape of our bubble ship's front. (The Voyagers are racing ahead of the sun in the same direction.)

What might count as our solar system's boundary?

"These in situ measurements," McComas and his colleagues wrote in a paper recently published in *The Astrophysical Journal*, "have provided the necessary ground truth as to the scale of the heliosphere, but as such, we only have direct measurements along two spacecraft trajectories at specific instances in time, providing important but very spatially and temporally limited information about the dimensions of the heliosphere."

Unlike the Voyagers, IBEX doesn't have a camera that collects light. Rather it has two sensors, on either side of its less-than-a-meter-wide hexagonal shape, that collect particles called energetic neutral atoms. Neutral atoms of hydrogen drift unimpeded through electromagnetic boundaries that separate interstellar space from the heliosphere. "They're sort of meandering," McComas says. Directly observing the interstellar neutral gas that flows into the heliosphere gives an estimate of the speed at which the heliosphere is moving relative to the interstellar medium. (At around 52,000 miles per hour, it's a comparatively leisurely pace.)

If a neutral hydrogen atom passes close enough to a proton in an ionized gas, the proton will snatch the electron from the hydrogen atom, and when it snatches that electron, the proton becomes a neutral, and the hydrogen atom becomes a new proton: a process known as charge exchange. The new neutral has the properties of the ionized gas. It will have a temperature and a bulk motion, corresponding to where the neutral was created, that can be used to pick out "hot" or energetic regions. "If you have a detector that can measure these energetic neutral atoms," says Gary Zank, a space physicist at the University of Alabama at Huntsville, who has worked on IBEX, "what you're basically doing is learning about where those energetic neutral atoms were created."

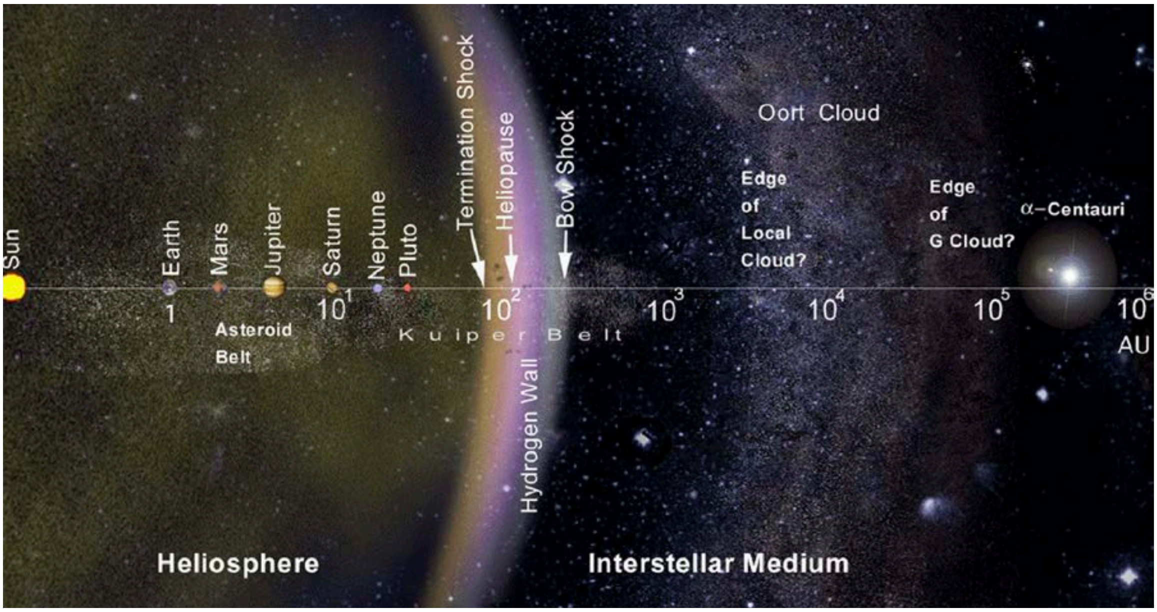
These can come from the heliosphere's boundary and from beyond the boundary. Populations of neutral atoms moving at around 310 miles per second come from the region dominated by the supersonic solar wind. Atoms going around 62 miles per second come from the inner heliosheath, where the solar wind becomes subsonic as it hits against the interstellar medium. Energetic neutral particles can also come from solar wind interacting with the moon's surface, and from processes occurring in Earth's magnetosphere.

These particles, coming toward us from all directions, some of them bouncing off of the inside of the heliosphere, clue scientists in on how the sun's solar wind interacts with interstellar space as our solar system drifts around the galaxy. Weighing a little more than the average American, IBEX has been orbiting Earth for more than a decade, observing the solar system's edge with enough success to have earned McComas the chance to probe the barrier further, with IMAP.

To investigate the distant barrier of our solar system, McComas has had to grapple with an internal barrier—his dyslexia, a condition that makes it difficult to interpret letters and words. But it may have helped set him on the scientific path he's on today, in more ways than one.

SINCE HE HAD DIFFICULTY learning to read in grade school, he gravitated toward taking apart and reassembling whatever he got his hands on. In high school, he started a business, using a propane torch to solder unusual jewelry that he sold across the Midwest, earning enough money over three years to actually consider foregoing college. Later, at MIT, he got involved in its center for space research, which needed a candidate to do fine assembly: a task McComas had experience in.

In a 2014 talk about his dyslexia and scientific career, titled "A Personal Journey from 'Slow' to the Interstellar Frontier," McComas says that, when he discovered



THE HELIOSPHERE'S SCALE The extent of the plasma bubble protecting us extends far beyond the orbit of Pluto as it pushes against the interstellar medium, as shown in this logarithmic scale.

INTERSTELLAR PROBE / JET PROPULSION LABORATORY / NASA

an interest in physics, he found it uncannily intuitive. "I felt like I could just understand the answers." In one slide of his presentation, he shows a graphic illustrating a finding he made in the 1990s, that the sun's solar wind is much faster at its poles. "This is sort of typical for how I've been able to communicate in my own area," he said. "Putting together the different pieces of knowledge into a single graphic that, if you're a space physicist, doesn't need a caption."

He credited dyslexia with helping him become a more collaborative scientist who can recognize people's strengths and weaknesses, and thereby form better teams. "It took hundreds and hundreds of people to do the IBEX mission. You need people with all kinds of different skills and you need them to work together well," he said. "So, I think there's a diversity of thinking that's easier for dyslexics to understand why that might be good."

Early results from IBEX made the cover of *Science* in 2009. The satellite captured a mysterious ribbon structure projected over an "all-sky" map flattened to two dimensions. "The IBEX results are truly remarkable, with emissions not resembling any of the current theories or models of this never-before-seen region," McComas said at the time. "We expected to see small, gradual spatial variations at the interstellar boundary, some 10 billion miles away. However, IBEX is showing us a very narrow ribbon that is two to three times brighter than anything else in the sky." The neutral atoms IBEX was collecting, in other words, were not coming from all directions in more or less equal amounts. It's a big hint to scientists that the way our sun's magnetic fields interact with the galaxy's magnetic field is much more complicated than they supposed. Still, scientists can use the ribbon to glean how we're moving through the galaxy's magnetic fields, and how those fields, in turn, influence our solar system.

The ribbon is like an imprint. It maps onto locations in the sky where the energetic neutral atoms would be seen to propagate from a source in straight lines as they pass unimpeded. "If you're looking with a detector," says Zank, "what you will see is in a certain radial direction all these energetic neutral atoms coming right back at you." It may not be unlike situations where we might catch a glint of sunlight in the ocean. On a sunny day, there is always a region where there's a much brighter sort of pattern of light, like a slightly broad line, says Zank. "The reason you see that brighter sort of light from the reflected light from the ocean," he says, "is that this is the light that is directed straight at your eyes."

Data started streaming in after Christmas, and it looked like IBEX's instruments were glitching.

In that November issue of *Science*, McComas ventured six theories to explain it. The list of potential explanations soon crossed over 10, though several are variations on a theme. Today, McComas is more-or-less convinced that one of them is right.

What seems to be happening, McComas explained, is that a fraction of the charged particles that were part of the solar wind, and are now neutralized, are propagating radially out, past the heliopause into the local interstellar medium. They become trapped and gyrate around the magnetic field draped across the heliosphere. Eventually, the energetic neutral atoms reneutralize and radiate back in, toward the heliosphere. This series of charge exchanges could explain the ribbon, which originates a few hundred astronomical units beyond the heliopause. (One astronomical unit, the distance between Earth and the sun, is 93 million miles.)

IBEX is able to probe plasmas at distances of a few hundreds of astronomical units. IMAP will take it up to 500 astronomical units or more. "There's a fundamental limit on how far you can see with neutral atoms," says McComas, "It's still a really long ways." The limit is related to the atoms' energies and charge exchange. IMAP, at a cost of over $600 million, will carry a suite of 10 instruments to allow McComas to, among other things, better verify his idea of what causes the ribbon structure. Measurements with greater sensitivity can pinpoint its source.

IMAP may help astrophysicists decide conclusively what our heliosphere looks like. The standard view seems to be that it looks like a comet, but Merav Opher, a space plasma physicist at Boston University, has been arguing, using simulations, for a croissant-shaped heliosphere, rounder and with lobes. "It has profound implications about how stars are encased in their own bubbles and how those bubbles filter galactic cosmic rays," she says. Opher and her colleagues predicted how the interstellar magnetic field would press on the heliosphere, making it asymmetric particularly in its southern part, which the Voyagers verified. It cannot be a complete sphere because the plasma has to flow out. "You need a horn," Opher says. "You need an exit of the plasma."

IMAP, which will map energetic neutral atoms in a higher energy regime than IBEX, will help constrain the models, particularly whether the heliosphere has a long tail, extending thousands of astronomical units, or a relatively more compact tail a fraction of that length. Still, Opher and her colleagues believe that in-situ measurements are crucial, and propose such a probe to go out several hundred astronomical units beyond the heliosphere for the 2030s.

With the launch of IMAP, McComas is looking forward to doing "a very complete science job." What would be ideal is discovering what sort of physics fundamentally controls our solar system's evolving space environment, and thus, the origin of the ribbon. One might hope this would include a surprise or two. It wouldn't be the first time. In our video call, McComas recalled an episode of sheer anxiety shortly after IBEX launched into space, in October 2008, from the Kwajalein Atoll atop a Pegasus rocket that was dropped from an airplane. Data started streaming in after Christmas, and it looked like IBEX's instruments were glitching.

"The first swathe [of data] showed this bright thing down here, south of the equator," McComas told me, which wasn't predicted by the prevailing theories. With his physical copy of the *Science* issue featuring his work on the cover handy, he pointed to a part of the all-sky map. The second swathe of data, he said, showed the bright swathe as well. It wasn't until the spacecraft made an adjustment, and a structure started to emerge, that the team exhaled: It was the ribbon. They were seeing something real.

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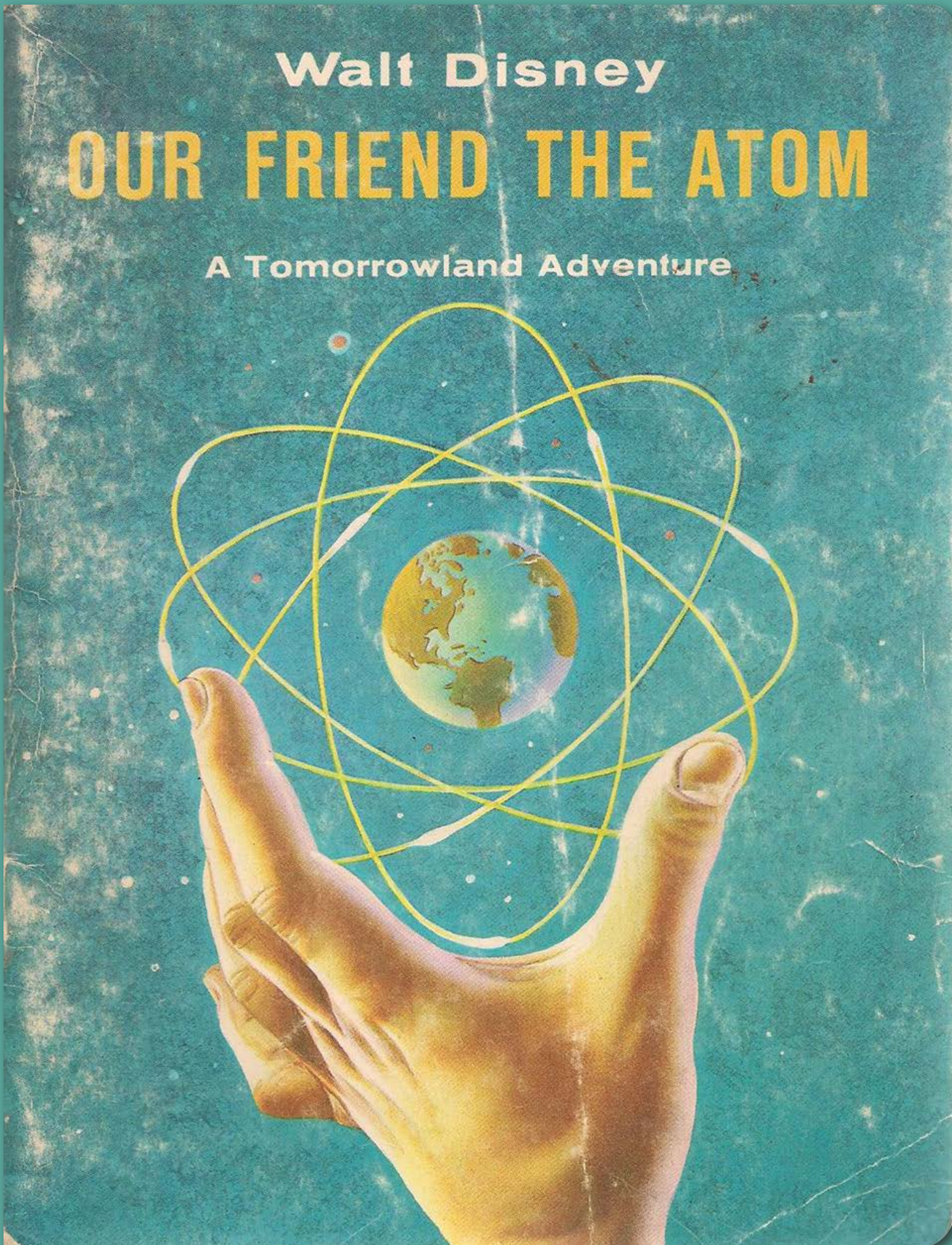

Walt Disney
OUR FRIEND THE ATOM
A Tomorrowland Adventure

The Disneyfication of Atomic Power

Inside America's propaganda campaign, "Atoms for Peace," launched in the wake of Hiroshima

BY JACOB DARWIN HAMBLIN

JOHN JAY HOPKINS' VISIT to Japan in 1955, as an informal emissary of "Atoms for Peace," must have seemed surreal to everyone involved. Hopkins was the head of an old American shipbuilding firm based out of Groton, Connecticut. Electric Boat Company had struggled in the 1920s and 1930s with its reputation as a "merchant of death," having sold warships to all sides in major wars. During World War II, it had stuck to the Allied war effort, producing several hundred patrol torpedo boats that became decisive in the island-hopping campaigns in the Pacific between American and Japanese forces. The Japanese had called them "devil boats," harassing Japanese ships and helping American marines to take control of the vast Japanese Pacific empire. The company had also produced dozens of submarines that killed Japanese sailors. One of these, the USS Barb, was alone credited with sinking 17 Japanese vessels, including the aircraft carrier Un'yō. The Barb even had pioneered the use of submarine-launched rockets, bombarding civilians in towns on Japan's home islands in 1945.

Just 10 years after Japan's defeat, and only three years after the departure of United States occupation forces, Hopkins was in Japan being treated not as a foe but as a hero. He had made some changes to his company, including its name. It was now called General Dynamics, with Electric Boat one of its subsidiaries, mostly hidden from view. He had hired a graphic designer to help him to rebrand, creating a series of posters with the words "Atoms for Peace" next to "General Dynamics" in several different languages. He made speeches suggesting that American technology was going to provide power and food to the world and that his company stood ready to participate in a kind of global Marshall Plan that harnessed the atom. Perhaps surprisingly, the first country to take him seriously was Japan, the only country to have been attacked with atomic bombs. Hopkins was capitalizing on President Eisenhower's 1953 "Atoms for Peace" speech, in which he declared the U.S. would use atomic energy "for the benefit of all mankind."

Hopkins was surprised to be invited there by rich newspaper magnate Matsutarō Shōriki, and after his arrival his astonishment only escalated. He was treated as a celebrity and dignitary, more like a head of state than the head of an infamous defense contracting company. His visit was heralded in local newspapers as the dawn of the new era in the nation's history. There were lectures and presentations about science, and there was entertainment galore, "on a scale lavish even by Japanese standards," as one CIA document put it. The event was pure pageantry, with women in geisha costumes, and a thousand of Shōriki's employees chanting "Banzai!" in his honor.

Although the promise of the peaceful atom has been imagined as a successful vision in the 1950s, only to be complicated by nuclear weapons proliferation and environmental concerns in subsequent decades, in reality "Atoms for Peace" opened a Pandora's Box right from the start. The speech itself was part of a concerted American propaganda campaign, and in some ways it worked like magic, providing the U.S. with a positive agenda at a time when genuine disarmament simply was not happening. It was launched cynically as a propaganda strategy, without a genuine peaceful program in place, and was nurtured with considerable publicity—including working with cartoon filmmaker Walt Disney to turn the atom into a "friend." The U.S. government eagerly sought success stories that showed the atom as a pathway to abundance and health, but it would struggle in the years to come to offer genuine solutions to developing countries.

The Americans were not the only ones capable of embracing a cornucopian vision of the atom. Eisenhower's initiative provided rhetorical tools to others who pursued political or even personal goals in their own countries. The first major efforts to take "Atoms for Peace" seriously were in East Asia, particularly post-occupation Japan and South Korea, freshly emerging from the Korean War. In both cases the U.S. would be confronted with its own empty promises because these countries explicitly asked for American help to build nuclear reactors to power their economic resurgence. Instead,


atoms for peace
ERIK NITSCHE
GENERAL DYNAMICS

The event was pure pageantry, with women in geisha costumes, and a thousand Japanese employees chanting "Banzai!"

U.S. officials stalled for time and wavered, unsure how—or if—they should genuinely encourage a peaceful nuclear industry outside the U.S. and Europe. Japan's was a particularly striking case, because of the sharp shift in attitudes about peaceful atomic energy—moving from deep skepticism in the late 1940s, to outrage at American weapons testing in mid-1954, to a rapid about-face that favored peaceful atomic energy, mid-decade. The apparent reversal surprised everyone, and soon American officials took credit for it as a propaganda win. Yet it also revealed troubling uncertainties about peaceful nuclear technologies, as U.S. government officials realized they were unable to control the pace and direction of Japan's nuclear ambitions.

BECAUSE THE U.S. PRESIDENT'S atomic proposal of late 1953 was conceptualized within a psychological warfare framework, the administration worked closely with newspapers to shape public discussion—starting within the U.S. The president counted on political allies in the press, such as William Laurence of *The New York Times*. Laurence was long accustomed to helping "sell the bomb," as one scholar put it, having been paid by both the newspaper and the U.S. government to report in precisely the way government officials wanted, adding his own insights and vivid writing style. His eyewitness account of the bombing of Nagasaki and subsequent essays on the meaning of atomic energy had won him the 1946 Pulitzer Prize for reporting. After the war, "Atomic Bill" Laurence played a crucial role in framing public attitudes about atomic bombings and about the Bikini bombs, and he was tapped to do the same for "Atoms for Peace." News articles bearing Laurence's byline, while not exactly as "official" as press releases, were reflections of what U.S. officials hoped to convey to the public, in the guise of detached reporting.

Together with the newspaper's longtime science editor, Waldemar Kaempffert, Laurence launched a publicity campaign on the pages of *The New York Times* focusing on the wonder of the atom, the importance of private enterprise, and the peace-loving attitudes of the president. Just after the new year, Laurence penned "Atomic Power Being Tamed to Turn Industry's Wheels," looking back at 1953 as the year marking a transition from military to peaceful atomic energy, as if that had been the intent all along. He expected the coming decade to bring "epoch-making progress" to detect and treat diseases and to put the atom to use "in a thousand and one fields of endeavor, as widely divergent as are archaeology and agriculture." He predicted that all the heretofore-unheralded applications might turn out as "tails wagging the atomic dog."

Laurence's predictions included the so-called breeder reactor, which would be able to use by-products of fission as fuel, allowing humans "to multiply nature's niggardly store of atomic fuels by a factor of 140, or about 14,000 per cent." That was 23 times what was produced by all conventional fuels combined, he enthused. The article led with an image of the naval submarine USS Nautilus at the center—labeled "power"— surrounded by other images representing oil research, new metals, chemicals and medicine, and plants and foods. The latter was one of Brookhaven's gamma gardens.

Laurence made the world seem wide open to fantastic possibility, and he hewed closely to the administration's line that peaceful uses of atomic energy were themselves a form of arms control. He spoke of the "transition" from military to peaceful uses as if playing a zero-sum game with the world's supply of uranium. The more it was used for peace, the less it would be used for war. He also reported on the first "atomic battery" made by RCA, using strontium-90. It was initially employed by the company's chairman of the board David Sarnoff to send a message via telegraph: "Atoms for peace. Man is still the greatest miracle and the greatest problem on this earth." Laurence heralded it as an important new source of electricity, and he believed strontium-90 would be widely available, cheap, and destined to "find thousands of potential uses in the developments of atomic energy for the peaceful pursuits of mankind the world over."

Eisenhower counted on political allies in the press, such as William Laurence of The New York Times, *who was accustomed to helping "sell the bomb."*

Major publishing houses helped promote the government initiative as well. Random House's series on science, "All About Books" included a volume on atomic energy, eventually published in 1955. Written by Rutgers University professor Ira M. Freeman, *All about the Atom* contained all of the optimism found in the president's program, especially for the poorest countries of the world. "The United States and other countries could lend nuclear materials and engineering help to the undeveloped regions of Asia and Africa," he wrote. "This would make the neglected parts of the world flourish. In just a few years, they could make more progress than in many centuries before."

Although Eisenhower did not use the term "Atoms for Peace" in his original speech, newspapers picked it up immediately. It was an old term—already employed from time to time, such as when discussing nuclear-powered electricity. Going forward it would be linked unmistakably to this particular speech and plan by Eisenhower. Other phrases would soon be added, notably "plowshare." It was a reference to the prophet Isaiah, whose memorable words from the Bible referred to soldiers beating their swords into plowshares, turning weapons of war into farm implements.

One corporate ally who immediately latched onto the president's speech was Hopkins. One of the General Dynamics' biggest government contracts was the USS Nautilus, a submarine built for war, powered by


l'atome au service de la paix
hydrodynamics
ERIK NITSCHE
PRINTED IN SWITZERLAND
GENERAL DYNAMICS
LITHOS R. MARSENS, LAUSANNE

an atomic reactor, and named after the submersible craft in Jules Verne's *Twenty Thousand Leagues Under the Sea*. The work on the ship was begun during the Truman administration, but the Nautilus' launch occurred on Jan. 21, 1954, less than two months after Eisenhower's historic speech. Hopkins spun the launch of the Nautilus less as a victory for the U.S. Navy and more as a step forward for humanity. One company-produced brochure about the launch noted, "The 'Nautilus' will be listed in the annals of man as the first demonstration of his ability to curb the destructive force of the atom and to turn it in positive directions." Gwilym Price, the president of Westinghouse (which manufactured the reactor itself), observed that the Nautilus was "a testimonial to the ability and determination of free men to act in the defense of human rights and dignity." The navy had a new class of submarine that could stay submerged for extended periods without the need for refueling, but those at the christening ceremony described it as a boon to humanity and a part of the new peaceful direction of the atom.

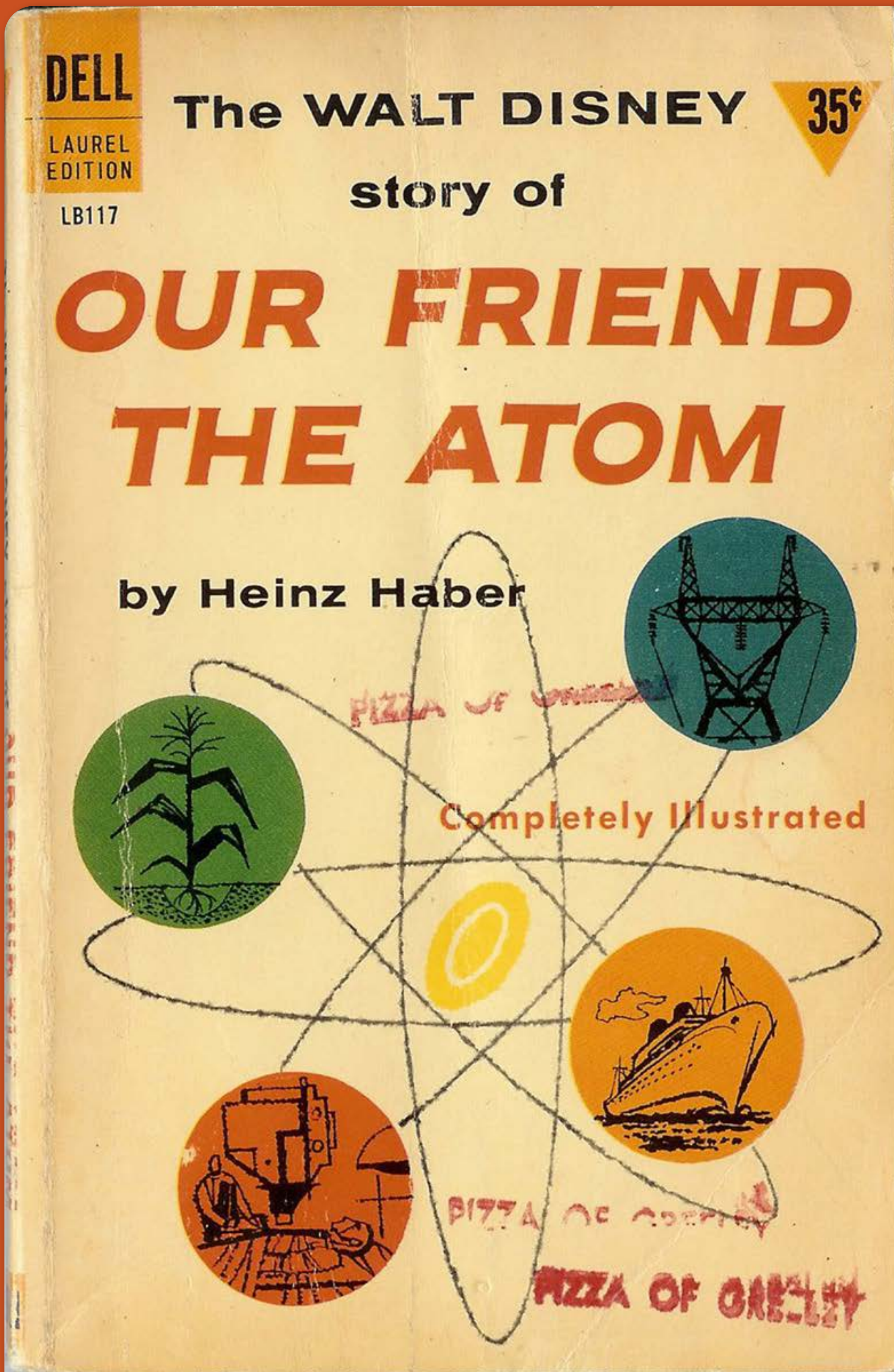
Hopkins saw the opportunity of using "Atoms for Peace" to consolidate the rebranding of General Dynamics as a purveyor of technologies beyond the conventional wartime domains of Electric Boat. He dreamed of atomic ships and airplanes and eventually would create a subsidiary—General Atomics—to sell research reactors to countries around the world. He had his sights set on August 1955, when the Eisenhower administration planned to sponsor a major international conference on the peaceful atom in Geneva, Switzerland. There would be opportunities for contractors to put up exhibits, and among these contractors were American household names like General Electric, Westinghouse, and Union Carbide. Hopkins was determined to seize the opportunity to mark his newly named company as modern, progressive, and futuristic.

His primary publicity instrument was the Swiss-born graphic designer Erik Nitsche, whose style fit this vision. Nitsche's work for General Dynamics would mark him as one of the most influential modernist graphic designers. His drawings were suggestive of a scientific mindset, with an aesthetic sensibility that blended imagination with clarity and orderliness. Simple yet elegant, with precise shapes and lines but abstract in concept, his artistic renderings were the perfect fit for the relatively unknown future of atomic energy. As one writer later wrote, "Nitsche's brand of artful futurism was copied by many others at the time and might be seen today as representative of the so-called 'Atomic Style' that emerged in the mid- to late-1950s." He made six posters for Hopkins for the 1955 conference, each featuring the firm's name along with the phrase "Atoms for Peace" in one language or another. The French one featured the word "hydrodynamics" along with a visual of the Nautilus, positioned not as a war vessel but as a harbinger of peace. The German one, on "aerodynamics," showed the atomic-powered airplane then under development. There was a Japanese one too, on "nucleodynamics," and it was highly abstract—a series of colored squares (some have described it as a rendering of isotopes), with an inset photograph of two physicians.

THERE WAS NO BETTER FRIEND to the atom, however, than cartoonist and film producer Walt Disney, who agreed to promote the peaceful atom with a new film to be aired on television. Disney producers later explained to the FBI that it took about a year and a half to prepare for it and to film it. "This type of film is usually not profitable for the company; however, Mr. Disney likes to do films of this type occasionally as a public service." Disney was already a household name for inventing Mickey Mouse in 1928 and making the 1937 blockbuster *Snow White and the Seven Dwarfs*. In early 1954, when "Atoms for Peace" needed some publicity, Disney was coming off the success of *Peter Pan* (1953) and was in the process of planning an ambitious theme park, to be built in Anaheim, California. He also had partnered with the American Broadcasting Company to produce a series of television programs for children. All of this put him in an important position to influence young families' attitudes about all manner of things, including atomic energy. The FBI's 1954 assessment of Disney was that he was reliable, cooperative, and "extremely prominent in the motion picture industry," and that year he became an approved FBI contact for the bureau's "Special Agent in Charge" in Los Angeles.

Disney's production, *Our Friend the Atom*, borrowed ideas already established by General Dynamics. On screen, Disney himself provides some introductory remarks while standing in front of several of the Nitsche posters. He makes a reference to Jules Verne's 1870 *Twenty Thousand Leagues Under the Sea*. "Fiction often has a way of becoming fact," he says, holding up the Verne book. Then he moves over to two scale models of submarines, one styled after the one in the story and another a replica of the "real" Nautilus—the USS Nautilus, the first ship to be powered by a nuclear reactor. He does not mention that it is a war vessel. "It's the first example of the useful power of the atom that will drive the machines of our atomic age," Disney states, adding, "The atom is our future." He then goes on to describe the many atomic projects that the Disney studio is planning in addition to the television program, including a book and ambitious exhibits as part of the Tomorrowland portion of the amusement park in southern California.

For Disney, this "public service" was a collaboration that would draw potential visitors to his new theme park. For his program on the atom, he drew from the same network of scientists he was already using to make a similar television program on space exploration. As narrator he chose Heinz Haber, whose gentle demeanor, foreign accent, and silvery hair lent the discussion some scientific gravitas. He was not a nuclear physicist, though. In the previous decade, Haber had been working as a rocket scientist in Nazi Germany and was likely introduced to Disney producers by fellow rocket specialist Werner von Braun. Both von Braun and Haber had been captured toward the end of the war by Americans under Operation Paperclip and went to work for the U.S. Army. Together with another colleague, Willy Ley, the two had written a series of essays on space exploration in *Collier's* magazine. These had captured the attention of executives at Disney, who saw space as the perfect subject for Tomorrowland. Producing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by Heinz Haber
Completely Illustrated
PIZZA OF GREELEY

For Walt Disney, this "public service" promoting the atom was a collaboration that would draw potential visitors to his new theme park.

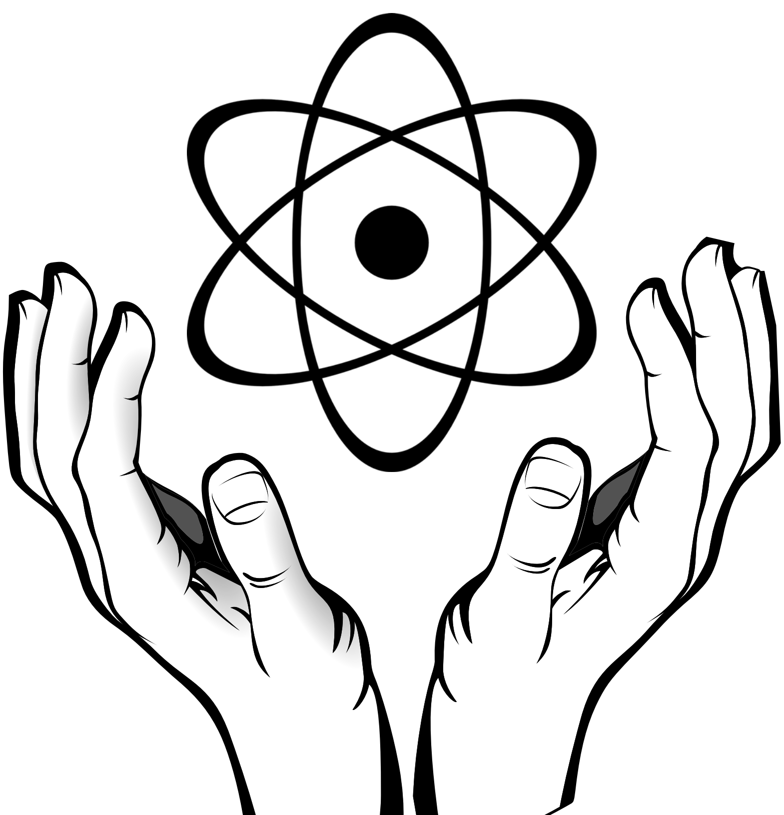
educational television programs about space exploration seemed like a great advertising opportunity for the new theme park. Kimball reached out to von Braun and soon both he and Haber became technical consultants for Disney. The first of the space programs aired on ABC on March 9, 1955. Von Braun focused on space, while Haber became the face of Disney's atom.

The Disney version channeled U.S. policy perfectly, with the book and television program both titled *Our Friend the Atom*. In the 1957 program, Haber eases into the discussion by saying that, yes, it was a science story, but that "it was almost like a fairytale. By a strange coincidence, our story turned out to be like the old fable from the Arabian Nights, 'The Fisherman and the Genie.' " Rather than discuss technical details, Haber begins by telling the story of a fisherman attempting to convince a magical creature, living in an ancient-looking container pulled from the sea, to do his bidding. Cartoons, orchestral music, and voice actors play out the story, before Haber reappears on screen to say that "we are like the fisherman. For centuries, we have been casting our net in the sea of the great unknown in search of knowledge. And finally," he says, holding up a rock, "we found a vessel. And like the one in the fable, it contains a genie. A genie hidden in the atoms of this metal, uranium." The cartoon genie then shows that it is radioactive by holding a Geiger counter next to it and drives the theme home: The genie is liberated, it first threatens to kill, and then it is "finally harnessed to grant us three wishes."

The publicity campaign for the television program and book was enormous. It involved syndicated news stories, magazine features, brochures, and even a school donation program calling on businesses to buy prints of the film to distribute in schools. The brochure for the donation program stated that "at the threshold of the atomic age we find our nation critically short of trained scientists and engineers so necessary if we are to reap the many benefits the friendly atom can bestow upon us." Of course, all of the cross-promotion was tied to Tomorrowland at Disneyland.

The television program proposed the atom not merely as a "friend," to be juxtaposed with the warlike atomic bomb, but also as a solution to a serious problem confronting the world—the limitations of nature. Haber notes that "the coal and oil resources of our planet are dwindling" and calls upon the genie to provide power. He also notes that humans continue to suffer from hunger and disease and says that our second wish for the genie should be "food and health." Finally the last wish is peace—to let the genie be a friend forever.

JACOB DARWIN HAMBLIN is the author, most recently of *The Wretched Atom: America's Global Gamble with Peaceful Nuclear Technology*. He is an American historian who is a professor at Oregon State University. He writes and speaks about international dimensions of science, technology, and the environment, especially related to nuclear issues, ecology, oceans, and climate.

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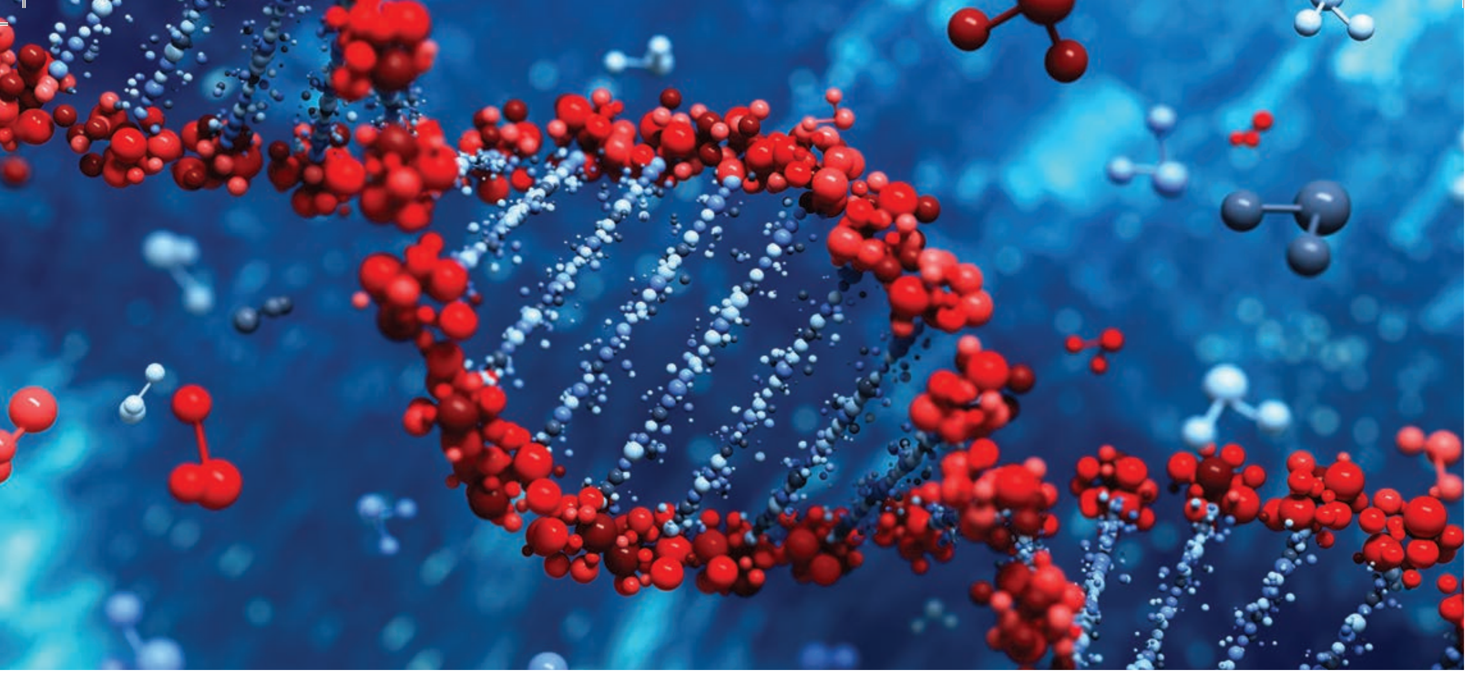

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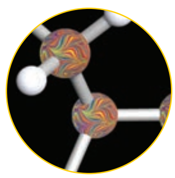

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Suzanne O'Sullivan

The neurologist on psychosomatic illness

INTERVIEW BY STEVE PAULSON

SLEEPING SICKNESS
In Sweden, I visited two little girls, aged 10 and 11. The 10-year-old had been in this odd comatose state for a year and a half, and her older sister had been like this for about six months. It was shocking. The 10-year-old looked healthy, but when her father tried to pick her up, she was floppy, like a rag doll. Her parents keep her alive with tube feeding. This has been happening in Sweden since the early 2000s. These are not just any children. They belong to families seeking asylum in Sweden, and they fall into this state of resignation syndrome when they are faced with potentially being deported from Sweden.

WHY THEY SLEEP
When I talk about disease, I'm referring to something which is objective, which isn't controlled by how we think about our bodies. But an illness is a perception of how one feels, and illnesses can be programmed through expectations in our brains. Let's imagine we're one of these asylum-seeking children and we know that the possibility of deportation sometimes leads to apathy. How would we respond when we felt those initial physiological changes? What can happen in illness is that our bodies respond how we expect them to respond. Think about what happens when you're being deported. First you feel a bit sick and then you don't have any energy. Then you don't feel able to get out of bed and then you close your eyes. It isn't unusual for somebody to manifest physical symptoms in the context of ideas, stories, and stresses.

JOHNATHAN GREET

BODY AND MIND
To a certain degree, illness is a social construct. If you believe that certain provocations will produce certain symptoms because it exists within the folklore of your community, it's easy for that to overwhelm your system and produce those symptoms. We shouldn't make the distinction between body and mind. Our body and mind interact together. They are real symptoms because they are disabling the children very severely.

HAVANA SYNDROME
In 2016, an American diplomat in Cuba heard a strange noise and got an odd set of symptoms that included things like headache, dizziness, unsteadiness, difficulty concentrating. That began the rumor that people in the embassy were being attacked by a sonic weapon. Then other people also said they heard a sound and got sick. Their experiences in the embassy were frightening. They were told to hide behind walls if they heard a strange noise. They were called to meetings and told to examine their bodies for symptoms. Well, what happens when you examine your body for symptoms? You find them. You immediately start noticing tingling and discomforts that you wouldn't normally notice. The doctors involved in the case said the diplomats are not acting or pretending, and they don't want to be sick. Now, if that's how you perceive a psychosomatic condition, you're pretty much saying to your patients, "Well, here are your choices: 'You're either pretending and you're mad and you want to be sick, or you're being attacked by a sonic weapon.'" Which would you prefer? The choice is obvious.


BALENCIAGA