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CONTACT

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

info@nautil.us

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Power of Myth

BY KEVIN BERGER

WE LIVE IN a vale of myths. They envelop us like the fog does San Francisco. When you have lived in San Francisco, as I did for decades, that can be magical. You can drive to an overlook and look down on the white billow blanketing the city. You are in a land of enchantment.

The myths we inherit can also blind us to reality. They lead us like The Sirens into personal and social wrecks. The beauty of science and good science writing is they lift the fog. Which is what this issue of *Nautilus* does. It explores the power of myths, their dark sides, and how science animates our world anew.

One lingering myth about human evolution is somewhere along the way we split off from our hominid ancestors and became human, imbued with humanity, and were no longer apelike. In "Portrait of the Human as a Young Hominin," Thomas Halliday, a paleontologist and evolutionary biologist, details the environment in which our ancestors evolved. The timeline of evolution is like a river, he writes. It doesn't stop and restart flowing.

"There was no moment at which humanity suddenly arose," Halliday writes. "We, like every other species, are the culmination of a series of partial replacements, the deaths and births of individuals in an ever-shifting population, with a continuity back in time and forward, connecting all living things together."

Science itself can be the source of pernicious myths, which persist when they're employed by writers with a biased personal agenda. When a recent example of an outdated myth, the "noble savage," reared up on social media, evolutionary anthropologist Dorsa Amir was inspired to knock it down.

In "A Viral Twitter Thread Reawakens a Dark History of Anthropology," Amir writes that "anthropology has been fraught with centuries of racism, colonialism, and imperialism, the effects of which still echo into the present and color how people talk about human variation. But like science more broadly, anthropology is self-correcting." Amir lays out for readers the careful science and research that shows the true lives of the Hadza tribe in Tanzania, the victims of the misrepresentation.

Cultural traditions of indigenous people, arising from their mythologies, are often seen in opposition to Western science. But as Nell Freudenberger writes in "Who Are the Scientists Here?" that view is being self-corrected. In a trip to Mo'orea, an island near Tahiti, Freudenberger witnesses native Polynesians and marine biologists from the United States and Europe find common ground among cultural traditions and practices in conserving the area's coral reef ecosystems.

After all, everybody, Western scientists and indigenous people around the world, are inspired by the same drive. In "As Creations Story Go, the Big Bang Is a Good One," astrophysicist Paul M. Sutter sounds the harmony.

"Here is where science can be its most beautiful, when it pulls hungrily from any source for a spark of inspiration to inform our knowledge of the universe, giving us a new tale to delight in," Sutter writes. "And here too is where science can be its most bold, when it finds the utmost boundaries of the known, a line once marked as impossible, and pushes unafraid into the dark."

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Preludes

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ZOOLOGY

The Machiavellians of the Animal Kingdom

When it comes to power plays, humans are not alone. Power—or more specifically the quest to attain and maintain power—lies at the heart of almost all animal societies. The subtle, and often not-so-subtle, ways that animals seek power over those around them are astonishing and informative, both in and of themselves and because they provide an evolutionary window through which we can better understand behavioral dynamics in group-living species.

One of the most informative insights into power dynamics is seen in mongooses. Mongooses mostly live in Africa and have long and slender bodies and one fierce demeanor. They may be most famous for attacking cobras. What mongooses demonstrate to evolutionary biologists is that individuals can increase their own power via their group. Michael Cant has been studying mongooses for 25 years. With mongooses, he says, "Battle lines are not to be crossed. If they are, all hell breaks loose."

Cant, a professor of evolutionary biology at the University of Exeter in England leads a team of seven Ugandan assistants, supervised by Francis Mwanguhya. The scientists study banded mongooses in Queen Elizabeth National Park in Uganda. Not only do all the team members know all the animals, but some of the banded mongooses appear to know specific members of the research team.

"There was one female," Mwanguhya says, who "did not like one of the researchers. Every time he turned up in the group, this particular female made a grumbling noise because this researcher had captured her group and [kept] them in the lab for [many hours before] releasing them." Mongooses can hold a grudge with the best of them: Mwanguhya was beyond surprised when, after his colleague was away for more than a year, he was greeted with the same grunts from the same female mongoose upon his return.

What started as an eviction had resulted in a full-fledged between-group power struggle.

Cant's early work focused on why there was high reproductive skew in groups: why a few dominant females produced young while suppressing reproduction in other females. Soon he began to learn that "mongooses are always puzzling, always surprising, they do everything wrong. They keep us scratching our heads for all sorts of reasons."

One of those reasons is that the dominant females in a group all give birth on the same day—indeed, on the very same morning. It happens on different days in different groups, but within groups the synchrony is astonishing. "You go there, and four or five females are massively pregnant and wobbling around," Cant says. "Then the next morning ... at eleven o'clock they emerge, all slim. We still don't know how that [synchronization] happens."

One of the other things that had him scratching his head, and ultimately led him to study between-group power scrums, was the periodic violent eviction of a subset of females from groups that were growing quickly. One day you see "peace and harmony and love and nibbling each other's necks, and then you go back the next day and all hell has broken loose," Cant says. "Some individuals, for reasons we don't know, have been labeled evictees and they just get relentlessly attacked by everyone. It is primarily females attacking females, but once an animal has been marked for eviction, even the little pups will come along and join in the kicking. There is a mob psychology to it."

As with humans, status means power. Matthew Bell, a behavioral ecologist now at the University of Edinburgh, has also studied mongooses. He has gathered data to show that high-ranking, pregnant banded mongooses tried to suppress reproduction by females lower in the power order. "The larger, more dominant, female would beat the crap out of the smaller ones. Massive disruption," he says.

Following one mass eviction, Cant discovered, something completely unexpected happened. Ten females were evicted from a group and approached a large group composed of 20 males and eight females. That was not the unexpected part. Mongooses live in groups. And so after an eviction, the most important thing to do is to get into or form a new group. "I went there in the morning and the big group was fighting against the females," Cant says, "driving them off." That, too, was not so surprising. But "then I went off and got some lunch, and when I came back in the afternoon, nine males had left the [large] group, joined the females, and were now fighting against their old group." That was surprising. What started as an eviction had resulted in a full-fledged between-group power struggle.

As memorable as that event was, Cant came to learn that it's not the typical way in which power struggles between groups unfold. Banded mongooses breed four times a year (with January and February as their two down months), and, sans a forced eviction, individuals don't usually disperse from groups. That leads to genetic relatedness within groups building up over generations, which, in principle, could lead to inbreeding—except that females have found a solution. They go searching for mating opportunities in neighboring groups. When they do, they are often followed by males from their own group, which has the effect of inciting fights between groups. "In the middle of the battle," Cant says, "females go and mate with males from the other group."

These between-group power clashes are a sight to behold. "When they are fighting, they are like single organisms," Cant says, "writhing balls of fur with claws, and they have these battle lines they draw, chasing in and out of bushes, screaming. Sometimes you suspect that animals don't even know if they ended up on the wrong side." It's such chaos that even when Cant and his whole team are there observing, they can't tell who's who. At the end of these clashes, which can last many minutes, there are often many casualties, including deaths, among males. Females almost always walk away unscathed—which is not to say that between-group power struggles are cost-free for females. When Cant and his team looked at pup survival rates, they found that pups at the den were less likely to survive if their group had been involved in an intergroup power struggle in the prior 30 days.

Power plays out at the group level in feral dogs in India, dolphins in Australia, capuchin monkeys in Panama, Argentine ants in California, red-tailed monkeys in Uganda. But it's groups of power-hungry mongooses who steal the show in the animal kingdom.

—Lee Alan Dugatkin

Adapted with permission from Power in the Wild: The Subtle and Not-So-Subtle Ways Animals Strive for Control over Others *by Lee Alan Dugatkin, published by The University of Chicago Press.*

ASTRONOMY

Were It Not for Cosmic Good Fortune, We Wouldn't Be Here

WHO DOESN'T WANT the trains to run on time? And thankfully, that's how the planets orbit the sun: dependable, and always on time. But it wasn't always like this. Scientists suspect the solar system, sometime in its early years, underwent a violent seismic shift. The orbits of the gas giants—Jupiter and Saturn—got tweaked big time, and the aftershocks affected all the planets, including Earth and Mars, as well as the asteroid and Kuiper belts.

VADIM SADOVSKI / SHUTTERSTOCK

In our new study, published in *Nature*, we rewrite the origins of this massive shift—called a "dynamical instability"—and explain how everything in the solar system today found its place. What's more, our idea is broadly applicable and may explain the orbits of exoplanets.

The idea of a dynamical instability crept into the minds of planetary scientists from the outside, from research on exoplanets. The first exoplanets astronomers discovered around stars like the sun were gas giants on orbits very close to their stars. Call them "hot Jupiters." They're exotic, circling about 1 percent of sun-like stars. But once astronomers discovered gas giants on more distant orbits—starting just wider than Mercury's orbit around the sun—they noticed that the planets' orbits were often extremely stretched-out.

It's not immediately obvious, but the stretched out orbit of a gas-giant exoplanet is a massive scar. It's a remnant of a violent past. When planets' orbits cross, it leads to close encounters that, due to gravity, deflect the planets' paths. After a series of encounters, one or more planets get ejected into interstellar space. The survivors have eccentric orbits—a telltale sign of something going seriously out of whack. At least three quarters (and probably 90 to 95 percent) of all giant exoplanet systems must be the survivors of dynamical instabilities.

Which raises the question: Did our solar system get lucky? Our planets have near-circular orbits—did we somehow avoid instability? Several signs point to no. The most compelling is that the giant planets' orbits appear to have been re-shuffled since they grew out of the sun's gaseous, planet-forming disk. Simulations show that the giant planets' orbits should have been near-circular and much more compact. Jupiter's orbit would be about the same as today, but the orbits of the other giant planets would be shrunk-down, putting Saturn much closer to Jupiter, Uranus close to Saturn's present-day orbit, and Neptune just a bit farther from the sun. Clearly, the orbits of the giants shifted a lot between their birth and today.

In 2005, researchers took the world of planetary science by storm after coming up with a theory, the Nice model, linking the instability with an apparent spike in the cratering rate on the moon called the "late heavy bombardment." An analysis of the rocks Apollo astronauts brought back from the moon suggested there was a delayed burst of impacts on the rocky planets about 500 million years after they formed, around 4.1 to 3.8 billion years ago. By that time, the oceans were already around, potentially harboring life. The Nice model has survived 17 years of intense scrutiny, and accounts for the orbits of the asteroid belt, Kuiper belt, Jupiter's Trojan asteroids, and even the irregular moons of the giant planets.

But a re-analysis of the moon's craters suggests that there was no cataclysm or spike. The impact rate declined smoothly instead. So, our only hint is that the seismic shift in the early solar system must have happened within the first 100 million years—although this doesn't tell us whether it happened before Earth and the other rocky planets finished forming or afterward. What triggered the big shift? We show, in our new paper, that it was likely the dispersal of the sun's planet-forming disk.

Did our solar system get lucky?

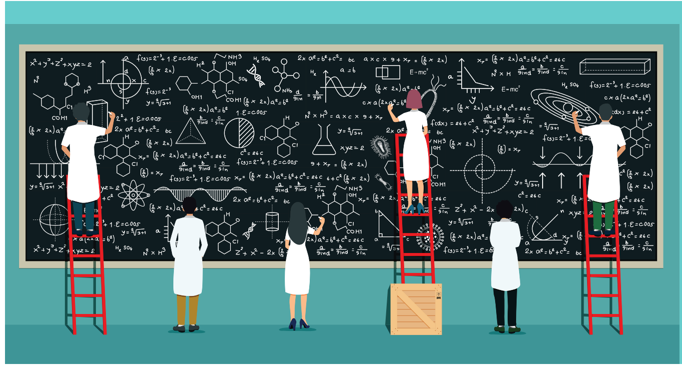
Stars that have just formed have disks of gas and dust orbiting them. Yet by 5 to 10 million years of age, almost all of those disks are gone. Where do they go? For the first few million years, the gas in the disks slowly drains onto the star (while some of the dust grows into rocky and ice-rich planets). Once the disk's density drops low enough, energetic photons from the star carve out an inner hole in the gas disk. Imagine a donut hole growing until the donut itself gets thinner and thinner and just … disappears.

The sun's disappearing donut is what shook the orbits of the already-formed planets. As the outward-sweeping inner edge of the gaseous disk passes by each planet in turn, it drags the planet outward with it. (Jupiter is an exception, as its large mass clears out a gap in the disk near its orbit, blocking the "push" from the sweeping inner edge.) In our simulations, we saw that as Saturn is pushed outward, it approaches the orbits of ice giants Uranus and Neptune. The net effect is to squeeze the planets' orbits closer together. The stability of planets' orbits depends on the spacing: More widely-separated orbits are far more stable. The squeezing of the system eventually triggers dynamical instability by causing one ice giant's orbit to cross that of another, or of Saturn's.

The gravitational effects of the instability would have stunted Mars' growth, potentially explaining why it's so much less massive than Earth. What's more, the instability would have led asteroids and comets to bombard the growing Earth, rather than one potentially already hosting primitive life. All of this means that planetary systems are bitten by the hand that feeds them, as instabilities among planets are triggered by the disks that spawned them.

The instability was a big deal for our solar system but, compared to those in other exoplanet systems, it was far weaker. Fortunately, Jupiter and Saturn must have avoided any close encounters, because if they had scattered off of each other, Jupiter's present-day eccentricity would be 5 to 10 times greater—similar to many giant exoplanets. In that case, there would be no Earth. Its building blocks would have been scattered into the sun.

—Sean Raymond, Beibei Liu, & Seth Jacobson



PHYSICS

Thinking Like a Scientist Will Make You Happier

JIM AL-KHALILI HAS an enviable gig. The Iraqi-British scientist gets to ponder some of the deepest questions—What is time? How do nature's forces work?—while living the life of a TV and radio personality. Al-Khalili hosts *The Life Scientific*, a show on BBC Radio 4 featuring his interviews with scientists on the impact of their research and what inspires and motivates them. His latest book, *The Joy of Science*, "was motivated by this sense that a lot of us have, that public discourse is becoming increasingly polarized," Al-Khalili tells *Nautilus*. "There seems to be a rise in irrational, anti-scientific thinking, and conspiracy theories. And there's no room for debate, particularly amplified by the internet and social media." His message is that we should all be thinking more critically.

What drove you to write a book about living by the scientific method now?

We are bombarded by information all the time, and your average person really doesn't know who or what to trust. But we can learn to know who and what to trust. We can employ some of the ways that we do science—examining biases, the importance of uncertainty, being prepared to change your mind in the light of new evidence. Those sorts of things go against human nature because we want to be right about our opinions. We don't like to be told we are wrong. But that's not the way we do things in science.

Do you think we can know reality, the world "out there," as it truly is, or is it more complicated than that?

This is an age-old question and it particularly came to the fore a century ago with the development of quantum mechanics: the most counterintuitive idea in science, the theory of the subatomic world. Famously there were long-running debates between the leading physicists of the time, Einstein versus the Danish physicist Niels Bohr. Einstein was a realist. He believed there's a real world out there and it's science's job to get as close as we can to that truth. In *The Joy of Science*, I lay my cards on the table. I would side with Einstein on that one. We may never reach it, but the world is the way it is. We can't make up our own narrative. We can't decide on our own reality. But Niels Bohr, the father of quantum mechanics—the guy was a genius—would argue that the job of science isn't to find out how the world is, because we can never find out how it is. The job of science is to see what we can say based on what we see, our perception, of how the world is. We can never say how the world *really* is.

Being able to admit you are wrong, in science is a strength.

Do you feel like that's a cop out?

Yes. We should say there's a real world out there, and it's our job to try and find ways of breaking out from the models that we create in our minds—the reality that we construct in our minds—that we hope reflects what the real world is like. I don't see any reason why we should absolve ourselves from that responsibility.

Why should we question our motives for believing what we think is true?

It's the way we do things in science. We constantly test our own ideas, because we know if we are wrong about something, other scientists eventually will discover it. Of course, some scientists will stick to their guns no matter what, but they don't last long. Those ideas don't survive very long. Just because you want something to be true or you want something to be correct, doesn't make it so. I think it's a nice lesson that wider society could adopt. Being able to admit you are wrong, to change your mind, in science is a strength, unlike in politics, where it's regarded as a weakness, right? Politicians don't like to admit mistakes or that they're wrong. Wouldn't it be refreshing if they could say, "Oh, actually. No, you've got a good point there. I've changed my mind. I now think this."

—Brian Gallagher

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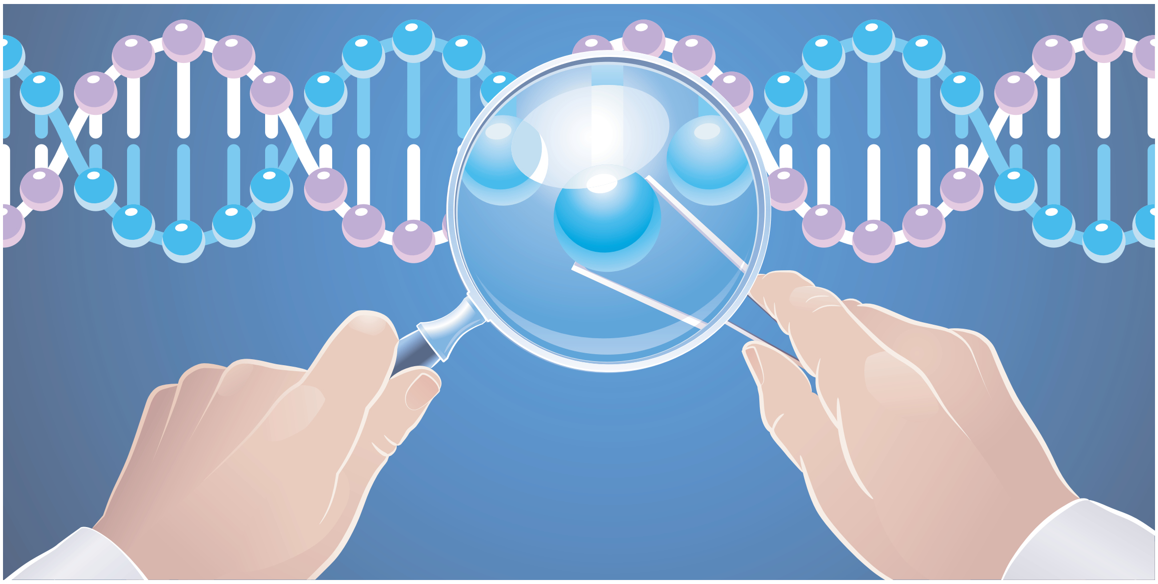


SERGEY TARASOV / SHUTTERSTOCK

HEALTH

Can Cancer Be Treated by Changing Its Cells?

IN 2017, KAREN KOSTROFF, an oncology surgeon at Northwell Health added a new talking point to her standard conversation with breast cancer patients facing tumor removal surgery. The new topic seemed to give her patients a sense of purpose. Kostroff was asking her patients if they would donate their tumors to science. Researchers were studying the malignant cells, hoping one day to disarm them and stop them from spreading.

Most cancer patients don't die from their primary tumor—the spot where it first develops. Once detected, surgeons cut it out or administer therapies to kill it—such as chemotherapy, radiation, or immunotherapy. But cancer cells have an uncanny ability to travel. They slip through blood vessels' walls and catch a ride in the bloodstream to new places. Once there, they begin multiplying and become nearly impossible to extinguish.

"Patients die because cancers metastasize," says David Spector, a cell and molecular biologist at Cold Spring Harbor Laboratory on whose behalf Kostroff is asking for tumor donations. "Everybody starts with a primary tumor, which we take out," Kostroff says. "But they die because the brain swells, or the lungs fill up with fluids, or the liver is so replaced by the tumor that the liver doesn't function anymore."

Spector focuses on deciphering the inner workings of the malignant cells that enable them to travel and invade other organs. He thinks he can stop the perpetrators in their tracks with a drug currently under development. Cells can experience a kind of identity crisis; they forget who they are and run rampant through our bloodstreams. The drug, when perfected, would reprogram the cells to remember who they are and start behaving normally.

It was the Human Genome Project, and the subsequent ENCODE project which aimed to create an encyclopedia of DNA Elements that steered Spector toward studying the secret life of cells and their RNAs. Once fully sequenced, the human genome revealed that only about 2 percent of our genome codes for proteins—the building blocks of cells and tissues. But a huge chunk of the genome—about 80 percent of it—is devoted to making various flavors of RNA molecules. The surprising findings left the scientific community rethinking the role of these RNAs.

“This drug seems to reprogram the cells and they suddenly remember who they are.”

An extremely versatile molecule, RNA has since earned its reputation as a workhorse of the cell, involved in nearly every aspect of cellular machinery, such as coding, decoding, regulation, and expression of genes. RNAs come in all sorts of shapes and sizes—some are short, some long, and others are circular, but each has a specific cellular job assigned. Human cells are composed of two major compartments: the cytoplasm where different molecular compounds function, and the membrane-wrapped nucleus that contains the chromosomes and the DNA. Some RNAs spend their entire lives inside the nucleus, where they were assembled. Others squeeze through the tiny pores in the membrane and leave the nucleus for the cytoplasm. There they carry out instructions for protein assembly or help stitch amino acids into proteins.

Spector focused his research efforts on the long non-coding RNAs, so named because they’re made of 200 or more nucleotides and because they don’t code for any proteins or help assemble them. Plus, they tend to stay inside the nucleus, a fact that was of particular interest to Spector. Because they don’t venture out into the cytoplasm, he inferred that they likely play a role in turning genes on the DNA ribbon on or off. That action can result in cancer if it doesn’t work properly—activating the wrong genes can lead to malignant growth, as can silencing specific genes that act as tumor suppressors.

After 18 years of studying the secret lives of cells and their RNAs, Spector’s team had zeroed-in on one culprit enabling breast cancer to spread: a long non-coding RNA called *MALAT1*. When healthy epithelial cells lining the surface of the milk ducts in the breast develop an excess of this molecule, they go bonkers. In biology, proper balance is key to health, so when some RNAs are overexpressed or under-expressed, diseases can develop.

The overexpression of this RNA makes breast epithelial cells lose their biological sense of self and start proliferating and spreading. “They’ve lost control,” explains Robert MacLeod, chief scientific officer at Flamingo Therapeutics, a company that is collaborating with Spector. “Normal epithelial breast cells know what they have to do, such as produce milk proteins when needed. But cancer cells think they need to grow and survive and look for a new home and metastasize to new organs.” It is as if the rogue RNAs act like the cells’ molecular murder accomplices, enabling them to sneak around. “We showed that the *MALAT1* RNA is involved in cells’ migration and metastases,” Spector says.

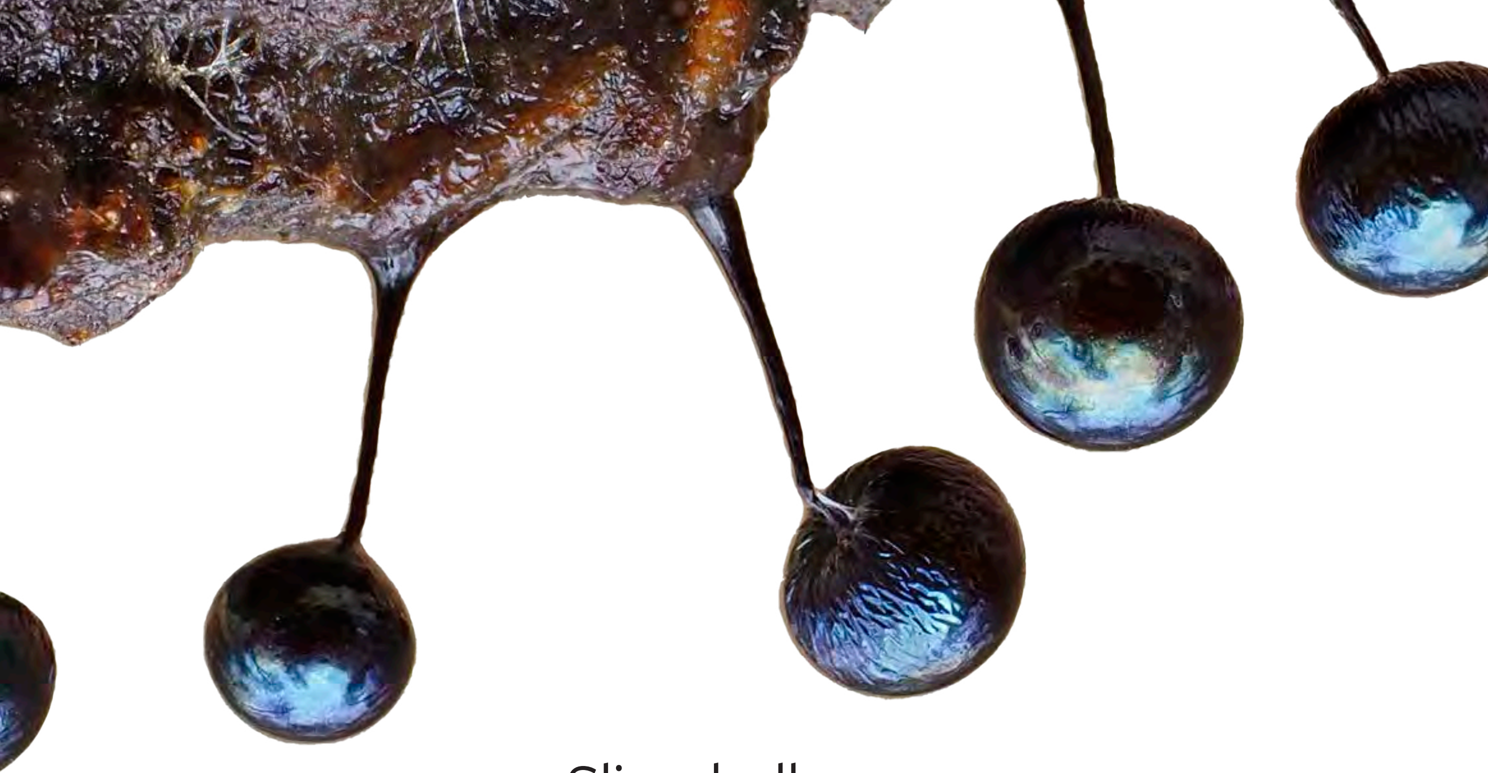
The next step was to see what happens if the amount of that RNA was reduced by a drug. Spector’s team and collaborators devised a clever molecular trick. They built a compound able to bind to the RNA, akin to how two sides of a zipper or Velcro straps stick together. Called an antisense oligonucleotide, the compound consists of 16 nucleotides that are complementary to a specific region on the *MALAT1* RNA so that when the two encounter each other in a cellular soup, they cling together. That marks the rogue RNAs for execution, molecular style. It sends a signal to a voracious team of enzymes that slice up the RNAs like miniature scissors.

But the most surprising thing happens after that, says MacLeod. With the decreased amount of *MALAT1* RNA in them, the cells recover some of their biological identity. “This drug seems to reprogram the cells and they suddenly remember who they are,” MacLeod says. “Oh, I am a breast epithelial cell, and I don’t need to metastasize and go someplace. Instead, I should do some things here at my home, such as supporting the mammary gland function.”

Spector’s team named their prospective therapeutic *MALAT1* RX. They found that it stopped the cancer’s progression in mice and in organoids—the mini-tumors grown from the chunks donated by Kostroff’s patients. The next step would be trying it in living people in a clinical trial.

Even though Kostroff’s patients who donated their tissues to Spector’s research may not benefit from this future drug, those a few years down the road may be luckier. “We started with no inclination that this may ever get to the clinic,” Spector says. “So the fact that we’re hoping to go to a clinical trial in about a year or two is extremely exciting. It would be a very significant triumph of fundamental research that we hope will really make a difference.”

—Lina Zeldovich



Slimeballs

THEY MAY BE BRAINLESS, but slime molds are influential movers and shakers around the world. In the miniature life-and-death dramas playing out beneath your feet on a forest hike, species like this *Lamproderma scintillans*, captured by photographer Andy Sands in a forest in England, are lead actors in life's final act: decomposition. As they prey on the bacteria, fungal spores, and other microorganisms that live in decaying plant matter, slime molds ooze around and over their rotting feeding grounds, facilitating the breakdown of their substrate.

DNA sequencing has revealed that slime mold should be classified as protists, single-celled organisms in the kingdom Protista. Like all protists, they start their lives as individual amoebas, but when food sources are scarce, they glom together to form long sticky lines, webbing out across a decaying log or mat of discarded leaves to better Hoover up their prey.

When it comes time to reproduce, species like *L. scintillans* sprout stalks topped by bulbous sporangia, fruiting bodies that hold hundreds of spores. In just the right combination of temperature and moisture levels, these disco-ball-like orbs burst, raining down the start of the next generation. Each spore develops into a single-celled amoeba, beginning a new cycle of life—and death.

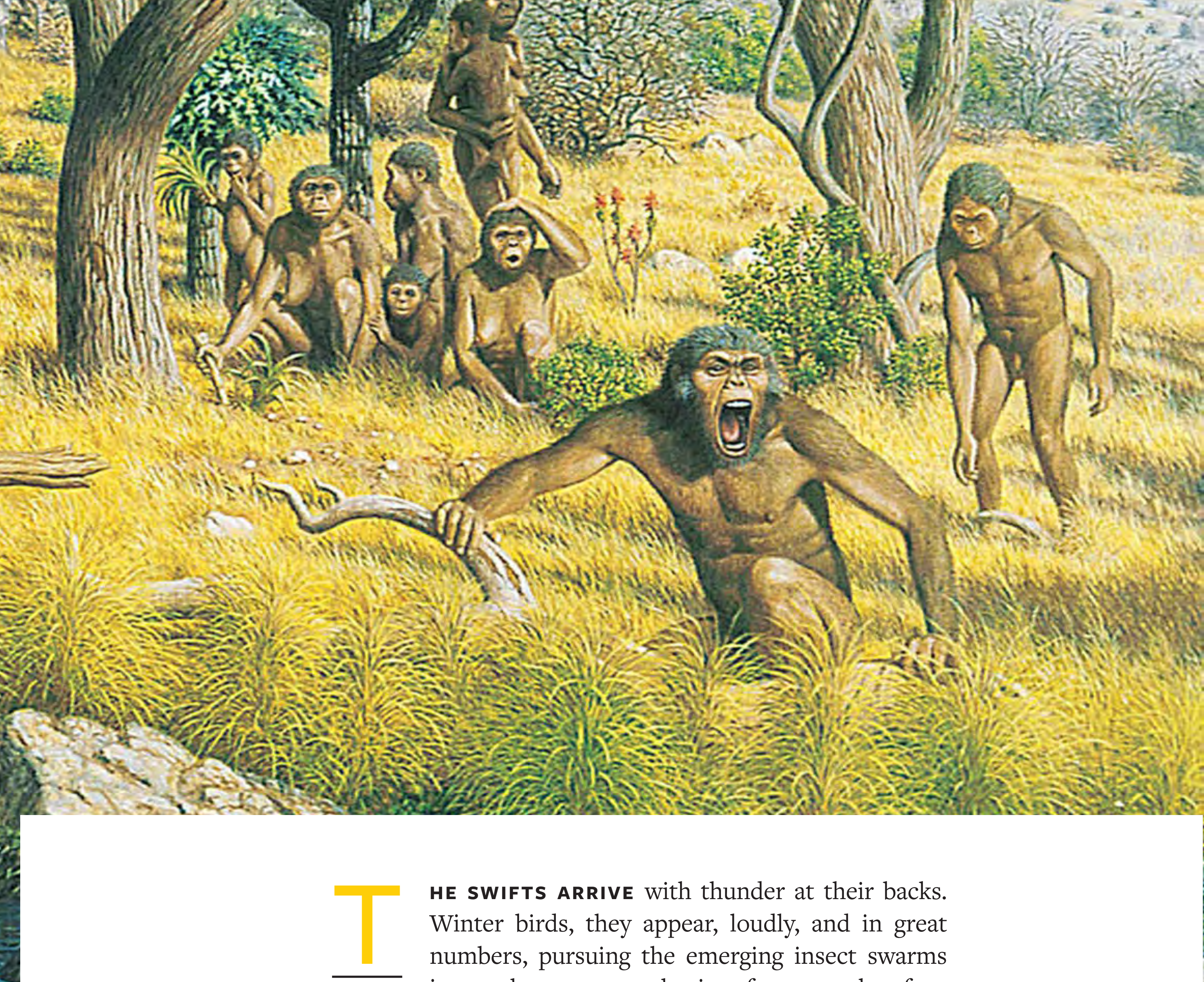
Photograph by Andy Sands; story by April Reese.

This story originally appeared in bioGraphic, *an online magazine about nature and solutions powered by the California Academy of Sciences.*

Portrait of the Human as a Young Hominin

How the world looked when we were Australopithecus

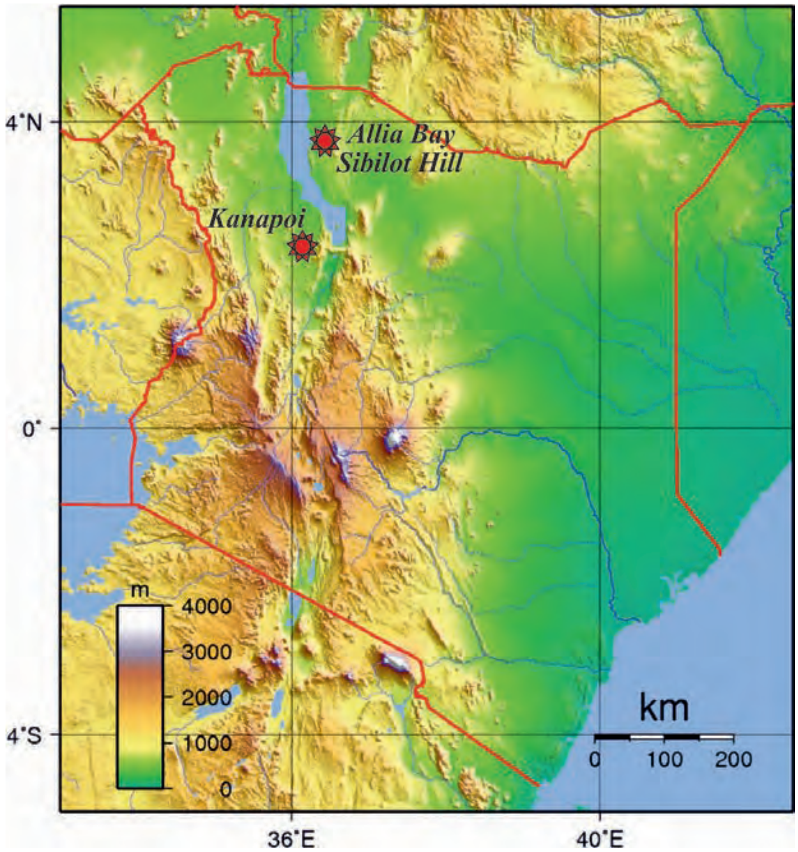
BY THOMAS HALLIDAY



WIKIMEDIA COMMONS

THE SWIFTS ARRIVE with thunder at their backs. Winter birds, they appear, loudly, and in great numbers, pursuing the emerging insect swarms just as the wet season begins after more than four months without rain. The arrival of the migratory birds marks the return of fertility and life, the continuation of a seasonal pattern that will last for millions of years to come.

The birds barrel through the mountain air of the East African highlands that will one day be part of Kenya and Ethiopia. The rise of these highlands, along with that of the Tibetan plateau thousands of miles away, has diverted the winds that once watered northwestern Africa, changing the patterns of rainfall across the region, and beginning the slow decline of the Sahara and Sahel into desert.



HOMELAND The Kanapoi area in the Kenyan Rift Valley was a dynamic world of diverging continents and seasonal thunderstorms in which the earliest humans emerged. In the Pliocene, on the banks of Lake Lonyumun, lived *Australopithecus anamensis*, the "southern ape from the lake," perhaps the oldest hominin of all. Paleontologists also uncovered *Australopithecus* fossils at the sites Allia Bay and Sibilot Hil.

WIKIMEDIA COMMONS

The great lake, Lonyumun, is evidence enough that rain can be plentiful here. Viewed from its stony shores, it may as well have been Kanapoi, an ocean; distant, blue-hazed mountain tops can be seen on a cloudless day, dipping their feet into the horizon. Only from the air are the limits of this lake, the shape of this drowned valley, apparent. As the swifts descend with scything screams, the blue-green lozenge provides them with a first glimpse of their destination.

Lake Lonyumun is spread wide and shallow, well over 300 kilometers from north to south and some 100 kilometers wide. It fills a vast crack in the continent, the East African Rift. Rising plumes of particularly hot magma in the Earth's mantle below hit the crust and spread out like steam hitting a ceiling. The drag of these magmatic currents is, slowly but incessantly, splitting Africa apart. The Somali plate, which holds the entirety of the eastern African coast, is separating from the Nubian plate, holding most of the rest of Africa. Further north, at Afar in Ethiopia, the Arabian plate is also splitting, a three-way junction that leaves a deep depression. The jagged line that runs down from Afar will one day split entirely open, heralding the birth of a new ocean where the rift now runs.

Now, the fractured land fills with rainwater, forming a series of rift lakes that change with climatic fluctuations. In the modern day, the area of Lake Lonyumun will house another lake, Turkana, from which no water ever flows. Lake Turkana is an alkaline, salty body of water, surrounded by volcanoes, as this region has been for millions of years. Its jade green, algal surface is often blown into a rage by powerful desert winds. Pliocene Kenya is wetter, and Lake Lonyumun is wider, spilling over the high ground toward the Indian Ocean. It is fed by rivers that carve through a base of laminated claystones, dense assemblages of mollusk shells, and thick, solidified sandbars, precursors to rivers that will still exist in the modern day—the Omo, the Turkwel, and the wide and gentle Kerio. The volcanic hills of the Pliocene are now being eroded, buried beneath this oxygen-rich river system.

It is in this dynamic world of diverging continents and seasonal thunderstorms that the earliest humans will emerge. Far in the future, there will be species of *Homo* here: individuals like the *Homo ergaster* juvenile known as Turkana Boy, and *Homo rudolfensis*, although it is possible that these are just variations within *Homo erectus*. But in the Pliocene, in Kanapoi among the acacias, where the Kerio flows into Lake Lonyumun, lives *Australopithecus anamensis*, the "southern ape from the lake," perhaps the oldest hominin of all.

The rain brings creatures out from hiding. In a fiery flash, a kingfisher breaks the river surface, feathers silvered with sunken air. Rebounding from the splash it has made with a fish in its beak, it flaps downstream to find a place to perch. Shovelnose frogs, fat little things, lumpy-backed and moss-colored, come together to mate, the male climbing on the back of the female as she digs down into the ground away from the river. Mice scamper through the greening grass, wary of the ambush of small carnivores—dwarf mongooses, dark-striped genets, and the earliest *Felis*, the wild ancestor of the domestic cat.

What distinguishes us from other animals? There was no moment at which humanity suddenly arose.

The low-running sleek of otters slide through the water, and the rain intensifies, as if it will never end. Its splashes form a low-lying fog of spray across Lake Lonyumun. The bull otter *Torolutra*, as big as a sea otter, and a hunter of fish—catfish, lokel, and the young of the idji—is very much at home in the rippling current. Wherever *Torolutra* are found, there are also their bigger cousins—bear otters.

With its muscular, flattened tail, an *Enhydriodon* swimming in the river would seem to be a floating, mossy log until it coils into a gleaming arch and dives. Searching for hard-shelled prey—mollusks, crabs, and the like—there are two species of bear otter in Kanapoi. Both have rounded pestles for teeth and use them to crush the same type of prey. It is believed that the two species can coexist only by dividing up their prey by size—the smaller of the bear otters going after younger individuals and smaller species of shellfish. The larger, *E. dikikae*, has the dimensions of a modern lion—two meters from whisker to tail and some 200 kilograms in weight.

Beneath the water, half buried in sediment, are round freshwater mussels, *Coelatura*, and the giant otter is searching for these. The juveniles are

The trouble with taxonomic labels is that they, like communities of organisms, aren't constant through time.

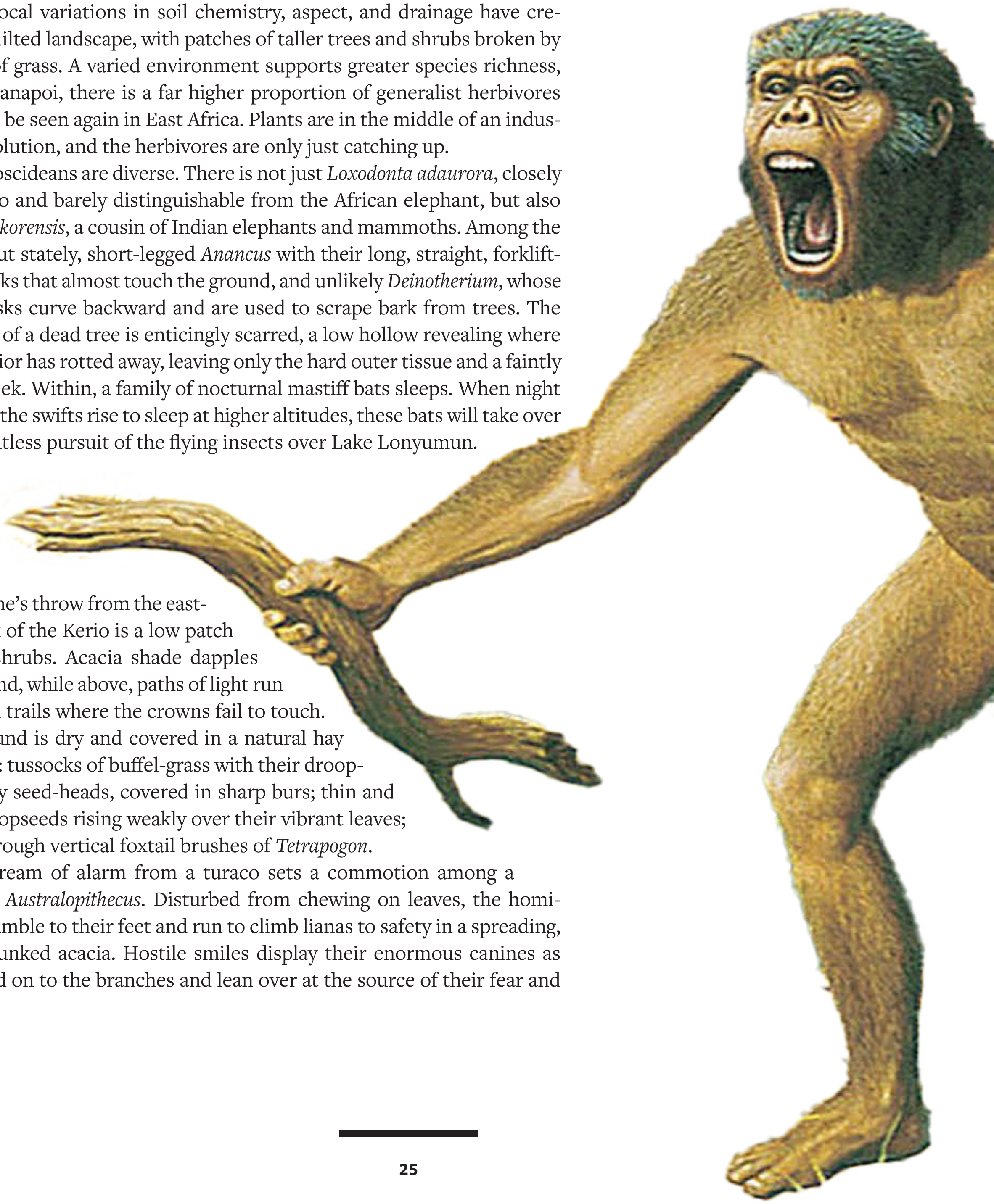
too small to concern the otter, but full-grown *Coelatura* are up to 6 centimeters long—a nutritious snack even if packaged with a crunch. *Enhydriodon* are less exclusively aquatic than most of their otter relatives, spending time relaxing on the bank, but still rely on the presence of large bodies of water in which to find their food.

A plunge from a kingfisher hardly causes a splash in the current. It emerges and lands on the back of a giant, silhouetted beast. The metallic blue bird stares at the water, taking advantage of this new fishing platform, which appears to be entirely unconcerned about its new associate. Two and a half meters at the shoulder, it stands cautiously in the muddy shallows, wary of the possible presence of gigantic horned crocodiles. Its short, whorled hair is matted down by the rain, with dark, long-lashed eyes shadowed by two bulbous projections. From the top of its head emerge two more, curving outward and backward to give the impression of an upturned sliver of a crescent moon. Not all giraffids are slender and long-necked; *Sivatherium* has the stockiness of an ox. Though they are an extremely rare part of the Kanapoi community, their kin are found from here in East Africa to the Himalayan foothills of India. They are the heavy-set relatives of giraffes and okapis, with full-grown males weighing well over a ton. But where sivatheres lack the charismatically gangly un-grace of a giraffe, they make up for it in the ostentation of their heads.

Around the banks of the Kerio, the rain has corralled the dust into a sheen of clay, but the slopes of rising hillocks are kept drier by well-drained sand. The land undulates, the higher ground sparsely specked with tree-shrubs and meadows of grass, while damper gullies are filled with forbs—non-grass fodder plants. Trees form a snaking avenue disclosing the course of the river for miles around. Where the Kerio River slows and drains into Lake Lonyumun, the water table is closer to the surface, and the canopy descends; shrubs compete with the trees, dissolving into thickets interspersed with wet, sandy ground, robed in sedges.

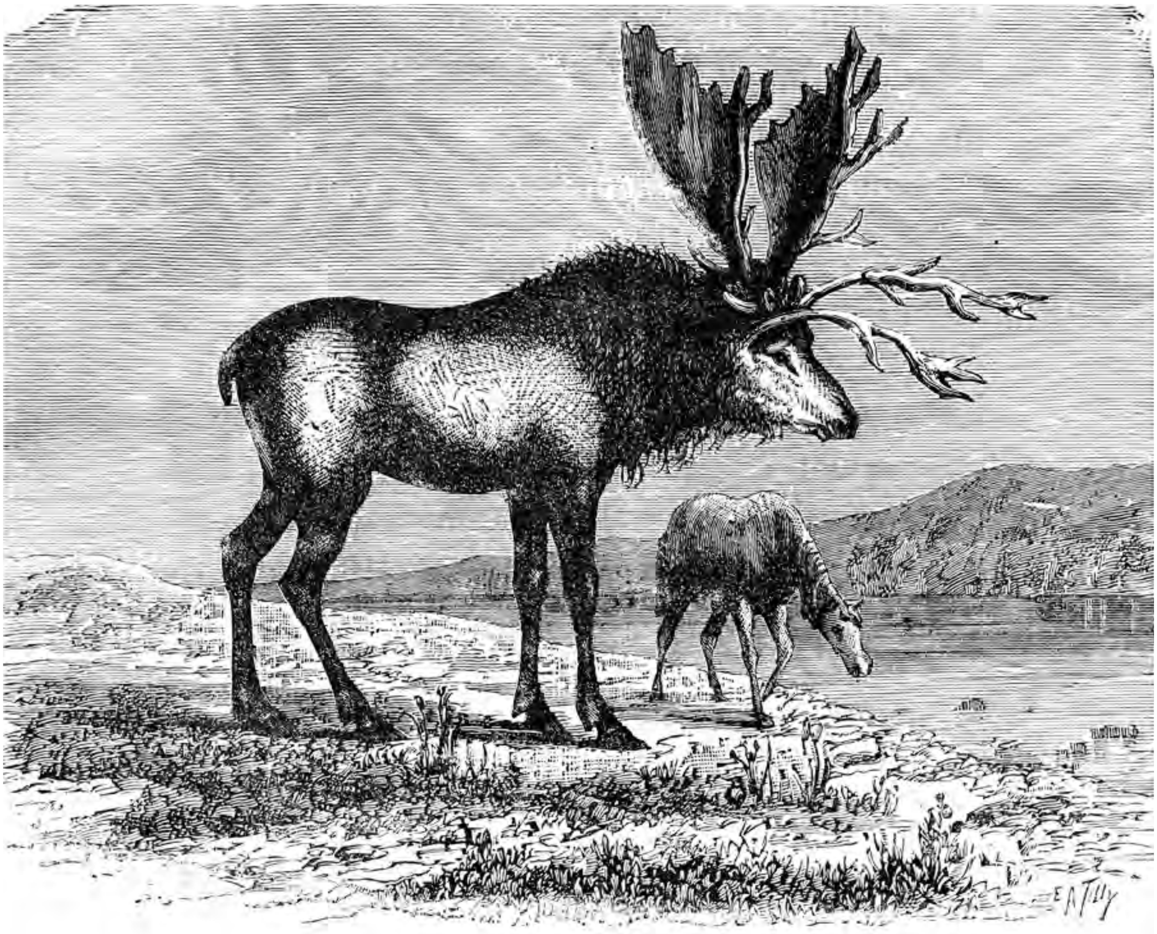
The local variations in soil chemistry, aspect, and drainage have created a quilted landscape, with patches of taller trees and shrubs broken by swards of grass. A varied environment supports greater species richness, and in Kanapoi, there is a far higher proportion of generalist herbivores than will be seen again in East Africa. Plants are in the middle of an industrial revolution, and the herbivores are only just catching up.

Proboscideans are diverse. There is not just *Loxodonta adaurora*, closely related to and barely distinguishable from the African elephant, but also *Elephas ekorensis*, a cousin of Indian elephants and mammoths. Among the trees strut stately, short-legged *Anancus* with their long, straight, forklift-truck tusks that almost touch the ground, and unlikely *Deinotherium*, whose short tusks curve backward and are used to scrape bark from trees. The skeleton of a dead tree is enticingly scarred, a low hollow revealing where the interior has rotted away, leaving only the hard outer tissue and a faintly fungal reek. Within, a family of nocturnal mastiff bats sleeps. When night falls and the swifts rise to sleep at higher altitudes, these bats will take over the relentless pursuit of the flying insects over Lake Lonyumun.



A stone's throw from the eastern bank of the Kerio is a low patch of tree-shrubs. Acacia shade dapples the ground, while above, paths of light run like snail trails where the crowns fail to touch. The ground is dry and covered in a natural hay meadow: tussocks of buffel-grass with their drooping, fluffy seed-heads, covered in sharp burs; thin and wispy dropseeds rising weakly over their vibrant leaves; and the rough vertical foxtail brushes of *Tetrapogon*.

A scream of alarm from a turaco sets a commotion among a troop of *Australopithecus*. Disturbed from chewing on leaves, the hominins scramble to their feet and run to climb lianas to safety in a spreading, broad-trunked acacia. Hostile smiles display their enormous canines as they hold on to the branches and lean over at the source of their fear and



ANCESTORS The *Sivatherium*, envisioned in this engraving, is an ancestor of the giraffe, though it has the stockiness of an ox. It would have grazed near our own ancestors, *Australopithecus*, around the grassy banks of the Kerio River, under the acacias, in what is now northwestern Kenya.

MORPHART CREATION / SHUTTERSTOCK

anger, while the swifts circle overhead in their endless ringing dance. There is something threatening them from low in the grass—a python, for which an australopithecine would be a good-sized meal.

The body hair of the upright *Australopithecus* is long. Their faces are ape-like, with jaws that project forward, and a sloping forehead tapering the head behind strong brows, to thick necks. The tallest are only about 150 centimeters tall, the same size as a chimpanzee, though they are less muscular, and there is a much bigger size difference between males and females than in modern humans. Their feet are not yet perfect for running; australopithecines have a slightly in-turned stance, helping them to climb the trees in which they sleep.

Having lost the initiative, the python retreats toward the river once more, sliding back toward the cracked trunk and buttressed roots of an echoke fig tree as the rain starts up

> Ever since our emergence, we have been altering our worlds to suit our biological requirements.

again. The australopithecines in the tree calm now, but remain in the branches, too spooked to return to the ground any time soon. Their food is mostly soft to tough plant material, with nothing hard, nothing really brittle, and no grassy plants.

AUSTRALOPITHECUS ANAMENSIS is the earliest species to be unarguably more closely related to humans than to chimpanzees and bonobos. A few other candidates are older, but there are disputes about whether they are closer to chimpanzees or humans, or whether they split off from our lineage earlier than chimpanzees. The life of *Australopithecus anamensis* is the beginning of the evolution of an initially diverse group of which we are the last survivors.

Ever since the earliest attempts at classifying the natural world, humans have been labeled separately from the rest of life, as something apart, something special. The trouble with taxonomic labels is that they, like communities of organisms, are not constant through time. In the modern day the distinction between humankind and our nearest relatives, the genus *Pan*, comprising chimpanzees and bonobos, is clear.

Were we to look at the population of apes that existed before the ancestors of chimpanzees and humans went their separate ways, we would see a single species, and we might give that species a name. Frequently, when a new species is born, it results from "budding"—an isolated population of a species changing relatively rapidly, with the ancestral species persisting in every meaningful way elsewhere. In such a case, we might continue to use the original name for the relatively unchanged population, but from the perspective of the "new" species, the number of generations from the pool of shared ancestors is hardly distinguishable. It is only with the benefit of geological hindsight that we can determine that a population in a slice of past time should be considered to be different. In real time, a species is a dynamic plurality, the sum of its component populations and individuals within and between which genes flow.

For humans, defining the point at which we are confident of claiming "humanity" is difficult. What, after all, distinguishes us from other animals? There was no moment at which humanity suddenly arose—the populations that led to *Pan* and the populations that led to *Homo* did not undergo a sudden shift—the mixing of two populations simply reduced to the point where no genes flowed. We, like every other species, are the culmination of a series of partial replacements, the deaths and births of individuals in an ever-shifting population, with a continuity back in time and forward, connecting all living things together.

To talk of the first humans is to hammer a signpost into an ancient river saying "no humans beyond this point," no matter the ever-flowing stream around its base. There is nothing essential to humanity, no single feature that intrinsically caused one creature to be a human where its parents were not. If we were to fast-forward, accelerate through time and follow these *Australopithecus anamensis* as the shared average features of the community shift into those of *Australopithecus afarensis*, the unimportance—or at least ambiguity—of this notion of species along the axis of time would be laid bare. In the time dimension, distinctions between Linnean ranks become meaningless. However hard you try to define every point before the signpost as non-human, and every point after the post as human, the river flows continually onward.

Australopithecus anamensis are among the first creatures we find within that river of humanity more closely related to us than to anything else that exists in the modern day. Although upright, *Australopithecus* are smaller than modern humans, about 130 to 150 centimeters tall, but still spend plenty of time in the trees, and retain the projecting jaws of non-human apes. No doubt as capable as chimpanzees with simple tools like stone hammers and anvils, they nevertheless predate the earliest human-knapped flint tools by half a million years. There are large body-size differences between males and females within their mixed social groups. As they shift into *Australopithecus afarensis*, their canines will reduce both in root size and in the extremity of their shape, the enamel will thicken, and the jaws shift to be wider set. Precisely how the australopithecines and later hominins grew and evolved in such a way as produced us is not well known; the course of the river has yet to be fully charted, and several paths will dry and evanesce to nothing, but *Homo sapiens* will appear not too far from its headwaters in the East African Rift.

The same is true of so many creatures in the cradle of Kanapoi. Those African elephants that can be found on the plains of Kanapoi, *Loxodonta adaurora*, are close relatives of modern African elephants, *Loxodonta africana*, but are a lineage that never made it to the present. The impala that graze on the grasslands are similar enough to modern impala to be assigned the same genus, *Aepyceros*, and are probably their direct ancestors. The giraffes here are almost identical to modern giraffes, a little smaller and with smoother foreheads, but with the unmistakable loping stride and long, ungainly necks.

Much, of course, will change in the interim, and many species will be lost. As creatures adapt and evolve, their niche-space shifts, and some will come to overlap and compete. Circumstantial evidence has led some to suggest that the bear otters of East Africa will ultimately meet their extinction because of hominins. The idea is that as the genus *Homo* arises, as tools become an ever-more important part of the ecology of hominins, the diet of humans will change from the herbivory of the australopithecines. This ever-more carnivorous niche will bring hominins into conflict with the other carnivores of East Africa, including the bear otters. The rocks record a decline in large carnivore number and diversity that peaks in intensity 2 million years before the present, just as the first species of *Homo* emerge from the Rift. The large carnivores that will survive to the present are the specialist meat-eaters—big cats, hyenas, and wild dogs—that prey on large, dangerous herbivores. Those that will be lost—otters, a bear, giant civets—are mixed feeders on plants, mollusks, fish, fruit—precisely the niche that we will ultimately make our own. If this is true, the bear otters of Kanapoi are destined to become perhaps the earliest species extinction caused by hominins.

Defining the point at which we are confident of claiming "humanity" is difficult.

Nature lovers often see the world as a dichotomy between some primordial, natural Eden and the cityscapes of the modern day. Humanity is seen as an external force, something separate to the ideal of "nature," which must be escaped to experience the

There is nothing essential to humanity, no single feature that intrinsically caused one creature to be a human where its parents were not.

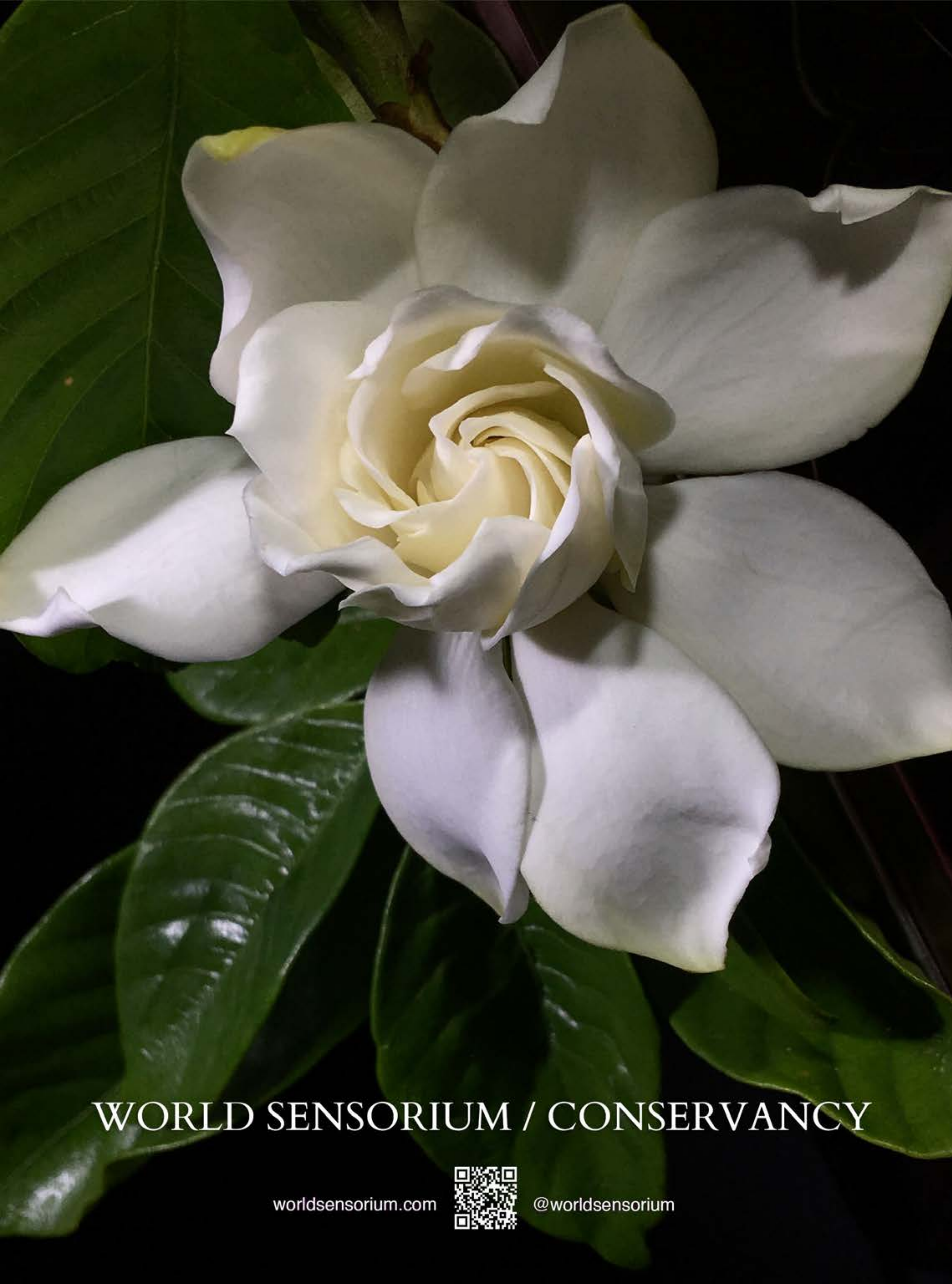
wild, and something which can only wreak a destructive force on the world. To take this view is to deny the naturality of humanity. Ever since our emergence, we have been fighting our corner, exploiting our own ecological niche, part of which is as a modifier of habitats, an engineer of ecosystems, altering the worlds in which we find ourselves to suit our biological requirements.

In Kanapoi, we see one of the earliest worlds largely recognizable as our own. The continents are almost at their modern positions, and the world is cool and ice-capped. Pliocene Earth resembles the recent interglacial periods, including the modern day. Kanapoi is a cradle, but not just of humanity. We are but one of the families that benefited from the ecological variability of East Africa, part of the earliest endemic African mammal community, with carnivores like hyenas, genets, mongooses, and wild cats. Among hoofed mammals, zebras, wildebeest, elephants, antelopes, and giraffes all trace their heritage to the shores of Lake Lonyumun at Kanapoi. Even among primates, Kanapoi is not just home to hominins. Early baboons, slight, long-limbed, and resembling mangabeys are here, too. The lake makes Kanapoi unique even among contemporaneous African fossil sites; no other site has such a diversity of aquatic and aerial birds.

The swifts still wheel over the Kerio valley, and stilts and storks still stride along the edge of the great rift lake. East Africa still has some of the most suitable landscape for dense concentrations of large herbivores in the world, and indeed the herbivores that live there are still very diverse. This regional diversity masks a bigger issue. There are equally suitable hotspots in India, in eastern Australia, and around the Great Lakes of North America, where large herbivores should exist, but do not. Even in the rich landscapes of Kenya, the presence of large herbivore communities is seriously under threat.

Many of the great beasts of the Pliocene past are long gone—sivathere and bear otter, giant pig and scimitar-toothed cat—and no intrinsic trait guarantees the continued survival of those still alive in our present. But even now, in the Rift Valley, there are glimpses of familiarity with what has gone so recently before, of the conditions in which we as humans slowly emerged. The planet may have lived long before us, but Kanapoi is the first world that humanity can claim as home.

THOMAS HALLIDAY is a paleontologist and evolutionary biologist. He holds a Leverhulme Early Career Fellowship at the University of Birmingham, and is a scientific associate of the Natural History Museum. His research combines theoretical and real data to investigate long-term patterns in the fossil record, particularly in mammals.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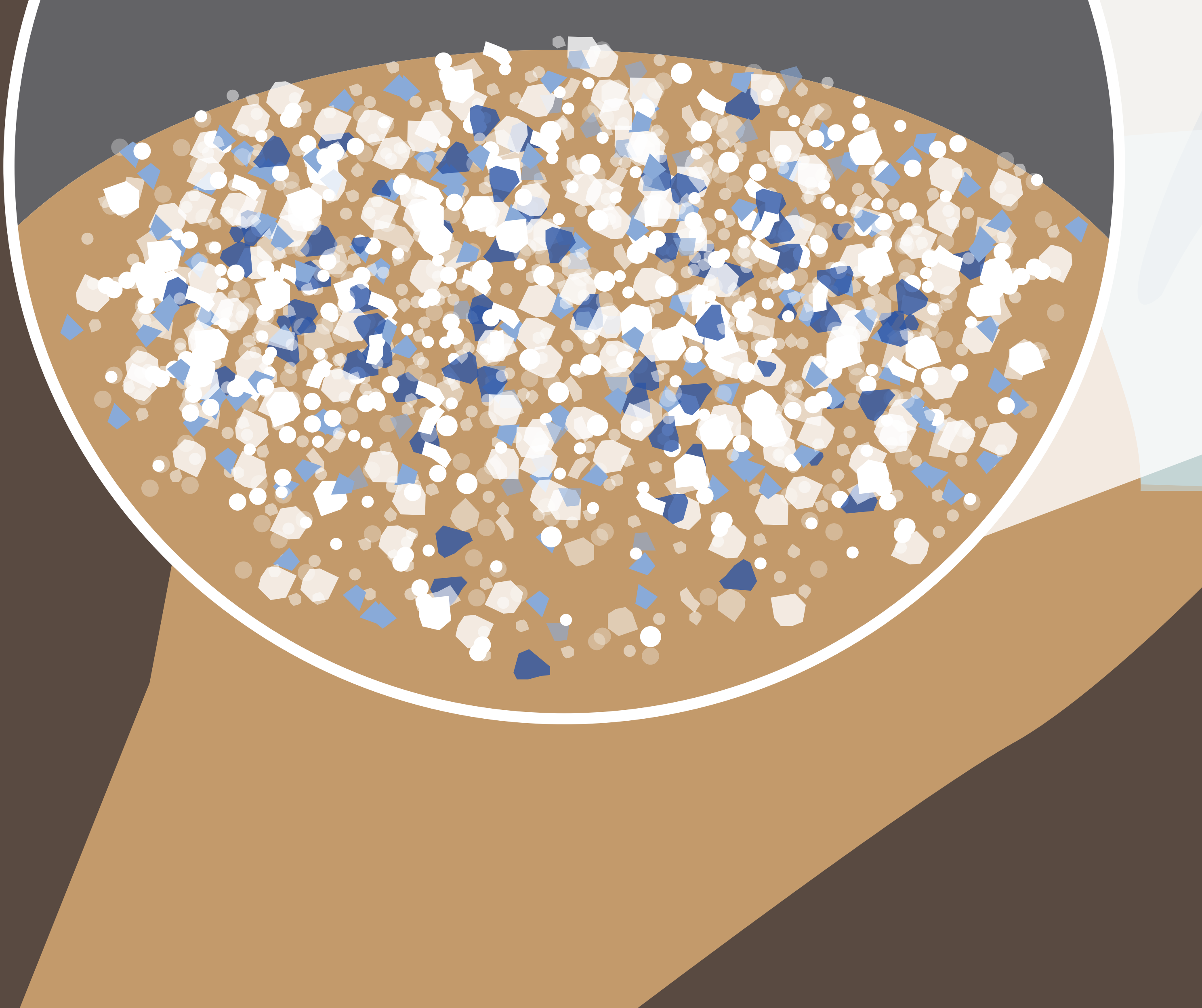
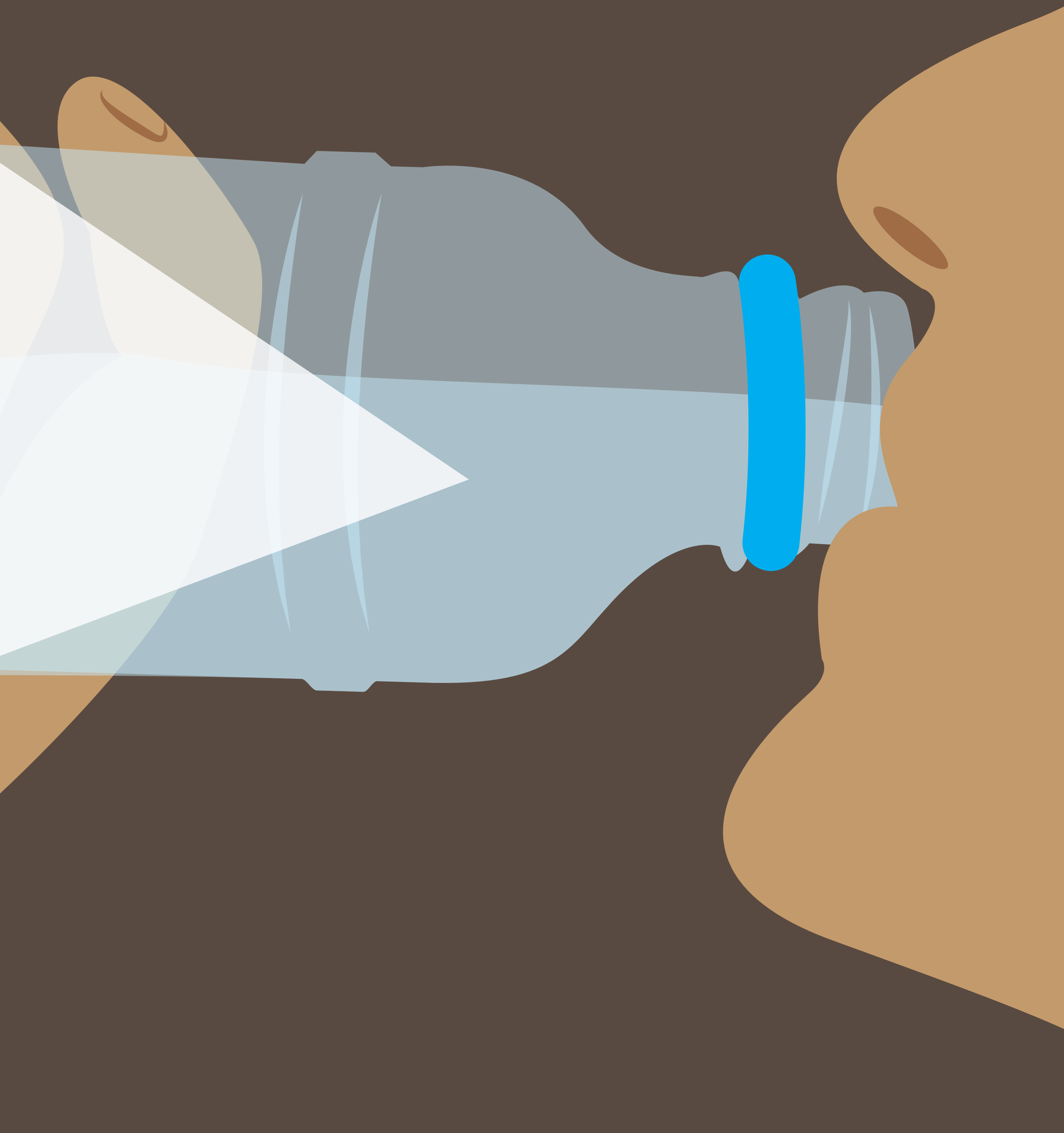
You Eat a Credit Card's Worth of Plastic Every Week

What is our hidden consumption of microplastics doing to our health?

BY KATHARINE GAMMON





M**ARTIN WAGNER WAS ANNOYED** that his colleagues were always talking about microplastics in the ocean. It was 2010 and the Great Pacific Garbage Patch had been headline news. Here was this massive gyre, formed by circular ocean currents in the Pacific Ocean, reportedly brimming with plastic particles, killing sea turtles and seagulls. Wagner, a professor of biology at the Norwegian University of Science and Technology, whose lab focuses on the impact of plastics on human and ecosystem health, felt like scientists were pointing to marine systems as the main repository of these tiny plastic particles. But wouldn't it make sense for them to exist in other systems as well? "It was like, wait a second, it must be in freshwater too," Wagner says today. He set out to search for microplastics elsewhere.

As we know, plastic is omnipresent. Plastic is cheap and easy to make and mold. We use this miracle polymer to store and transport food, make our clothes and cosmetics, cars and boats, detergents and fertilizers, transfuse our blood and floss our teeth. But it also takes between 20 to 500 years to break down a single piece of plastic in a landfill. Those bagged salad containers will be with us for generations to come.

When it comes to the environment, plastic is a scourge. We've seen the images of marine animals entangled in fishing lines and six-pack holders, beaches piled with plastic items like shopping bags, water bottles, and old toothbrushes. But it's microplastics that increasingly have been the focus of environmentalists and scientists. Microplastics are plastic debris less than 5 millimeters long. They enter the environment from the natural decomposition of plastic or by being shed by the countless products that contain plastic chemicals.

Microplastics have been found in places as remote as Antarctica[1] and the summit of Mount Everest,[2] in fish guts, and in honeybees.[3] Researchers recently found tiny plastic particles in the lungs of surgical patients, the blood of donors, and the placentas of unborn babies.[4] We can breathe in polyethylene from our T-shirts because wastewater plants can't fully filter them out. Microplastics are in our food—carried into the food chain by water or plankton—and in our toothpaste and dental floss.

When it comes to eating microplastics, scientists have documented plastic particles in about 40 percent of the human diet, including beer, honey, salt, and seafood. A graduate student in the United Kingdom collected mussels from different parts of the country and predicted that consumers ingest 70 microplastic particles for each 100 grams of mussels.[5] Meanwhile, another study showed beer samples had about 28 particles per serving.[6] People may be eating as much as a credit card's worth of plastic each week[7]—or more, because scientists still haven't figured out how to reliably determine microplastic levels in meat, vegetables, grains, or packaged foods, which means we still don't know how much plastic we actually eat.

Yet despite all the new knowledge about microplastics and the even tinier nanoplastics, smaller than a millimeter, that enter the human body through ingestion or inhalation—available in a dizzying array of sizes, colors, and chemical makeups—there remains a gaping question. What exactly does it mean for human health?

WE DO KNOW for certain that, in principle, plastics in our system can be bad for us. One of the earliest bodies of research on the impact of plastic particles on humans examined the so-called "flock worker's lung," a condition developed by employees of a Rhode Island plant that processed nylon flock,

PAGES 34-35: ORAKUNYA / SHUTTERSTOCK

short fibers cut from cables of synthetic monofilaments to produce velvet-like materials used in upholstery, blankets, and clothing.[8] The factory had almost no ventilation, and epidemiologists found that workers there had levels of lung cancer that were three times higher than among the people in the area who didn't work in the factory. At first, they suspected the workers were inhaling chemicals, but when they studied the lungs of some of the workers who had died, they found nylon fibers lodged in the lung tissue.

"This was significant," says Scott Coffin, a research scientist who leads California's development of regulations for microplastics in drinking water. "It was the late 1990s, and this was the first case that showed microplastics causing cancer in humans."

The finding was buried in scientific literature for 15 years, Coffin says, mostly because of terminology: The reports used the term "nylon flocking" instead of "microplastics." Scientists have worked to clarify that kind of distinction. For example, researchers quantified how many microfibers we set loose when we wash a fleece jacket.[9] A 2022 study[10] led by the City University of Hong Kong found that a clothes dryer releases up to 561,810 microfibers during 15 minutes of use, and Coffin says it's likely that the burst of fine particle pollution released when we clean the lint from the dryer vent is many times higher than the U.S. Environmental Protection Act's recommendations for occupational exposure to inhaling particles.[11] "You might notice there's a small cloud of dust. That's trillions of nano sized plastic fibers you're inhaling," says Coffin. "It's only a momentary exposure, but no one warns you about that."

Even some of the most essential ways that we protect our health can expose us to microplastics. Wearing masks is universally recognized as the most effective protection against contracting and disseminating COVID-19, but a study by Chinese scientists found that nearly all types of masks also increased the intake of microplastic fibers.[12] When they did experiments using simulated breathing and seven masks, all except for the KN-95 produced more fibers than they filtered out.

The good news, scientists say, is that the majority of microplastics don't stick around—we exhale or excrete them. But Coffin and other researchers admit that they have no idea how much exactly that "majority" is—intestinal absorption is estimated to be around 0.3 percent, he says, though he also says that's probably an underestimate.[13] And some debris—especially long and skinny fibers—do end up in the deepest part of the lungs.

GREG BRAVE / SHUTTERSTOCK

PLASTIC AWAKENING Plastic trash poisons and kills countless animals every year. Public outcries have led to laudable environmental cleanups. Scientists are now bringing the fallout from microplastics into public awareness.

In March, 2022, a lab in the Netherlands published research that examined lung tissue from eight volunteers and found plastic fibers in 80 percent of them.[14] Jeanette Rotchell, an aquatic toxicologist at the University of Hull who was an author of the study, says she was less surprised than her land-oriented colleagues to find plastic in those hard-to-reach places. That's because, with a background in marine ecology, she had seen the inflammation in fish gills and guts from microplastics. The biggest particles were about the length of a sesame seed, but long and thin, and they were wedged deep in the deepest part of the lungs. Still, Rotchell

Scientists have documented plastic particles in about 40 percent of the human diet.

cautions about making a leap from animal to human studies. "You can see inflammation effects in mussels and fish," she says. "But I think for humans, we don't have enough data yet with environmentally relevant levels and types of plastics."

Coffin, who is trying to figure out how much microplastics humans are exposed to, and what that means, says we still don't fully understand how the size, shape, color, and chemical makeup of plastics influences their health impact. Most plastics appear to have a similar effect on the human body, says Coffin, except for polyurethane, a flexible foam commonly found in furniture, bedding, and carpets, which may be twice as toxic as other types, though few studies have compared polymer toxicities in mammals.

SCIENTISTS DO KNOW some of what happens when these particles enter the body, says Wagner. The body produces an inflammatory response, which happens when damaged cells release chemicals to isolate the foreign substance. This response can trigger oxidative stress. "Some papers suggest that actually, nanoplastics could interfere with the energy production and mitochondria and that might induce oxidative stress," which essentially means that the body's ability to repair damage in itself is thrown out of whack, he says. "But we're really in the dark about how that happens."

Particles that end up in our bloodstream or tissue first need to cross a physical barrier in the gut or in the lung, Wagner says. Animal studies show that if particles are small enough, they can pass through tissue and end up in the bloodstream or in other organs directly.[15] "And then what happens after is not very well known," says Wagner. "Does it get excreted? Is there some way of getting rid of those particles? There's really not a lot of experimental work being done on that."

Microplastics can also carry micropollutants into the body,[16] says Andrey Rubin, a doctoral student at Tel Aviv University's Porter School for Environmental Studies. Pesticides, drugs, hormones, even heavy metals can interact with and get absorbed by microplastics. Chemicals added to plastics really drive toxicity, and household exposures can come from unexpected places, Coffin says. "If you are eating microplastics that are shed from food safe materials, those chemicals are less likely to cause harm than inhaling microplastics from something that is never supposed to enter the human body, like fibers from rugs or furniture." Additionally, a study published in April 2022 showed how waterborne germs can catch a ride on plastic particles and travel through the environment to find new hosts to sicken.[17]

As Wagner points out, studies on animals have shown microplastics can disrupt endocrine functions,[18] or hormonal systems, which regulate biological processes such as body growth, energy production, and reproduction. Many chemicals are used to make plastics, and one, bisphenol A, found in plastic containers and bottles, is a notable endocrine disruptor. In lab studies, scientists have found that bisphenol A mimics the hormone estrogen and can lead to damage in sperm development.[19] Further research has shown that microplastics, and not just those with bisphenol A, can cause damage to the testes and lead to the production of deformed sperm cells that have a harder time reaching eggs.[20] Microplastics can also have effects on female reproductive health, such as inflammation in the ovaries and lower-quality egg cells. "I'm seeing a very consistent picture that there's actually some reproductive health effects that nanoplastics and microplastics can induce," says Wagner.

What amount of microplastics disrupt human reproduction? Too early to say. "We know how many [bits of plastic] it takes to impact the reproduction of rodents, but we can't compare exposure numbers to people," Coffin says, in part because of the difference in body size proportionate to the plastic particles and the ability of rodents to reproduce easily. Coffin expects more solid data within the next three years.

So, can regulators advise an allowable daily dose of microplastics? "We will eventually have a recommended level," Coffin says. "It would be based on an idea of a threshold," which would draw a clear line between the safe and unsafe amounts of debris. In the past few years, driven by public concern, the amount of research papers on microplastics has been growing exponentially. "But even as we have produced a lot of research as a community," Wagner says, "I think the knowledge really hasn't increased at that kind of rate."

The rate that has increased is plastics production: 367 million metric tons of plastics were manufactured in 2020. That amount is predicted to triple by 2050.

KATHARINE GAMMON is a freelance science writer based in Santa Monica, California, who writes about environment, science, and parenting. You can find her at the beach or on Twitter @kategammon.

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He Fast-Forwarded Evolution into the Future

Forty years ago, a paleontologist pictured Earth millions of years from now. His vision is a wake-up call for us today.

BY ED SIMON

SOME 50 MILLION YEARS from now, a long-limbed, long-necked, and long-eared herbivore roams the temperate woods and grasslands of the Northern Continent. The Common Rabbuck (*Ungulagus silvicultrix*) appears to be a cross between a white-tailed deer, a giraffe, and a rabbit. Its natural predator is a wolf-sized muscular rodent with fearsome fangs called the Falanx (*Amphimorphodus cynomorphus*), which hunts in a pack. In the rainforest canopies in what had once been Africa and Asia, a lean and tall cat called the Striger (*Saevitia feliforme*) moves through the branches with opposable fingers and prehensile tail.

These are only a few of the dozens of animals that appear in *After Man: A Zoology of the Future*, Dougal Dixon's 1981 book that takes readers to the late Cenozoic epoch known as the Posthomic, the era "After Man." In his introduction to *After Man*, biologist, author, and TV presenter Desmond Morris would enthuse, "as soon as I saw this book, I wished I had written it." Nominated for the Hugo Award, and something of a cult classic, *After Man* would go on to spawn a series of books, a television show, and the discipline of speculative evolution, which combines art, literature, and science to imagine not just how creatures might appear in the future, but how they might have developed in alternate timelines or on other planets.

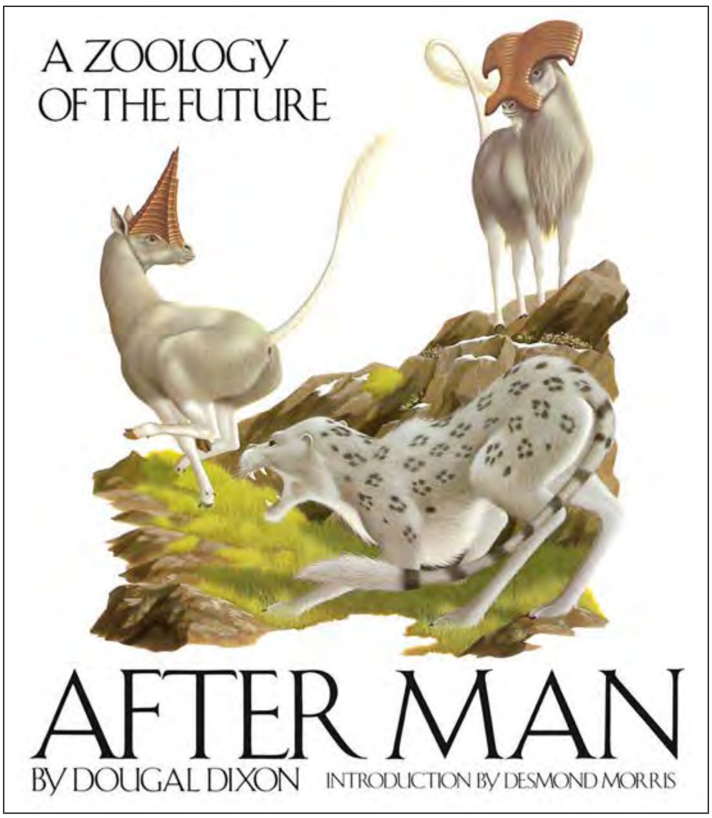
With the latest report from the International Panel on Climate Change, released in February 2022, it's time to revisit *After Man*. According to a *New York Times* article on the report, the "dangers of climate change are mounting so rapidly that they could soon overwhelm the ability of both nature and humanity to adapt." In the midst of this apocalyptic state of affairs, it's worth imagining what a world "after man" might offer. Perhaps *After Man* can compel us to consider the "long now," a long-term perspective, and picture what Earth could be like after humans have gone. It's an exercise in a type of humility that only science can afford.

BLUELOTUSART / SHUTTERSTOCK

Dixon, a Scottish paleontologist, didn't conjure a tale about a time-traveling biologist, or offer an account of humanity's last days. *After Man* is mute on the causes of our extinction. Dixon leaves you wondering what did us in as you explore his haunting, imaginary space. With immaculate drawings of imaginary beasts based on Dixon's notes for a team of illustrators, and the fine calligraphy in the margins, *After Man* feels as if it were the notebook of a 19th-century naturalist. It makes you grapple with the idea of human extinction in an uncanny manner. The paradoxical or impossible artifact—*After Man* could only have been written by a human long after humanity's extinction—offers the "same sense of wonder that we get from contemplating the natural world around us," said Susannah Lydon, an assistant professor of plant science at the University of Nottingham in the United Kingdom. "*After Man* was one of my most treasured books as a small child and it's fair to say that the ideas are hard-wired into my understanding of the world."

The book is able to have that impact partly because Dixon based it, he told me in a recent conversation, on the actual "physical and ecological conditions that have driven evolution." Dixon drew from concepts like convergence and parallel evolution, Cope's Rule and Bergman's Rule, mimicry and niche partitioning, island dwarfism and display, parasitism, symbiosis, and commensalism—the "whole gamut of observed biology." He said, "It was a matter of seeing what works for animals of today, and what we know of what worked for animals in the past. If it worked then, and it works now, it is going to work for animals of the future."

This sort of storytelling filled a niche that popular science readers didn't even know was in need of filling, the literary equivalent of Rabbucks evolving and swarming into forests after the extinction of deer. Inspired by *After Man*, speculative evolution has proliferated in film, literature, and online. In his *New York Times*-best-selling 2007 book *The World Without Us*, science journalist Alan Weisman tread the imaginative trail Dixon had blazed. He invites us to envision what would happen



AN IMPOSSIBLE BOOK Written in the style of a 19th-century naturalist's guidebook, Dixon imagines a comprehensive evolutionary history of the next 100 million years of Earth's history, covering ecology and geology, as well as the complex biology of dozens of invented animals whose evolving anatomical details he describes from the present onward.

PHOTO BY GREG GOEBEL / FLICKR

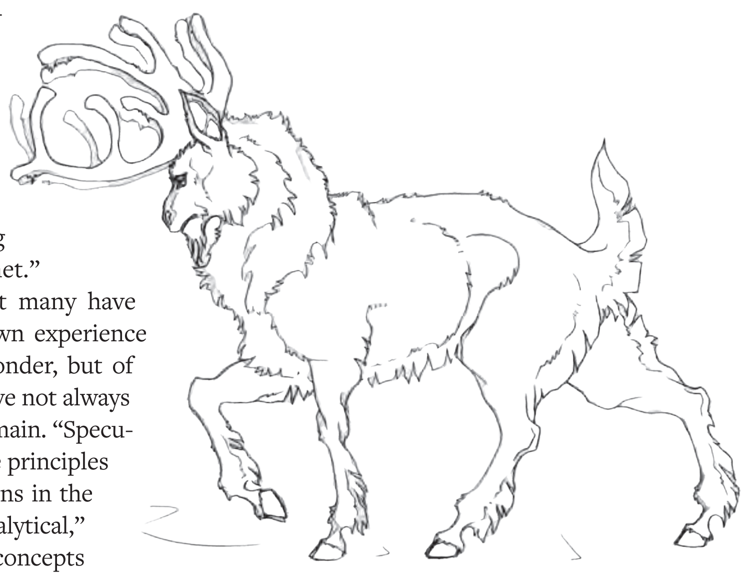
if humanity suddenly vanished—what effect our absence would have on both natural and constructed environments. Weisman recounted to me that when his manuscript for *The World Without Us* was being edited, "someone there who'd worked on *After Man* sent me a copy because he thought I'd enjoy the illustrations, which of course I did." Recognizing the pertinence of a kindred project, Weisman included *After Man* in his book's bibliography. Both books present science with a creative flourish that's not necessarily encountered in more staid scholarship.

This sort of storytelling filled a niche that readers didn't even know was in need of filling.

"The result is speculation built on fact," Dixon wrote in his introduction to the original edition. "What I offer is not a firm prediction—more an exploration of possibilities."

And what possibilities! In the jungle, the Striger often stalks a long-armed primate called the Kiffah (*Armasenex aedificator*). It has red fur and a blueish, weathered face almost pushed into its chest. Its natural defense against the Kiffah is its relative degree of intelligence and sociability. Off the coast of Antarctica, meanwhile, are the aquatic Vortex (*Balenornis vivipara*), the world's largest animal at 30 tons and at least 36 meters in length. This whale-like creature—with a massive beak that sieves out the plankton it ingests—is actually a bird, directly descended from the penguins who once swam the frigid waters. Then there are the Night Stalkers (*Manambulus perhorridus*), their common name true to their status as being among the most terrifying creatures of the Posthomic age. Picture a bipedal, 5-foot-tall bat—compact, with a fur-covered body—that appears as if it walks on its arms with its legs swung over its shoulders. Giant sonar where its ears and eyes would be, it gallops and shrieks through the grasslands of the island continent of Batavia.

"I've always been a bit of a fantasist," Dixon told me. "Grew up on the shores of the Solway Firth, between Scotland and England. Beautiful, but many found it bleak and desolate. Despite the beauty of the landscape, when I walked there as a child, I used to imagine myself wandering the shores of a plesiosaur-infested Jurassic lagoon, or the crystalline coastline of a steamy ocean beneath low-hanging ringed moons on an undiscovered planet."



This is an emotional reaction that many have described when writing about their own experience first reading *After Man*, not just of wonder, but of wisdom: the awareness that humans have not always been here, and that we won't always remain. "Speculative biology applies precisely the same principles that researchers use to interpret patterns in the fossil record, and in that sense it's analytical," Lydon said. "You're using evolutionary concepts

POSSIBLE WORLDS After *After Man*, Dougal Dixon continued mining the evolutionary possibilities of life on Earth in later books, envisioning worlds where non-avian dinosaurs hadn't gone extinct, as well as one where humanity evolves into the deep future.

to move forward from an initial starting point only, rather than attempting to interpret the patterns in a hugely incomplete, hugely biased dataset smeared through deep time."

An exercise as pedagogical as it is scientific, speculative evolution functions as a type of *Gedankenexperiment* existing at the nexus of science fiction and fact. "It is a matter of giving fictitious examples of factual processes," Dixon said. *After Man*'s operative aesthetic is one of scientific *wonder*. It reminds us that imagination can be as central as analysis in a scientific endeavor, and that our attraction to the sciences is as poetic and lyrical as they are logical and pragmatic.

Dixon's own career, which had a veritable Cambrian explosion following the publication of *After Man*, has engaged a sense of wonder in later books, including *The New Dinosaurs*, which envisioned a world where non-avian dinosaurs hadn't gone extinct; *Man After Man*, which applied the same principles from his most celebrated title to human futures; and *Greenworld*, a taxonomy of an extraterrestrial planet (so far only released in Japan).

After Man makes the geological concept of "deep time" deeply personal. It takes on what the theologian and philosopher Thomas Berry described as the challenge to "create a new language, even a new sense of what it is to be human ... to transcend not only national limitations, but even of species isolation, to enter into the larger community of living species ... a completely new sense of reality and value."

Such deep-time thinking as described in *After Man*, Berry's *The Dream of the Earth*, Stephen Jay Gould's *Time's Arrow, Time's Cycle*, and John McPhee's *Basin and Range* exist precisely to embody that command of creating a new vocabulary commensurate with the reality of being finite individuals in a nearly infinite cosmos. When wonder is combined with wisdom, tempered perhaps with the anxiety that comes after considering the incomprehensible breadth of deep history far before and beyond the confines of our tiny lives, the resulting emotion is the sublime.

In a critique of *After Man*, literary scholar Matthew J. Wolf-Meyer castigates what he terms the "nihilism of deep time." In his book *Theory for the World to Come: Speculative Fiction and Apocalyptic*

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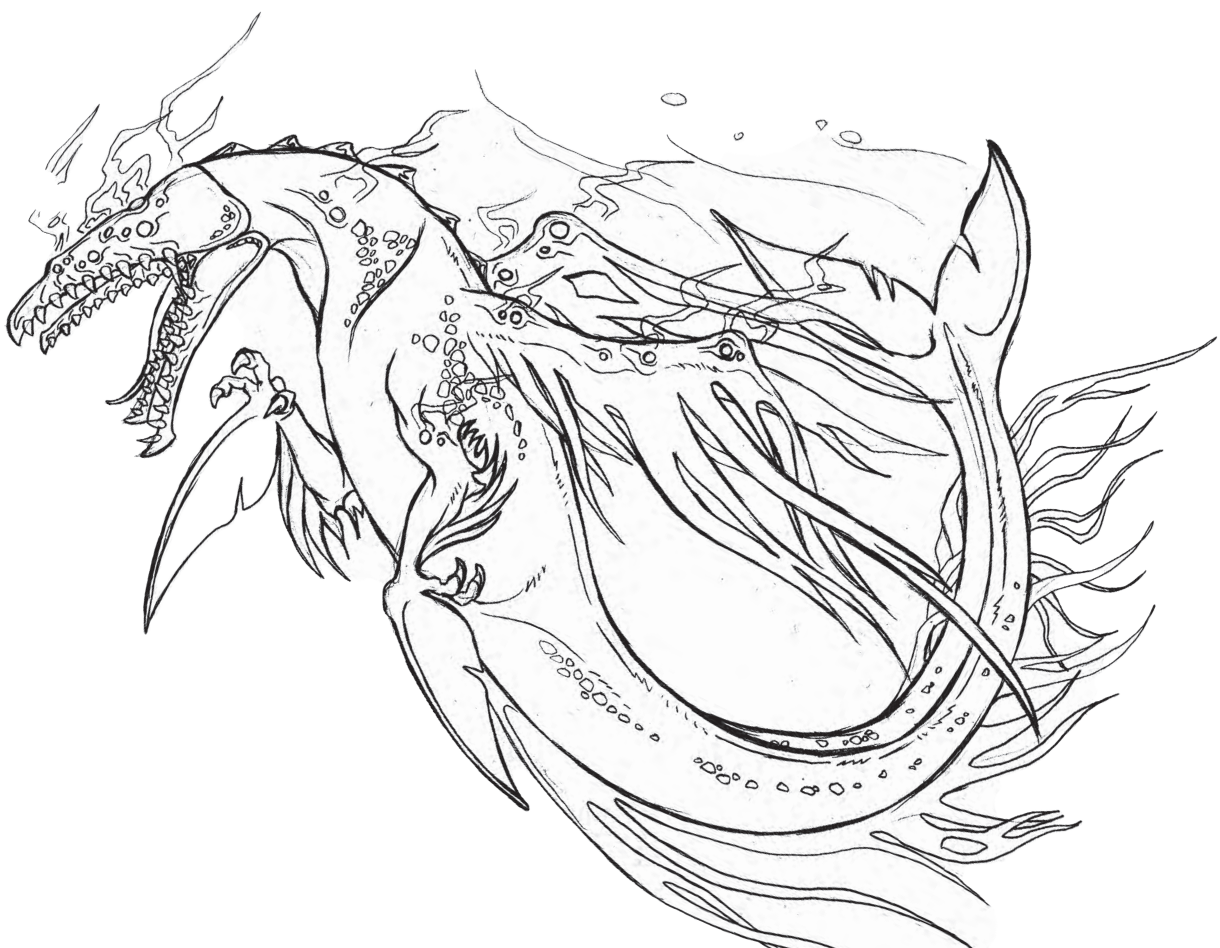
Anthropology, he writes that Dixon "supports a damned-if-we-do, damned-if-we-don't approach to the Anthropocene and catastrophes in general." This, I think, is a wrongheaded interpretation, for we ask not for whom the bells of deep time toll—they toll for all of us.

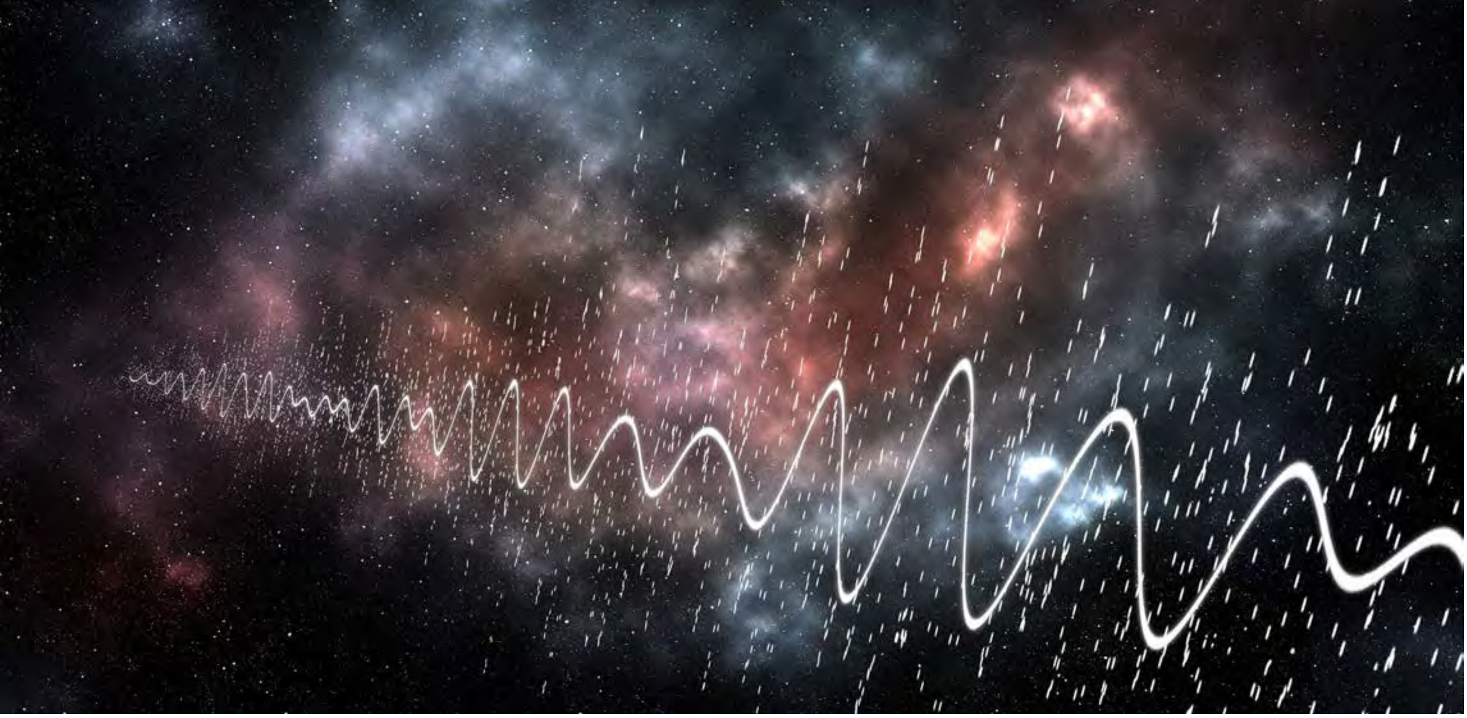
Thirteen millennia from now, and the Earth's axial tilt will shift, altering what seasons occur in which hemisphere; 15,000 years from now and the North African Monsoon shift will convert the Sahara from a desert into a tropical rainforest once again; 50,000 years from now Niagara Falls will have completely eroded away; 2 million years from now and the effects of ocean acidification will be largely reversed, coral reefs having returned. Ten million years into the future and biodiversity will once again be restored to where it was before the sixth mass extinction of the Anthropocene; 80 million years into the future and Hawaii will have completely sunk into the Pacific; in a quarter of a billion years the continents will have coalesced into a new Pangea.

In 10 million years, biodiversity will be restored to where it was before the sixth mass extinction.

Whether or not we like it, one day there very likely will be a Posthomic age. What *After Man* inculcates with its readers is the ability to imagine and make peace with this reality, to walk on the proverbial shores of Solway Firth and to appreciate the Plesiosaurs along its banks, and the strange alien moons shining above it.

ED SIMON is a staff writer at *The Millions* and contributing writer at *Belt Magazine*. His most recent books are *Pandemonium: A Visual History of Demonology* and *Binding the Ghost: Theology, Transcendence, and the Mystery of Literature*. Follow him on Twitter @WithEdSimon.





RYTIS BERNOTAS / SHUTTERSTOCK

We Better Think Twice About What We Say to ET

Extraterrestrials could take our intergalactic message in entirely the wrong way

BY CALEB SCHARF

PARENTS AROUND THE WORLD tell their children to be careful about speaking to strangers. It's good advice for our innocent offspring, because even if the risk of a dangerous interaction is very small, the consequences could be very great. Yet when it comes to the idea of sending unsolicited messages out into the cosmos to try to get a response from technological alien life, we seem to forget these sensible domestic rules. That goes for everything from the earliest messages beamed into space to one outlined last month by a group of researchers from the Jet Propulsion Laboratory at Caltech and several international organizations. Each could spark consequences beyond our control.

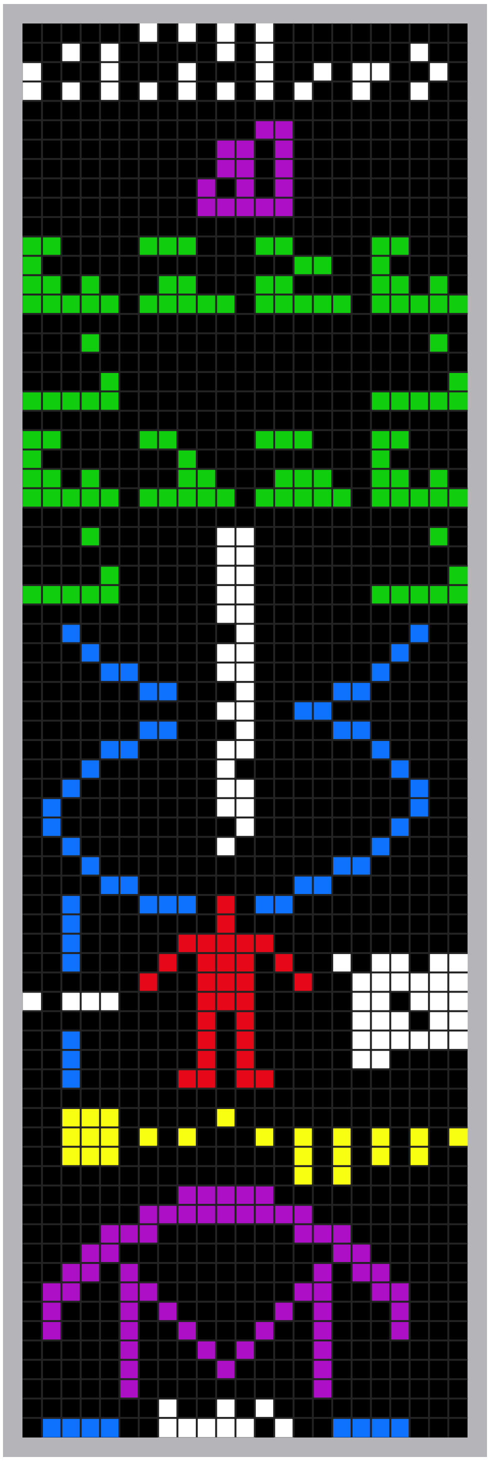
As a case in point, the first deliberate, high-powered radio message sent by humanity to another world lacked any semblance of careful thought, or any poetry. It consisted of the Morse code dots-and-dashes for three words: "MIR," "LENIN," and "USSR." Mir means "peace" or "world"; the other two words need little explanation.

This cryptic transmission was beamed into the cosmos in November 1962 from the Pluton Complex in Crimea by a planetary radar made from 16-meter-wide radio dishes mounted on a structure built out of railway bridge trusses and the hulls of a pair of repurposed Soviet submarines—a brutalist architect's delight. The message was used to produce a radar echo from the planet Venus, but decades later scientists realized that the eventual lucky recipient of this pronouncement is a star some 2,100 light-years away, and therefore not yet aware of its role in human history.

The oddly parochial nature of this first step in extraterrestrial messaging was not without precedent, or so very different from efforts that followed it. For instance, there's a famous but probably apocryphal anecdote about how, in 1820, the physicist Carl Fredrich Gauss proposed sending signals to other worlds by creating a vast representation of the Pythagorean theorem of right-angled triangles, carved into the Siberian tundra and outlined with pine forest. Gauss may or may not have suggested this, but having invented the heliotrope for reflecting sunlight over great distances, he did write to the German astronomer Heinrich Olbers in 1822 about building a huge heliotrope array of hundreds of mirrors to message "our neighbors on the Moon."

In the late 1800s, the French inventor Charles Cros also thought about mirrors for signaling Mars or Venus, except his idea was to use these to focus sunlight and to burn features onto the desert zones of those worlds, possibly the most aggressive notion of extraterrestrial messaging thus far envisioned. To be fair, Cros had a special kind of creative mind, as demonstrated by his proclivity for writing poems such as *The Kippered Herring*, presaging the absurdist antics of Monty Python by more than a half-century.[1]

By the 1970s, our vastly improved knowledge about the universe and our increasingly complex technology led to more sophistication. Most famously, in 1974, the Arecibo radio observatory in Puerto Rico (that could also transmit as a planetary radar) sent a demonstration message toward a globular cluster of stars about 25,000 light-years away. The act of transmission itself was a bit of a throwaway stunt; the more interesting and rigorous work went into constructing the message: a string of 1,679 bits of clearly non-random, attention-provoking data that could be displayed as an image depicting items like the decimal number system, life's elemental constituents, the shape of DNA, and a few other tidbits about the human form, and the architecture of our solar system. In this sense the Arecibo message was mostly a *Gedankenexperiment*, a thought experiment in how we might "ping" an alien species to get noticed.



A TETRIS-Y TRANSMISSION The act of transmitting this message, in 1974, from the Arecibo radio observatory, was a bit of a throwaway stunt. Constructing the message, on the other hand, took some clever thinking. It's a string of 1,679 bits of clearly non-random, attention-provoking data that could be displayed as an image (which wasn't actually colorized) depicting items like the decimal number system, life's elemental constituents, the shape of DNA, and a few other tidbits about the human form, and the architecture of our solar system.

ARNE NORDMANN / WIKICOMMONS

Most recently, in April, physicist Jonathan Jiang and his colleagues published their idea of "A Beacon in the Galaxy": an updated binary-code message that could be transmitted toward a star cluster nearer to the Milky Way's center, to increase the "reach" of the signal to potentially habitable systems.[2] The message uses images of 128 by 128 pixels—compact enough to transmit efficiently, but large enough to depict a wealth of information, from our location details to mathematical proofs, biological data, particle physics, and so on.

To fend off concerns about talking to strangers, these scientists suggest that it's likely for long-lived, technological intelligences to have figured out how to be cooperative and peace-loving, or else they wouldn't have survived. This rather hopeful sentiment echoes others across the years. However, it's rooted in our experience as a parochial, planet-bound species. In our world of finite resources, the strategy of cooperation, and even altruism, is indeed often successful—and is seen across individual genetic lineages and between species. But it's not at all clear that this can apply to life elsewhere.

In truth, all of these laissez-faire approaches to messaging extraterrestrial intelligence, or METI, minimize what could be serious risk factors. The first is whether any one group of humans should be speaking on behalf of the entire species, and the second is whether METI is actually fundamentally dangerous.

That latter risk is the most difficult to assess, in the same way that the possibility of any kind of extraterrestrial communication is incredibly difficult to evaluate because of the array of assumptions that have to be made. Will, for example, intelligences across the universe have any properties in common? Will the pieces of information that we think are universal and recognizable mean anything at all to aliens? We might imagine, like with Pythagoras' Theorem or Arecibo's list of atoms and DNA, that some qualities of the world will be discovered by all species technologically capable of hearing our messages. But it's hardly a given, and what appear to us as dry facts about the natural world could represent wholly different things to an alien, for whom a geometric rule might connote an act of aggression, or a molecular structure might represent a holy relic.

The late Stephen Hawking felt that the biggest concern is not in appearing aggressive, but in attracting aggression. He questioned whether making our presence known isn't just an invitation for any roaming interstellar species on the lookout for resources to show up ready to consume and conquer. A 2017 paper by Peter Todd and Geoffrey Miller analyzed the possible evolution of extraterrestrial psychologies and concluded[3] that sending out hopeful messages to ETs is basically announcing that you live somewhere without competition, in effect saying, "Here is a delectable treat—a home-world with valuable and easy-to-acquire resources, lightly guarded by a gullible young species."

That sentiment can seem a little off-base though. After all, resources like water and metals are abundant in the cosmos. You'd hardly need to raid an inconvenient little planet for any of these things. Maybe though there are more precious, but harder to quantify resources in planetary habitability, and in the wealth of novelty produced by billions of years of natural selection and evolution—these things could be worth traipsing between the stars for.

Should any one group of humans be speaking on behalf of the entire species?

> Ideas can be dangerous, especially meme-like ideas that spread contagiously.

For others, like the science-fiction author Liu Cixin writing in his trilogy *The Three-Body Problem*, the danger comes from the “Dark Forest Hypothesis.” This posits that all species want to survive, and if they succeed, they will continuously expand. But our galaxy has finite usable spaces and resources, and it is impossible to obtain real-time knowledge about other species due to the limits of the speed of light. Everyone is intent on their own survival and must assume that by the time they learn of aliens, those aliens may have already developed more capable technology, and greater ambitions. Consequently, the most logical and prudent course of action is to remain silent and try to eliminate any other species that you learn of, before they eliminate you, or before they evolve to a level where they can eliminate you. In other words, keep your head down in the forest, or else.

These are all pretty grim assessments. But there are also hazards from the mere act of communication. In 2014 I wrote in *Nautilus* about the potential for transmitted information to destabilize and perhaps even destroy a civilization—whether intentionally or unintentionally. Ideas can be dangerous, especially meme-like ideas that spread contagiously and could, in principle, be “weaponized” to destroy just as effectively as a massive fleet of spacecraft.

Nonetheless, the astronomer and SETI expert Jason Wright has pointed out that we tend to fall prey to a "monocultural fallacy" in thinking about alien civilizations when we assume that decisions and actions will be made as one. Clearly that is not true for humans, and messages have gone barreling out into the cosmos because a few people have decided to send them and the rest of our species simply hasn't cared to notice. If there is any characteristic that is most likely to apply to alien species it may well be this same one; whoever messages us, or hears us, could easily be a few specialists, or obsessives, who may or may not have influence over their civilization.

Perhaps though, in the end, the most decisive factor lies in the stratification of time due to light's finite speed. This means that all decisions to do with ETs (whoever's ETs those are) will be based on extrapolation from information that gets more and more outdated with distance. You may have just picked up the "Hello World" (or "MIR") signal from a distant star, but by now that species could be a bomb-wielding interstellar terror or have been rendered harmless by extinction. If you return a message you simply don't know what state the recipient will be in when it receives that signal, or what state you will be in if you get a conversational reply. That isn't just a problem for distances of hundreds of light-years, even a few light-years makes a difference—just consider our own changing conditions between the middle of 2019 and 2022, or between 1938 and 1945.

Just like our parental admonition to never talk to strangers, we should think carefully about talking to species when we can't talk to them in any temporally fixed way, or know how our future selves will deal with this. The Soviet researchers who sent "MIR," "LENIN," and "USSR" off into the galaxy couldn't have known what was coming down the line for their way of life. Perhaps the real risk of messaging extraterrestrials is that no one will ever get to have the conversation they'd like.

CALEB SCHARF is the director of astrobiology at Columbia University. His latest book is *The Ascent of Information: Books, Bits, Genes, Machines, and Life's Unending Algorithm*. Follow him on Twitter @caleb_scharf.

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UNESCO / ALEXIS ROSENFELD

Who Are the Scientists Here?

Mo'orea, a Pacific Island, spotlights the rift in conservation between foreign scientists and Indigenous people

BY NELL FREUDENBERGER

THE FIRST THING WE DID after arriving in Mo'orea, a high volcanic island 20 kilometers northwest of Tahiti, was pick up a hitchhiker named Didier. I was visiting the island with Hannah Stewart, a Canadian marine biologist with a passion for tiny "housekeeper" crabs as well as Polynesian culture. Stewart was busy with the first iteration of a new class she'd created to bring Berkeley undergraduates to Mo'orea. The students stayed at the University of California's Gump South Pacific Research Station, but ranged over the island, learning about biodiversity, environmental policy, and Tahitian culture from local experts.

Stewart pulled over so that I could look down the densely foliated hillside to the lagoon. Coconut palms stuck their heads over a white sand beach, from which thatched tourist bungalows crept out over impossibly turquoise water, splotched with shadowy outcroppings of coral. Stewart is the kind of outdoorsy blue-eyed blonde I envied in high school, but what's really appealing about her is a kind of impetuous energy that makes it seem, when you're with her, like anything could happen. Didier must have felt it, too, because he immediately asked in French whether she was single. Hannah let him down gently, then asked a question of her own: What did he know about the American research station on the island?

"Gump?" Didier said. "I thought that was closed."

"That's the problem," Stewart said to me after Didier hopped out. Marine conservation in Mo'orea was stymied by foreign scientists' failure to communicate with the island's Indigenous people and other local communities. "That's what we're trying to address with this class."

I had come to Mo'orea because of something Stewart told me during our first call in the summer of 2021. "We're not just training scientists, because we maybe—probably—don't need more scientists," she said. The reasons Stewart was fed up with academic research—the parachuting in and out of field sites to collect data, and the intense specialization inside even very similar subfields—were what interested me. I'm a novelist, and I sometimes write about scientists. Imaginary worlds rest heavily on concrete detail, and nothing is more concrete than a complex experimental set-up in a lab. Because conflict is at the heart of fiction, I wanted to know more about the tension between scientists and French Polynesia's Indigenous communities, today referred to as Mā'ohi peoples in Reo Tahiti (the Tahitian language).

Coral is abundant in the Society Islands of French Polynesia, which include Mo'orea and Tahiti. Known as "rainforests of the sea," coral reefs are the world's most colorful manifestations of biodiversity. Nearly 25 percent of marine species live in or around these reef-building sessile organisms, which are threatened, and in many places decimated, by climate change and coastal development. Their revival is critical to oceans' health, as well as the health of over 500 million people worldwide who rely on them for sustenance. Mo'orea is an epicenter of coral reef science because of the longevity of its two research stations. The French station CRIOBE was founded in 1971, followed by Gump in 1985.

Still, there's a lot the scientists don't know. Two months before I arrived in Mo'orea, media around the world reported the discovery of a new coral reef by a deep-sea mapping mission, supported by UNESCO (United Nations Educational, Scientific, and Cultural Organization). Scientists used the word "pristine" to describe the reef, made up of rose-shaped coral whose spreading plates evolved to capture light. The reef is located between 100 and 210 feet below the surface in the mesophotic zone, the deepest oceanic layer that sunlight can penetrate. Its depth possibly explains its health, protecting it from warming seawater, acidification, and pollution that have been so deadly to coral at shallower elevations. Amid all the bad news about coral degradation, the reef's existence was hailed as an encouraging discovery. "This remarkable discovery in Tahiti demonstrates the incredible work of scientists," stated a press release by UNESCO.

When I asked Rahiti Buchin, head of the Tahitian competitive spearfishing club Team Tefana, about the rose coral reef, he replied by email: "Who discovered it? Our ancestors and certainly not those who boasted about it in the local and international press." He wrote in French, still the predominant language in Tahitian schools, but used the Indigenous word *tupuna* to refer to his ancestors.

The disconnect between Mā'ohi and foreign scientists was evident in Stewart's class one afternoon. We were gathered in Gump's *fare pote'e*, a thatched Polynesian pavilion at the edge of Cook's Bay. Mount Mou'aputa towered over us, identifiable in Mo'orea's lushly forested volcanic range by the round hole just below its summit, intermittently hidden by clouds. The students were learning about the debate over *Plan de Gestion de l'Espace Maritime*, or PGEM—a type of marine protected area that had been extremely contentious on the island—and *rāhui*, a traditional practice of resource management which can include, for instance, a ban on the use of a particular marine resource for a specific period of time.

Claude Teiho, who looks like an aging movie star, with thick silver hair and the muscular frame of an

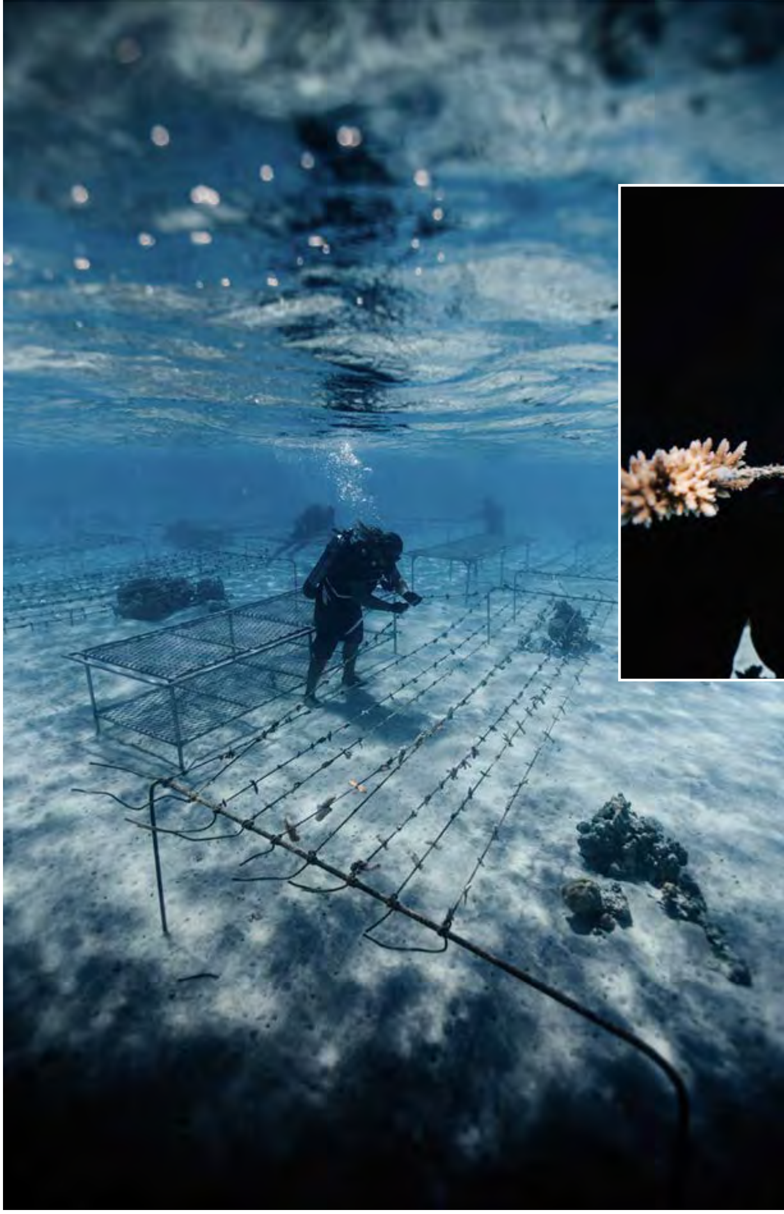
"It's way more sexy and fun to plant a coral or adopt a coral than to eat less meat or fly less."

expert free diver, is president of the island's fishers' union. Sitting on a red plastic chair facing a semi-circle of students, he explained that he made his first spearfishing gun himself out of wood and the inner tubing from bicycle tires, using a spoon as the trigger mechanism. His first goggles were made from the bases of two glass soda bottles. Teiho explained that coral reefs had long been affected by nature's cycles. In 2010, he said, Mo'orea was hit by an outbreak of the crown-of-thorns starfish that decimated reefs by feeding on stony coral. Along with a cyclone the following year, the venomous purple sea stars devastated all but around 2 percent of Mo'orea's reef. Teiho's son Taiano, who was sitting in on the class, told the students that he'd been terrified by the state of the lagoon at that time, but that his father had reassured him by explaining that the reef had the capacity to regenerate on its own.

What Teiho predicted had come true, and within eight years the reef had regenerated. In 2019, however, a severe bleaching event destroyed 50 percent of the coral on Mo'orea's forereef, the portion of the barrier reef that faces the open ocean. Coral bleaches because of thermal stress; after a period of time at an intolerable temperature, the coral expels its symbiotic zooxanthellae—the microscopic dinoflagellates that provide food through photosynthesis in exchange for shelter, but can be toxic to their hosts at high temperatures. The tiny plants can return to the coral when the water cools, but with prolonged or repeated bleaching, the coral will die and quickly be overgrown with algae.

When the students asked Teiho about climate change as he's observed it over 50 years fishing in Mo'orea, he connected its impact on the lagoon to the fact that many Tahitians had lost their ability to understand lunar cycles. That sounded less like science than folklore, and the conversation moved on to other topics. Stewart asked Teiho whether he knew what was going on at Gump Station. Teiho shrugged and said, "a lot of research." Stewart shook her head at the scientists' failure to connect with local communities, especially around environmental policy. "We have to do better," she murmured. Teiho gestured toward the lagoon. "You don't need a degree to understand this," he suggested. "It's obvious."

LOCAL COMMUNITIES AND FOREIGN SCIENTISTS share the goal of reviving the area's reefs. Both are testing restoration concepts that fall into the broad category of assisted evolution, including strategies designed to boost the reefs' resilience to anthropogenic stressors. The problem is the number of competing interests in a lagoon that is immeasurably valuable to science, to tourism, to fishers, and most of all to the people who call the 50-square-mile island home.



CORAL GARDENING A local Mo'orea conservation group, the Coral Gardeners, source "super corals"—those that have demonstrated the ability to recover from or resist a bleaching event—and, using fragments, grow those corals in underwater nurseries on metal coral trees or ropes.

RYAN BORNE FOR CORAL GARDENERS

Early one morning, I kayaked across Cook's Bay to talk with Taiano, a founding member of a conservation organization, Coral Gardeners. The gardeners work out of a modest office that backs onto the bay, under a galvanized steel roof equipped with solar panels. Kayaking was the most efficient way to get there from Gump, and I attempted to look nonchalant as I lugged my boat out of the water in front of an international group of bronzed 20-somethings, who either surf seriously or look as if they might. Taiano, who grew up with Titouan Bernicot, the organization's founder, first noticed white flecks in the water while surfing in neighboring 'Ōpūnohu Bay. Free diving to investigate, he and Bernicot found bone white coral, which they then Googled to learn about bleaching and ocean acidification. This marriage of local experience and technology is typical of the organization, apparent in the Silicon-valley-style pitch deck Taiano showed me on his laptop under the tamanu tree growing out of an opening in the office's back deck.

The gardeners' method involves sourcing super corals—those that have demonstrated the ability to recover from or resist a bleaching event or other human-induced stressor—directly from the reef, and

LOCAL TRADITION Hinano Teavai-Murphy, president of a community-based organization that aims to preserve Polynesia's biocultural heritage, collaborates with scientists on Mo'orea, yet says ocean conservation depends on a traditional island practice.

FRANK MURPHY

then using fragments, or nubbins, to grow those corals in underwater nurseries, on concrete "cookies," metal coral trees, or ropes. Their nonprofit's mission to plant 1 million corals is backed by a limited liability company that sells merchandise and allows donors to adopt a coral online, as well as an ambitious social media campaign and list of supporters that includes former Tesla engineer Drew Gray and singer-songwriter Jack Johnson.

Although it seems like a no-brainer that the scientists from the French and American research stations on the island would work with skilled young science communicators, the Coral Gardeners' recent scientific mentors have been visitors from abroad. Taiano said that he believed the director of CRIOBE was amenable, but that there were—and here he switched from business-speak to surfer—some "haters" at the research station who were afraid that working with the gardeners would pollute their mission.

CRIOBE is made up of a grassy campus of low buildings with green-painted corrugated metal roofs at the apex of ʻŌpūnohu Bay. Massive Mount Rotui towers over the labs; according to one legend, warriors from Raiatea in the Leeward Islands tried to steal the mountain, dragging it with a braided rope toward the sea. Detected by a powerful woman of the island, one of the criminals was turned into a block of coral that still sits in the Papetō'ai reef pass.

I spoke to a coral specialist at CRIOBE, Laetitia Hédouin, one of the scientists who'd been quoted in the press about the mesophotic reef off Tahiti. Despite the initial reports, she said, the exploratory mission hadn't "discovered" the reef but had been the first to "study it scientifically." I asked what she thought of the Coral Gardeners. She acknowledged their success in communicating the plight of reefs to a wide audience but was worried about the impact of the message that by adopting coral, people could help save the reef. "Potentially that money is worth more if it is invested in reducing CO_2 emissions. The thing is that for people it's way more sexy and fun to plant a coral or adopt a coral than to eat less meat or fly less." But when you mention that at a conference, she said, everyone leaves the room.

Hédouin prefers the term "assisted renovation" to "assisted evolution," because she doesn't believe human beings can return the reef to its natural condition. "When you talk about planting coral," she told me, "the first question is, which area do you want to restore? And why is that area dead? And what are the sources of stress? Are they gone? Is there a natural recruitment of coral, because if there is, there is no need to plant coral." She described the recovery of the coral after the 2010 sea star outbreak and the cyclone as "amazing"; after the 2019 bleaching, however, "the story was different," and the reef above 10 meters still hadn't recovered.

Recently Hédouin's team had been crossfertilizing parent corals that had experienced a bleaching event with those that had never bleached. Using the natural fluorescence of coral tissues—red or green—to count the larvae under fluorescent light, they saw something that surprised them: The bleached coral parents were releasing significantly more red- than green-fluorescing larvae. The distinction was important, because the red fluorescent larvae had the ability to survive up to a week longer at a high temperature than their green siblings and were more prone to swimming longer distances in the pelagic larval phase. Hédouin's team hypothesized that by releasing more red fluorescent larvae, the bleached parent corals were provisioning their offspring to fight thermal stress, sending a sort of biological message that encouraged them to disperse farther in hopes of finding a more hospitable environment.

The best way to teach young people about the ocean was to take them out at night, so they were forced to use all their senses.

It was a fascinating finding; the question was, where were they going to go? "We really need to get out of the lab," Hédouin told me. Like the Coral Gardeners, her team had multiple coral nurseries in Cook's and ʻŌpūnohu Bays, including a new one at a depth of 30 meters, in front of the Hilton Hotel. Hédouin envisioned more nurseries at that depth, as a repository for the coral diversity of Mo'orea. "We are very limited in terms of intervention, and so we really need to favor the natural process for recovery and reproduction," she said. "Planting corals deeper allows you to protect them from bleaching and other threats." She distinguished between research science and conservation, saying that identifying more resilient coral was instructive for scientists, but in order to conserve reefs, deeper nurseries were going to be crucial. At 30 meters, the coral grew more slowly, but were less likely to be stressed: "It's a good compromise."

ONE BRIGHT EVENING I was sitting outside the Gump dorm with the students in the Island Sustainability Program, eating *poisson cru*, the typically Tahitian raw fish and vegetables marinated in coconut milk and lime. Flecks of white and orange light hit the dark green bay as the sun disappeared behind the mountains. “Why can’t they collaborate?” asked one young woman, referring to the scientists and the Coral Gardeners. Her question emphasized that the time for territoriality in ecology was gone, and that the scientists were going to have to work with the self-described “small group of island kids”—from French, Mā’ohi, and other international backgrounds—who had managed to convince people halfway across the world that they wanted to spend 25 euros to adopt a chunk of *Acropora*.

This was one of many astute observations I heard from the Berkeley students. At the same time, they were aware that the criticism leveled at scientists who drop in and out of field sites for research could be aimed at them, despite the very place-based course of study they were pursuing on Mo’orea. In the future, Stewart hoped the Island Sustainability Program would expand to include students from the University of French Polynesia and Hawai’i, or even Pacific-wide. That seemed crucial to the program’s success, since it was impossible not to notice how few Tahitian or other Indigenous scientists—I met one in the course of my research—have worked at either station, whose history on the island stretches back half a century.

As the students shared their experiences with me, they mentioned one person whose influence on them during their time in Mo’orea had been indelible. Hinano Teavai-Murphy is president of the community-based Association Te Pu ‘Atiti’a, which aims to preserve Polynesia’s biocultural heritage; in her long career, she has also taught school and collaborated on numerous film projects, including Disney’s *Moana*. I’d watched a video of her speaking at the United Nations on World Oceans Day in 2019, telling the Polynesian creation myth of Ru and Hina in a deep, resonant voice, gesturing with her hands. The performance was so mesmerizing that I wasn’t surprised when it was difficult to get an interview. Her husband Frank Murphy, who runs the Tetiaroa Society—the nonprofit that stewards the coral atoll Marlon Brando bought in 1967 after filming *Mutiny on the Bounty*—sometimes has to act as a gatekeeper, because so many people want to talk to his wife.

We finally arranged to meet on a warm Tuesday evening at Gump, on the balcony of a hillside bungalow overlooking Cook’s Bay. Although she’d spent the day traveling back and forth to government meetings in Tahiti by ferry, Teavai-Murphy arrived at Gump in a crisp brown-and-white floral suit and traditional woven hat, a strand of luminous black pearls around her neck. We sat at a wooden picnic table drinking mango juice, the acrid smoke from a mosquito coil burning in a frying pan at our feet, and talked about the meaning of the Mā’ohi word *rāhui*.

Teavai-Murphy explained that a *rāhui* isn’t only a restricted area. It’s also a period of time when “you learn how to save.” You “really sacrifice yourself, your family, your community.” The problem, in her view, was that the occidental concept of a marine protected area—a restricted zone with controversial features like permanent no-take rules for fishing—had been translated in the local government’s planning meetings almost 20 years ago as “*rāhui*.” “This is where they brought confusion into the minds of the people,” Teavai-Murphy said.

While the original marine-protected areas, or PGEM, blocked off a portion of the zone forever—usually and transparently those directly in front of hotels—a *rāhui* might be a temporary ban on an area or resource that allowed it to recover. Traditionally, Tahitians sacrificed in what was called the season of scarcity, *Matari’i-i-raro*, which began when the Pleiades sank below the horizon in May, to reap the benefits during *Matari’i-i-ni’a*, the season of plenty, as soon as the constellation was visible again in November. The imposition and lifting of *rāhui*—for example, on pelagic fish in the lagoon or on breadfruit from particular trees—was one way in which they had maintained their relationship with the land, and they performed ceremonies to mark those transitions. There was a religious and cultural aspect to *rāhui* that was absent from the PGEM; without it, Teavai-Murphy said, “the relationship was gone.” After the PGEM was imposed, the fishers who’d attended the government meetings felt that they’d “participated in their own loss.” They stopped coming to the meetings.

“If you respect that cycle, we would never be in trouble today,” Teavai-Murphy said. “You respect the

CULTURAL LINK On Mo'orea, the nautilus-shaped Te Fare Natura ecomuseum sits adjacent to the French science lab, CRIOBE. It opened in 2021 with the goal of honoring Polynesia's cultural and natural history and sharing scientific research with the public.

NELL FREUDENBERGER

spawning of that fish—you leave that alone. And when there is a time to go out and fish pelagic fish, these are the stars that tell us we can fish bonito."

The fisher Teiho wasn't storytelling when he connected the loss of traditional knowledge about lunar cycles to climate change; those cycles were integral to the functioning of *rāhui*. Scholars believe there were approximately 100,000 people living on Tahiti and Mo'orea in 1767, at the time of first European contact. That population existed comfortably without imports, sustaining their islands' abundant natural resources through local trade, as well as a complex program of *rāhui*.

As we were talking, it got dark on the deck; dogs barked, and the forest around the lab came alive with the sound of insects. I had always been taught about the scientific revolution as an enlightenment before which there were only legends. But in Mo'orea I came to think that it isn't an accident that western science coincided with urbanization, that when people moved into cities, they suddenly required a more attenuated method of understanding the natural world. Over the past week, walking back to my bungalow at night, it had been so dark that I'd sometimes stumbled on the two asphalt tracks that switch-backed up the hill; but if I looked up, I could see the Milky Way more clearly than I ever

> "When you look at the fishermen, he is the one in the water every day. His word is better than the word of the scientists."

had before, a deep, celestial latticework that caught the tiny island in a spangled net of stars. I'm not great with constellations, but I could pick out the Pleiades; it made perfect sense that the rising and setting of Matari'i would once have dictated the give and take between human beings and their natural surroundings, because those seven bright stars seemed close enough to touch.

Teavai-Murphy was ambivalent about some of the restoration efforts underway in the lagoon. She was careful to say that she approved of the Coral Gardeners success in publicizing the predicament of coral reefs around the world and was especially enthusiastic about the work they did in local schools, but for her even the name of the organization was problematic. Planting corals, she felt, suggested that "you can go on doing what you're doing, because we have the solution. Really for me this is the wrong idea about doing conservation. It's an insult to our ecosystem." She supported the scientists at Gump and CRIOBE but believed that their efforts at assisted renovation were something "for the lab"; in the lagoon, the delicate balance of *rāhui* needed to be reimplemented.

"Now we are moving toward a process of *rāhui*," Teavai-Murphy said. Since 2016, the PGEM has undergone a collective revision process; at the same time, the grassroots *Association Rāhui* has been working to create a new plan for resource management, but the process was fractious, with a byzantine collection of local organizations involved. Two successful *rāhui* were working in Tahiti, though, on the remote southeastern tip of the island called Fenua ʻAihere (literally, "uncultivated land"). One *rāhui* was completely closed to marine activities for renewable three-year periods, while another operated with rotational fishing limits around a closed *puna*, or source, with the goal of preserving coral and reef species. The *rāhui* were managed by *tōmite*: committees that included fishers, government officials, local conservationists, and religious leaders, who emphasized the importance of passing the sacred elements of *rāhui* to the next generation.

Historically residents of the area had mistrusted scientists, both because of the traumatic history of colonization and the very contemporary fear that conservationists were out to sabotage fishers' livelihoods. But more recent efforts were getting a warmer welcome. After a team from CRIOBE began showing up to learn from residents about *rāhui*, the residents not only tolerated but appreciated the scientists' ecological inspections of the sites. One Taiarapu mother expressed her hope that someday "maybe our children could work with them, in collaboration."

One crucial element of the *rāhui* is that they be monitored by local people, to prevent fishing where it isn't allowed. A paper by Pauline Fabre whose coauthors include noted Pacific Studies scholars Tamatoa Bambridge and Alexander Mawyer, quotes a Teahupo'o resident describing a local grandmother and her grandchildren, who have started conscientiously reporting infractions on the area protected as a *rāhui*: "When they see [an infraction on the *rāhui*], they call the city hall."

Teavai-Murphy stressed that these *rāhui* were not an uncritical return to an ancient practice, which had been hierarchical: A group of breadfruit trees might be encircled with banana leaves to prohibit harvesting until a chief's lavish wedding feast. Management by committee and monitoring by residents on the ground had not only shifted priorities from postponed consumption to reef resilience but had made the new *rāhui* more democratic.

I mentioned to Teavai-Murphy the account of the *tupuna*, the grandfathers who had spearfished down to the mesophotic reef. "When you look at the fishermen, he is the one in the water every day," Teavai-Murphy said. "His word is better than the word of the scientists or of the police." Her voice deepened with emotion as she remembered a revered elder, Yves Teihotata, known as Papa Mape, an expert in traditional lunar cycles, astronavigation, and the island's vast catalog of birds, fish, and plants. He maintained that the best way to teach young people about the ocean was to take them out at night, so they were forced to use all their senses. "He was a scientist of the ocean," she said.

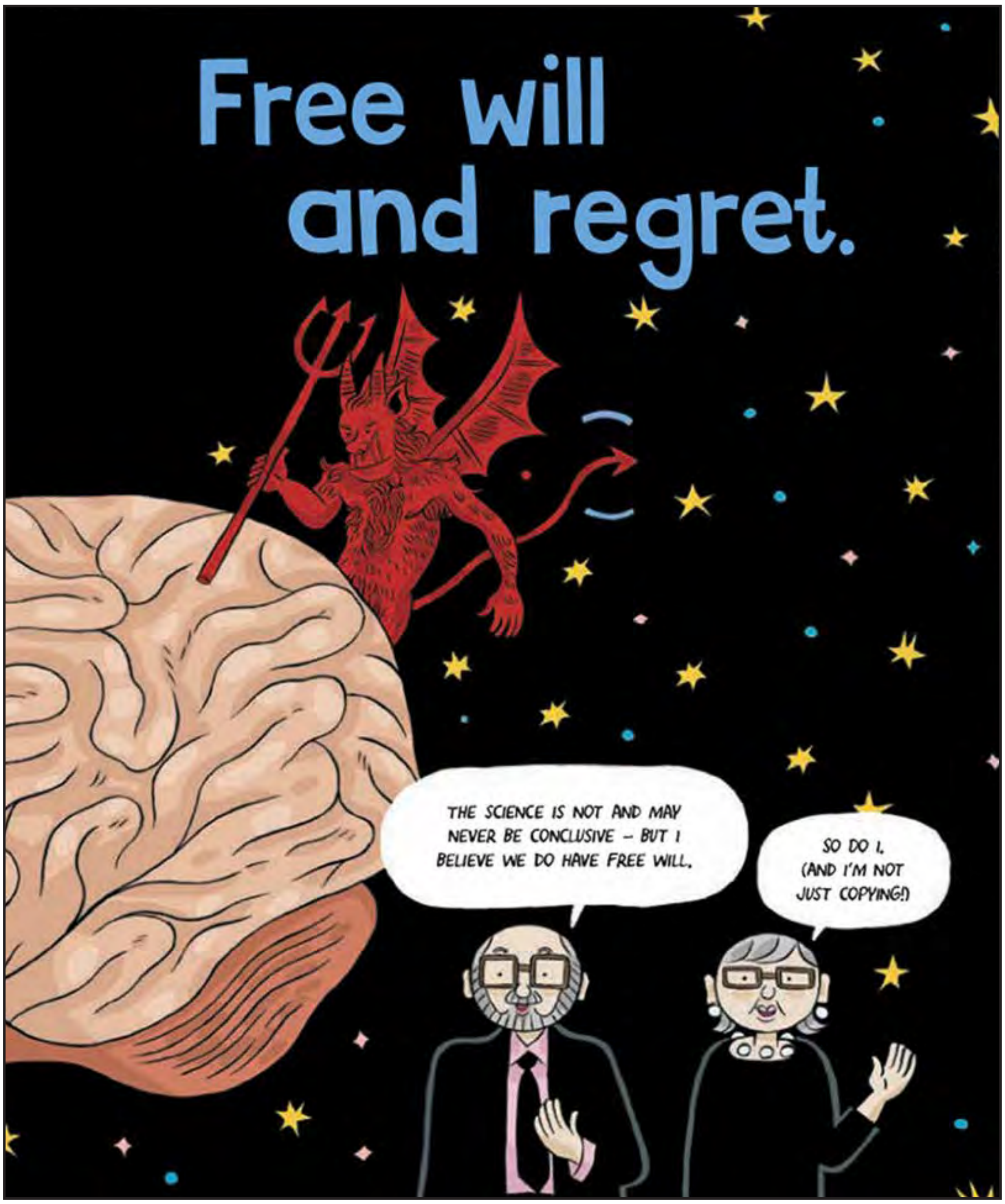
Maybe Stewart was right that Mo'orea didn't need any more scientists because it had had them all along; or maybe there was a place for Western science inside the parameters of *rāhui*, enforced by a grandmother with her eyes on the lagoon.

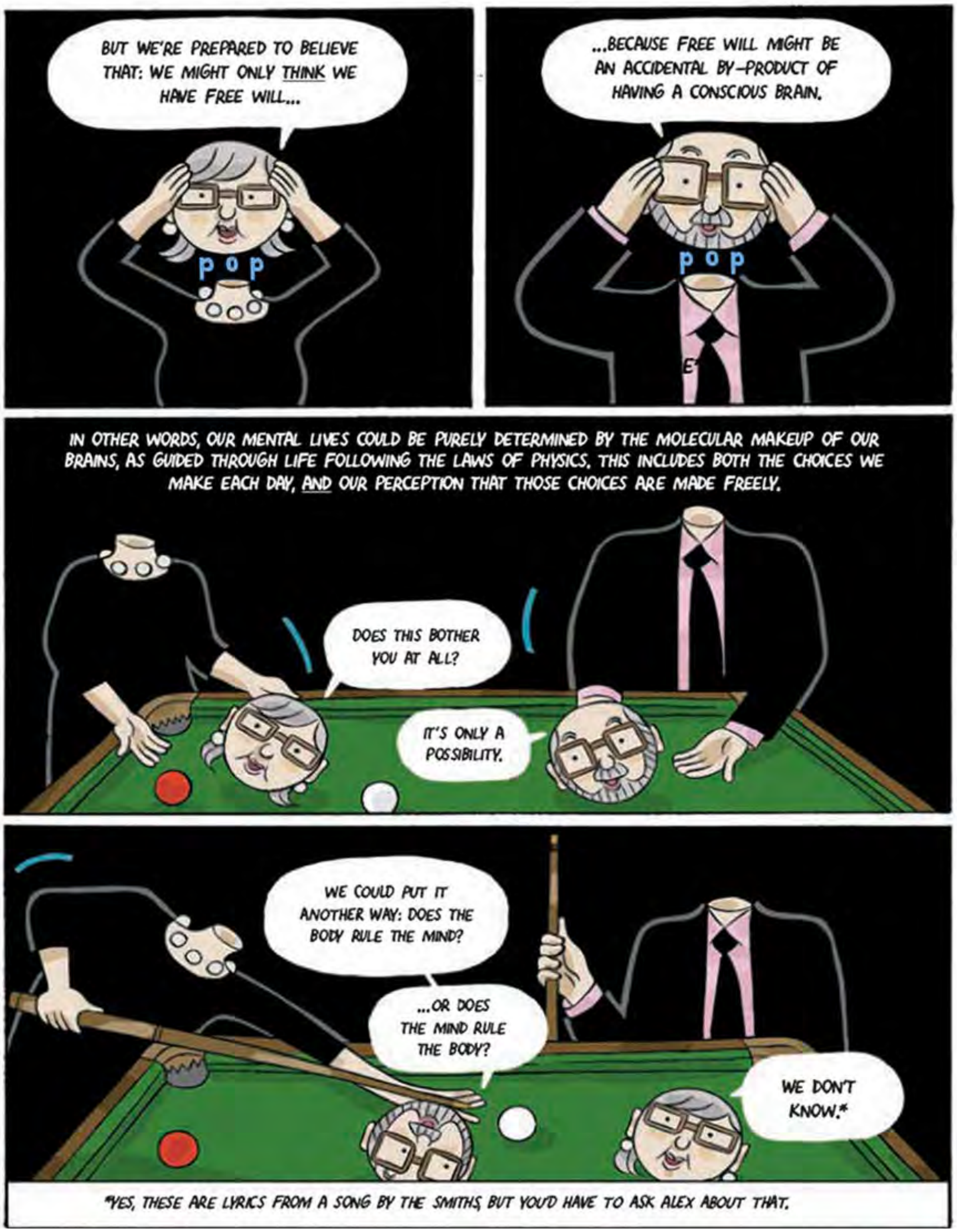
NELL FREUDENBERGER is the author of three novels, most recently *Lost and Wanted*, and the short story collection, *Lucky Girls*. Her fiction and nonfiction has been published in the *New Yorker*, *Harper's*, and *The New York Times*.

Free Will, Illustrated

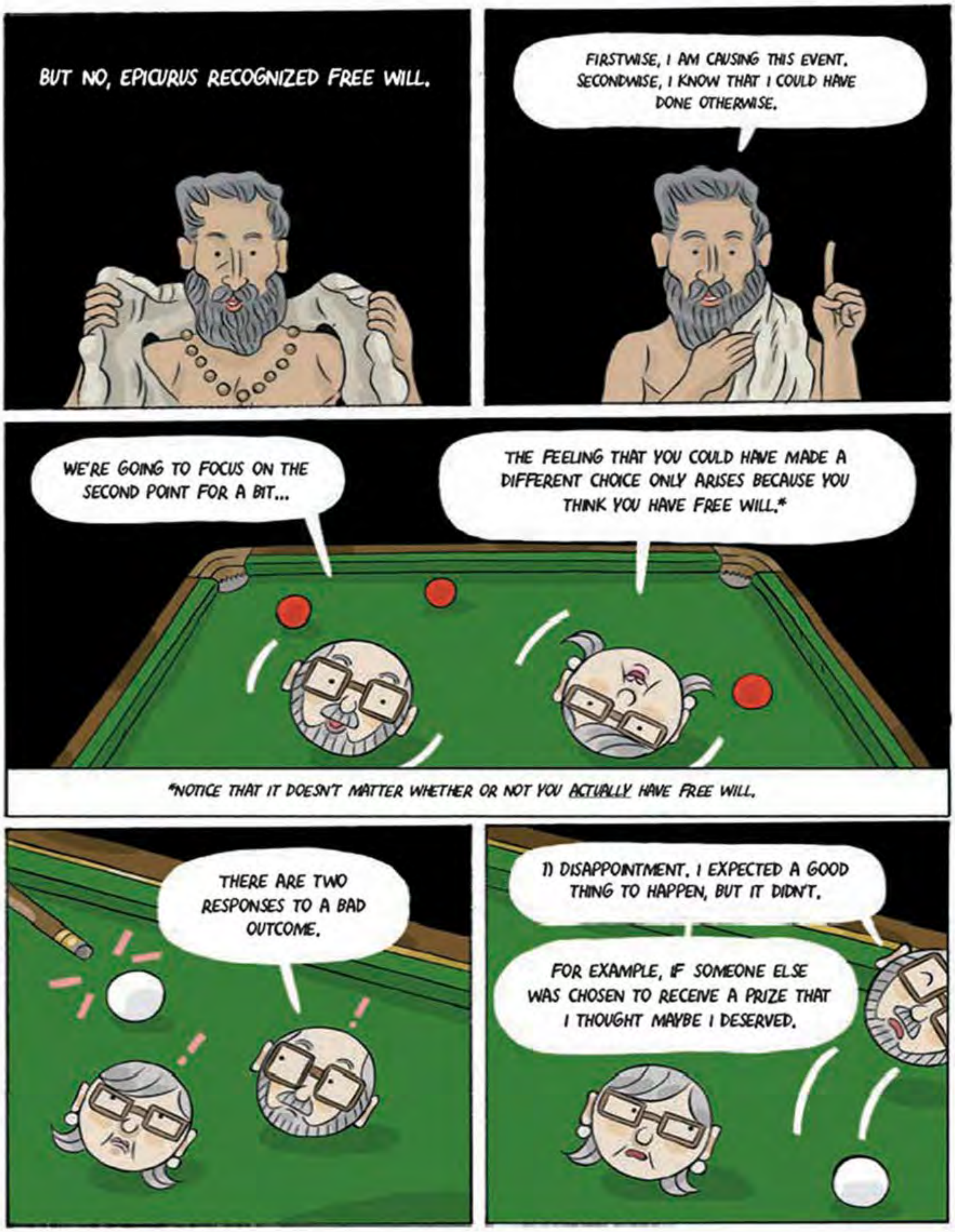
Does the body rule the mind? Or does the mind rule the body?

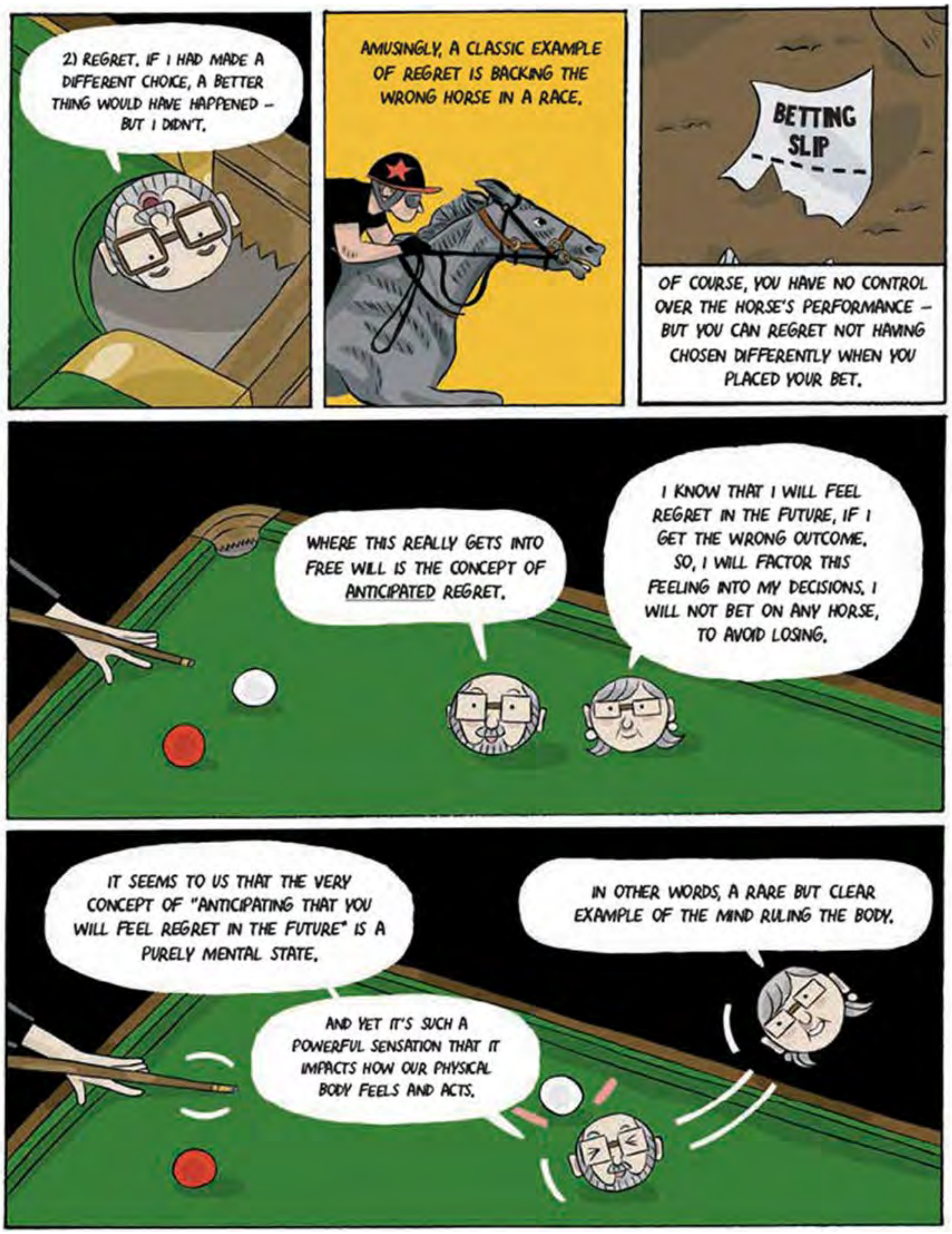
BY UTA FRITH, CHRIS FRITH & ALEX FRITH
ILLUSTRATED BY DANIEL LOCKE

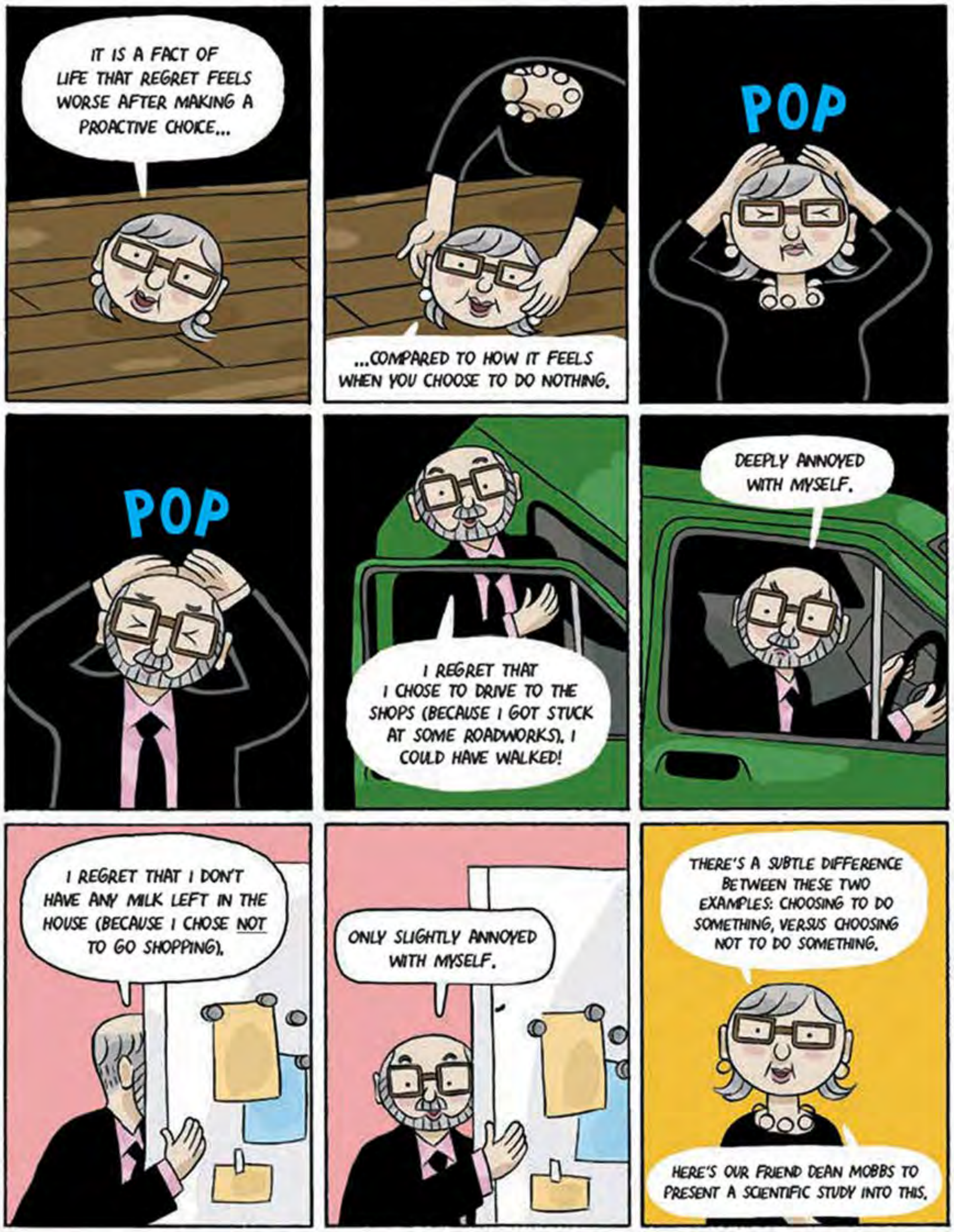



BUT WE'RE PREPARED TO BELIEVE THAT: WE MIGHT ONLY THINK WE HAVE FREE WILL...
POP
...BECAUSE FREE WILL MIGHT BE AN ACCIDENTAL BY-PRODUCT OF HAVING A CONSCIOUS BRAIN.
POP
IN OTHER WORDS, OUR MENTAL LIVES COULD BE PURELY DETERMINED BY THE MOLECULAR MAKEUP OF OUR BRAINS, AS GUIDED THROUGH LIFE FOLLOWING THE LAWS OF PHYSICS. THIS INCLUDES BOTH THE CHOICES WE MAKE EACH DAY, AND OUR PERCEPTION THAT THOSE CHOICES ARE MADE FREELY.
DOES THIS BOTHER YOU AT ALL?
IT'S ONLY A POSSIBILITY.
WE COULD PUT IT ANOTHER WAY: DOES THE BODY RULE THE MIND?
...OR DOES THE MIND RULE THE BODY?
WE DON'T KNOW.*
*YES, THESE ARE LYRICS FROM A SONG BY THE SMITHS, BUT YOU'D HAVE TO ASK ALEX ABOUT THAT.

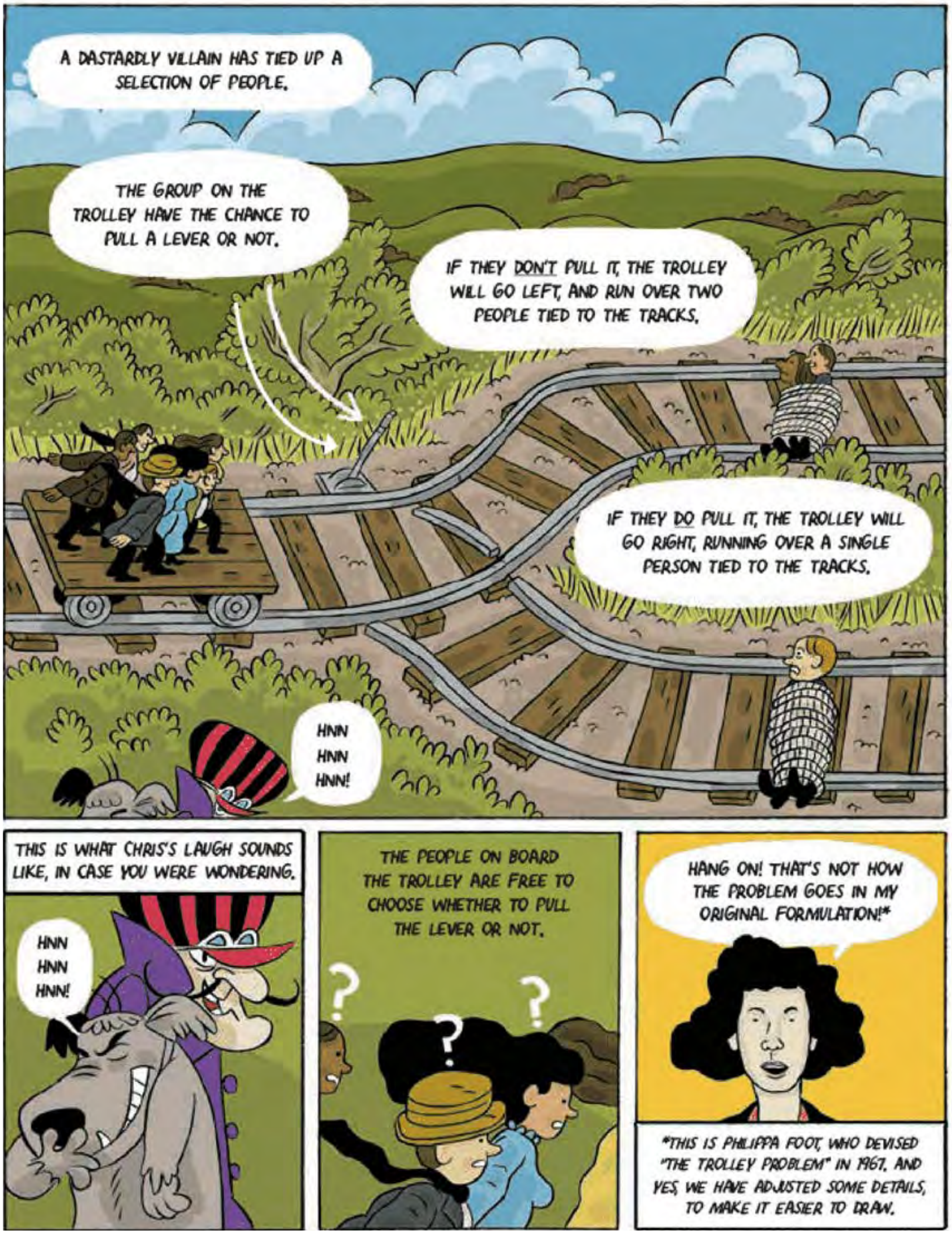

AS YOU CAN IMAGINE, THE QUESTION OF FREE WILL IS NOT AT ALL NEW.
BEFORE I STUDIED PSYCHOLOGY, I WAS SOMETHING OF A CLASSICIST. I READ A CERTAIN AMOUNT OF GREEK PHILOSOPHY.
MEET EPICURUS, BORN 341 BC IN ATHENS.
Χαιρε*
*GREETINGS AND SALUTATIONS
HE IS THE SORT OF PHILOSOPHER PEOPLE ACTUALLY ENJOY READING ABOUT BECAUSE HIS MAIN AIM WAS TO DISCOVER THE SECRET TO A HAPPY LIFE.
A CURSORY READING OF HIS IDEAS LEAVES SOME READERS...
...THINKING HE DENIES FREE WILL.
HAPPINESS, FOR EPICURUS, WAS ALL ABOUT RELAXING AND LETTING LIFE AND THE UNIVERSE TAKE OVER.
EVERYTHING'S JUST ATOMS, MAN.*
*THE EXISTENCE OF ATOMS WAS FIRST POSITED BY DEMOCRITUS, A CENTURY BEFORE EPICURUS LIVED.


BUT NO, EPICURUS RECOGNIZED FREE WILL.
FIRSTWISE, I AM CAUSING THIS EVENT. SECONDWISE, I KNOW THAT I COULD HAVE DONE OTHERWISE.
WE'RE GOING TO FOCUS ON THE SECOND POINT FOR A BIT...
THE FEELING THAT YOU COULD HAVE MADE A DIFFERENT CHOICE ONLY ARISES BECAUSE YOU THINK YOU HAVE FREE WILL.*
*NOTICE THAT IT DOESN'T MATTER WHETHER OR NOT YOU ACTUALLY HAVE FREE WILL.
THERE ARE TWO RESPONSES TO A BAD OUTCOME.
1) DISAPPOINTMENT. I EXPECTED A GOOD THING TO HAPPEN, BUT IT DIDN'T.
FOR EXAMPLE, IF SOMEONE ELSE WAS CHOSEN TO RECEIVE A PRIZE THAT I THOUGHT MAYBE I DESERVED.

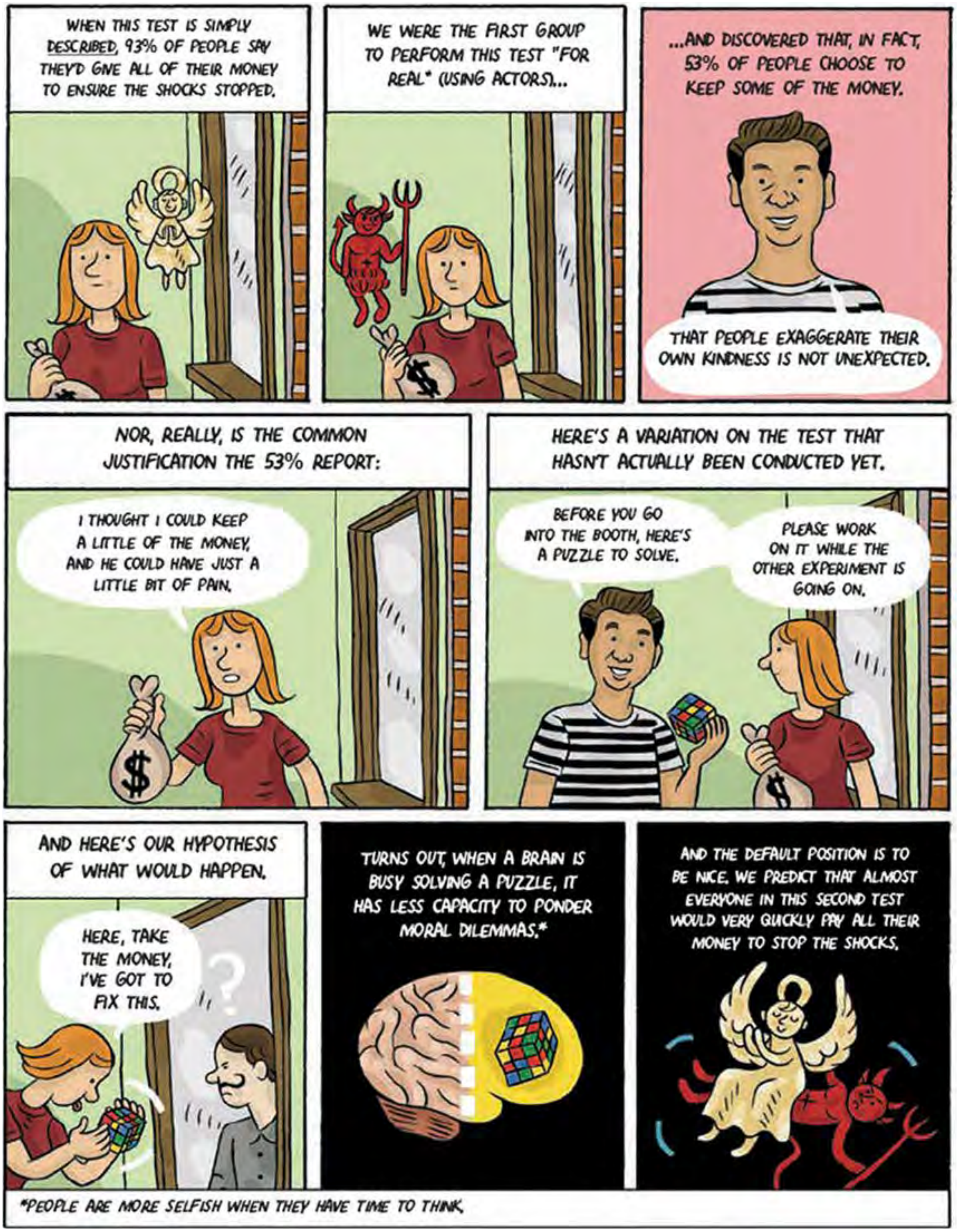

2) REGRET. IF I HAD MADE A DIFFERENT CHOICE, A BETTER THING WOULD HAVE HAPPENED – BUT I DIDN'T.
AMUSINGLY, A CLASSIC EXAMPLE OF REGRET IS BACKING THE WRONG HORSE IN A RACE.
BETTING SLIP
OF COURSE, YOU HAVE NO CONTROL OVER THE HORSE'S PERFORMANCE – BUT YOU CAN REGRET NOT HAVING CHOSEN DIFFERENTLY WHEN YOU PLACED YOUR BET.
WHERE THIS REALLY GETS INTO FREE WILL IS THE CONCEPT OF ANTICIPATED REGRET.
I KNOW THAT I WILL FEEL REGRET IN THE FUTURE, IF I GET THE WRONG OUTCOME. SO, I WILL FACTOR THIS FEELING INTO MY DECISIONS. I WILL NOT BET ON ANY HORSE, TO AVOID LOSING.
IT SEEMS TO US THAT THE VERY CONCEPT OF "ANTICIPATING THAT YOU WILL FEEL REGRET IN THE FUTURE" IS A PURELY MENTAL STATE.
IN OTHER WORDS, A RARE BUT CLEAR EXAMPLE OF THE MIND RULING THE BODY.
AND YET IT'S SUCH A POWERFUL SENSATION THAT IT IMPACTS HOW OUR PHYSICAL BODY FEELS AND ACTS.

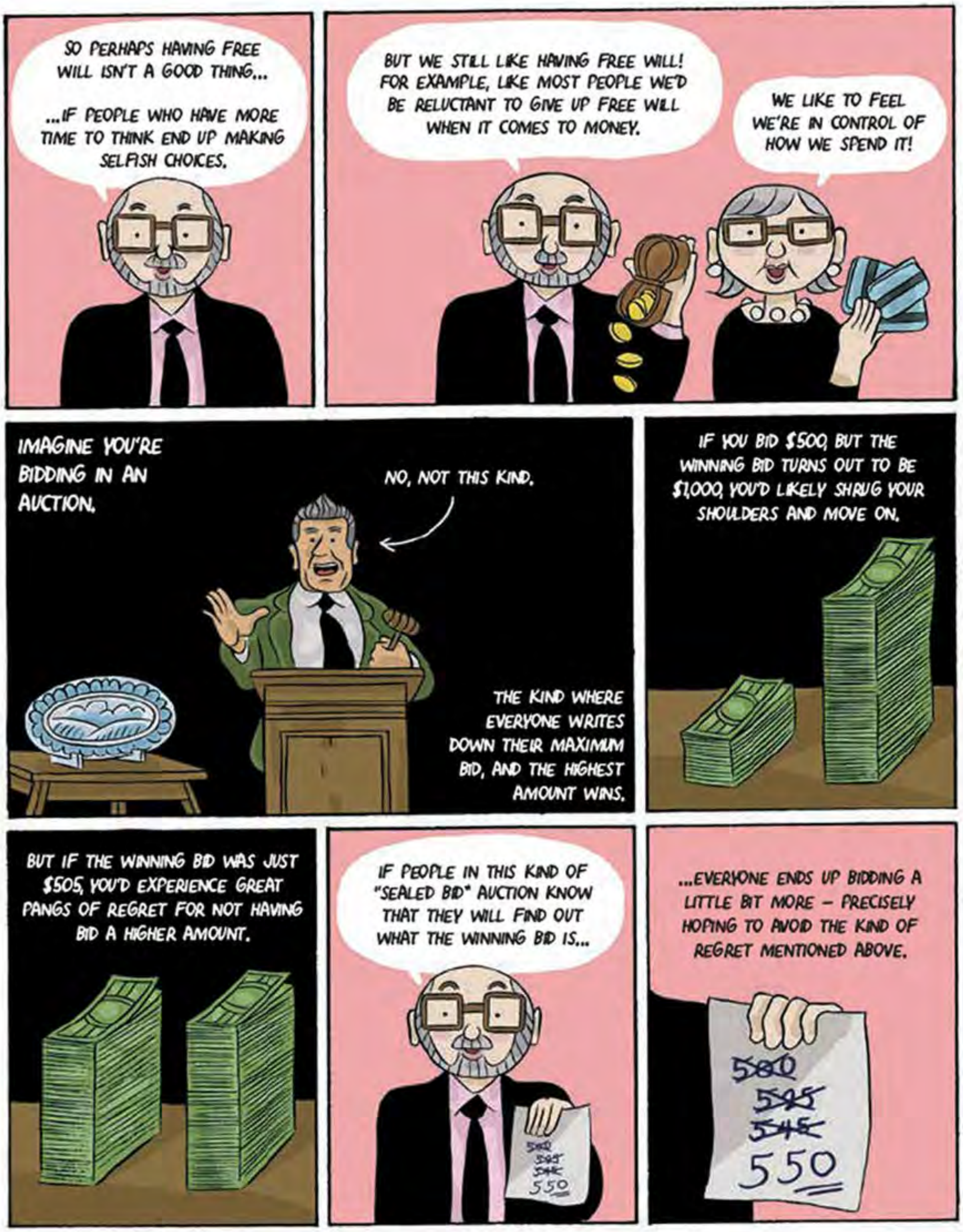

IT IS A FACT OF LIFE THAT REGRET FEELS WORSE AFTER MAKING A PROACTIVE CHOICE...
...COMPARED TO HOW IT FEELS WHEN YOU CHOOSE TO DO NOTHING.
POP
POP
I REGRET THAT I CHOSE TO DRIVE TO THE SHOPS (BECAUSE I GOT STUCK AT SOME ROADWORKS). I COULD HAVE WALKED!
DEEPLY ANNOYED WITH MYSELF.
I REGRET THAT I DON'T HAVE ANY MILK LEFT IN THE HOUSE (BECAUSE I CHOSE NOT TO GO SHOPPING).
ONLY SLIGHTLY ANNOYED WITH MYSELF.
THERE'S A SUBTLE DIFFERENCE BETWEEN THESE TWO EXAMPLES: CHOOSING TO DO SOMETHING, VERSUS CHOOSING NOT TO DO SOMETHING.
HERE'S OUR FRIEND DEAN MOBBS TO PRESENT A SCIENTIFIC STUDY INTO THIS.

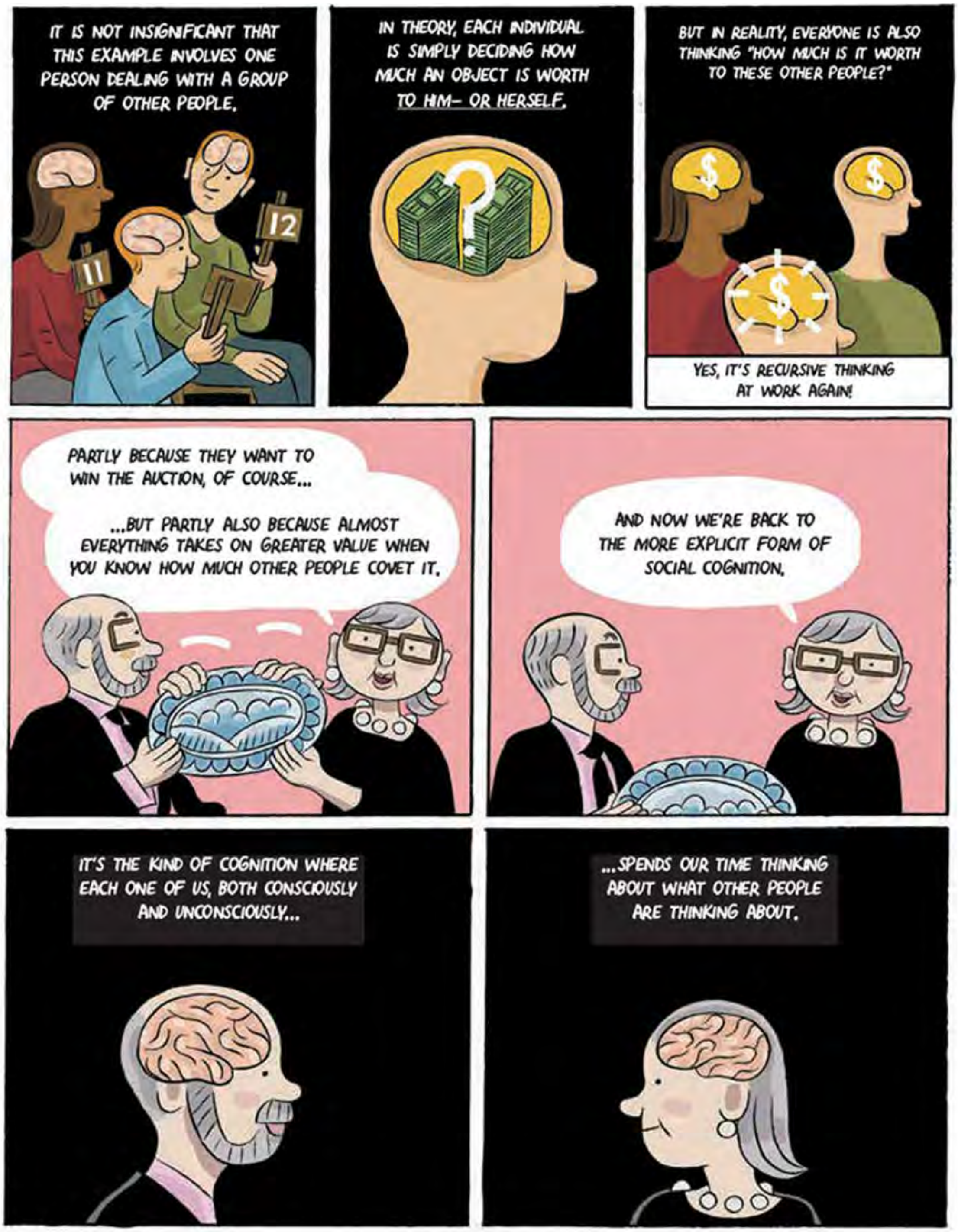

HELLO! NOW, I RAN AN EXPERIMENT* BASED ON A CLASSIC ETHICS EXPERIMENT, THE TROLLEY PROBLEM.
THIS KIND OF TROLLEY?
PRECISELY.
*WELL, I COWROTE THE PAPER. YOU'LL MEET THE FIRST AUTHOR, ORIEL FELDMANHALL, SHORTLY.
IN THIS CLASSIC VERSION OF THE PROBLEM, A TROLLEY CARRYING A GROUP OF PEOPLE IS RUNNING ALONG A RAILWAY TRACK, WITH LIMITED CONTROL.
A LITTLE DISTANCE AHEAD, THE TRACK SPLITS INTO TWO FORKS.
COLLECTIVELY, THE GROUP OF PEOPLE HAVE TO MAKE A MAJOR DECISION. THE ASSUMPTION IS THAT THEY HAVE FREE WILL, AND THE DECISION THEY WILL MAKE IS A FREE ONE.
IT'S NOT AN EASY DECISION, MIND!

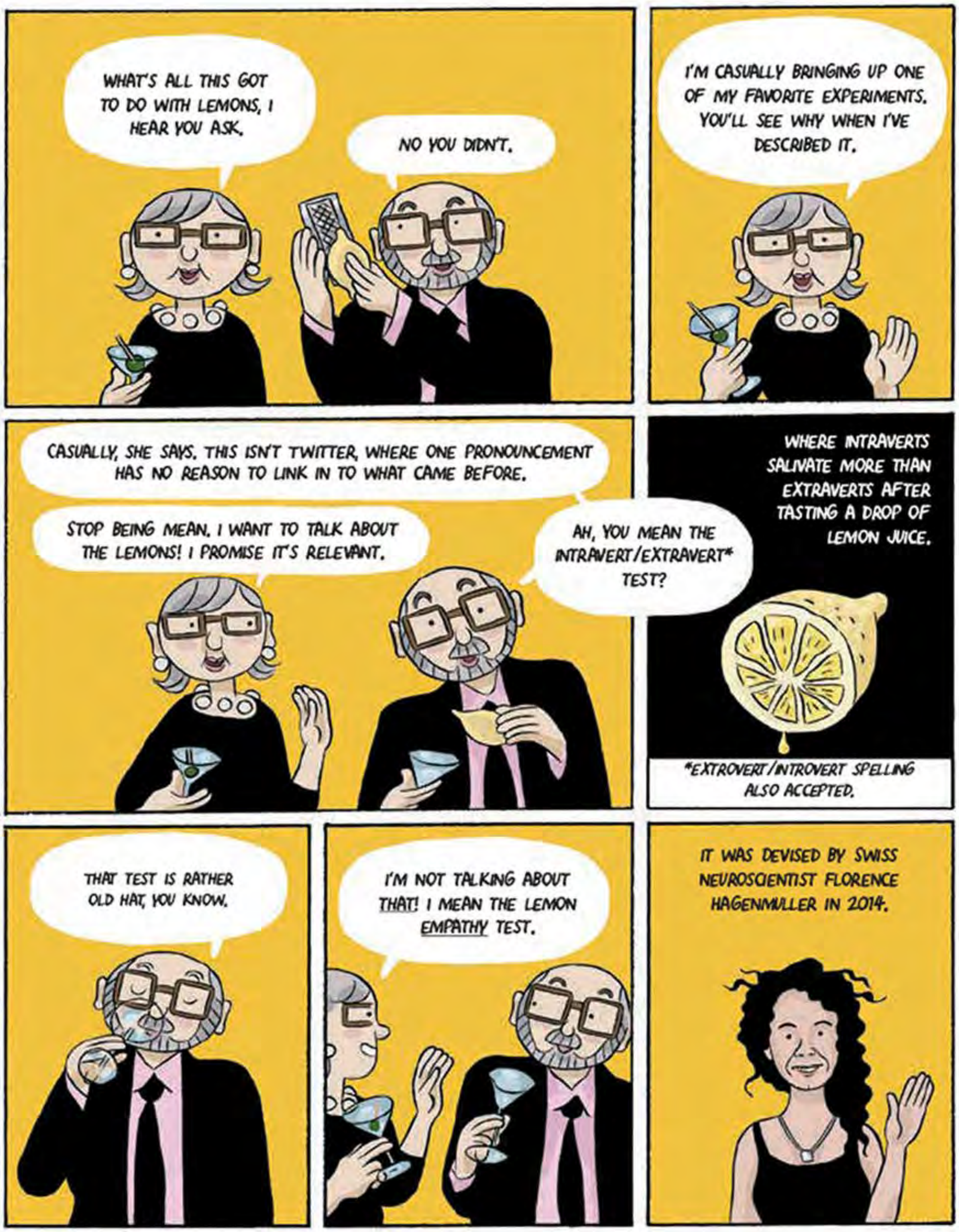

A DASTARDLY VILLAIN HAS TIED UP A SELECTION OF PEOPLE.
THE GROUP ON THE TROLLEY HAVE THE CHANCE TO PULL A LEVER OR NOT.
IF THEY DON'T PULL IT, THE TROLLEY WILL GO LEFT, AND RUN OVER TWO PEOPLE TIED TO THE TRACKS.
IF THEY DO PULL IT, THE TROLLEY WILL GO RIGHT, RUNNING OVER A SINGLE PERSON TIED TO THE TRACKS.
HNN HNN HNN!
THIS IS WHAT CHRIS'S LAUGH SOUNDS LIKE, IN CASE YOU WERE WONDERING.
HNN HNN HNN!
THE PEOPLE ON BOARD THE TROLLEY ARE FREE TO CHOOSE WHETHER TO PULL THE LEVER OR NOT.
?
?
?
HANG ON! THAT'S NOT HOW THE PROBLEM GOES IN MY ORIGINAL FORMULATION!*
*THIS IS PHILIPPA FOOT, WHO DEVISED "THE TROLLEY PROBLEM" IN 1967. AND YES, WE HAVE ADJUSTED SOME DETAILS, TO MAKE IT EASIER TO DRAW.

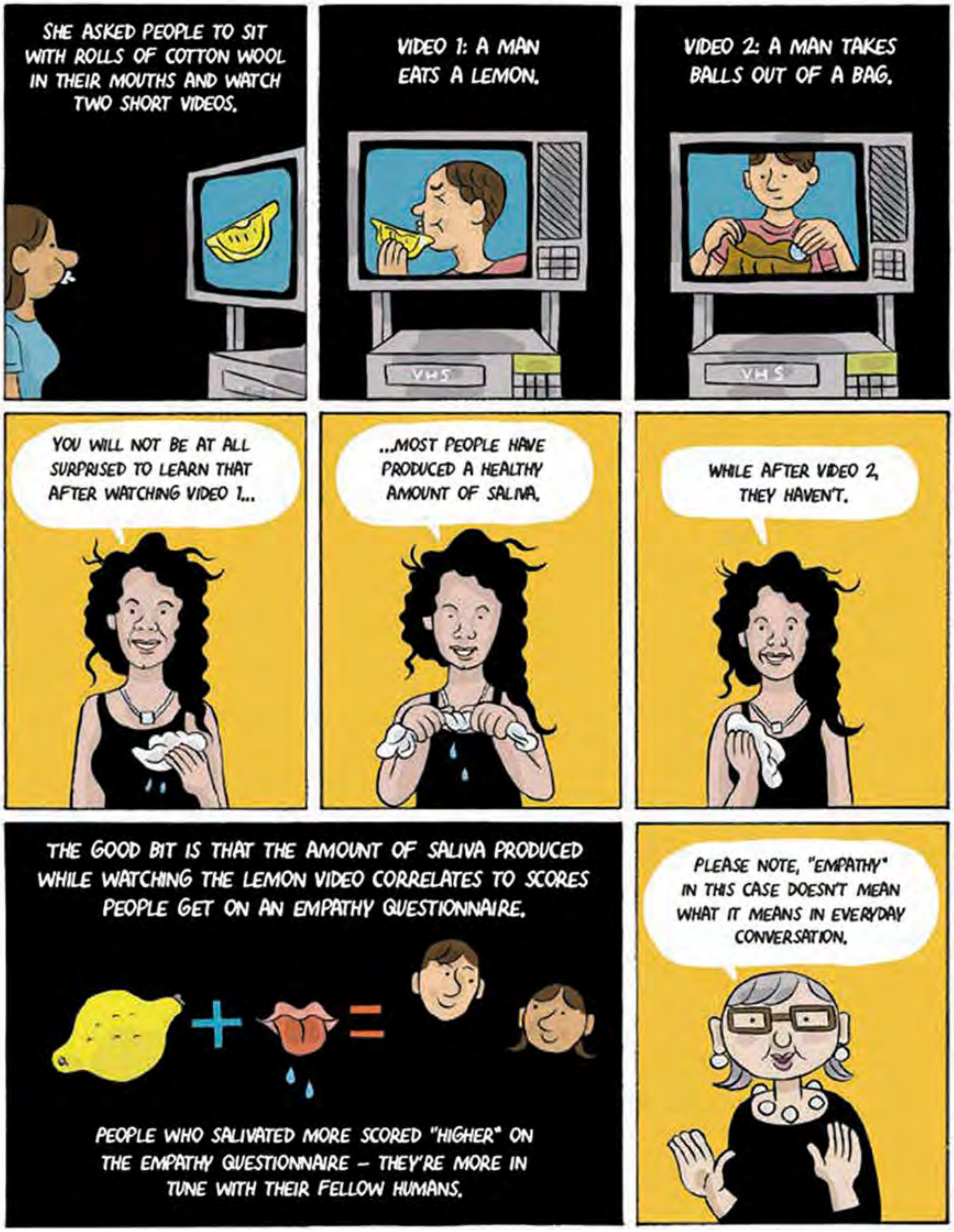

THE POINT IS, IN THIS SCENARIO, EVERYONE HAS TO SPEND TIME DEBATING AND, ULTIMATELY, TO MAKE A CHOICE. CRUCIALLY, THERE'S ALSO TIME FOR THEM TO JUSTIFY THAT CHOICE TO BOTH THEMSELVES AND EACH OTHER...
...AND THERE'LL BE TIME TO REGRET THEIR DECISION LATER.
I DIDN'T SET UP A FIENDISH TRAIN TRACK AND ASK PEOPLE TO COMMIT MURDER.
THIS IS ORIEL FELDMANHALL.
I USED THOSE OLD PSYCHOLOGY TEST STANDBYS, HARD CASH AND ELECTRIC SHOCKS.
I INVITED EACH TEST SUBJECT INTO A BOOTH...
...WHERE THEY WITNESS A TORTURER ADMINISTERING SHOCKS TO A MAN STRAPPED TO A CHAIR.
(THE TESTEE DOESN'T KNOW THAT BOTH ARE REALLY ACTORS PRETENDING.)
THE TESTEE IS GIVEN A BAG OF MONEY, AND TOLD THAT SHE CAN PAY THE TORTURER.
THE MORE SHE GIVES, THE LESS THE TORTURER ACTIVATES THE SHOCKS.
AGONY
PAIN
NO PAIN

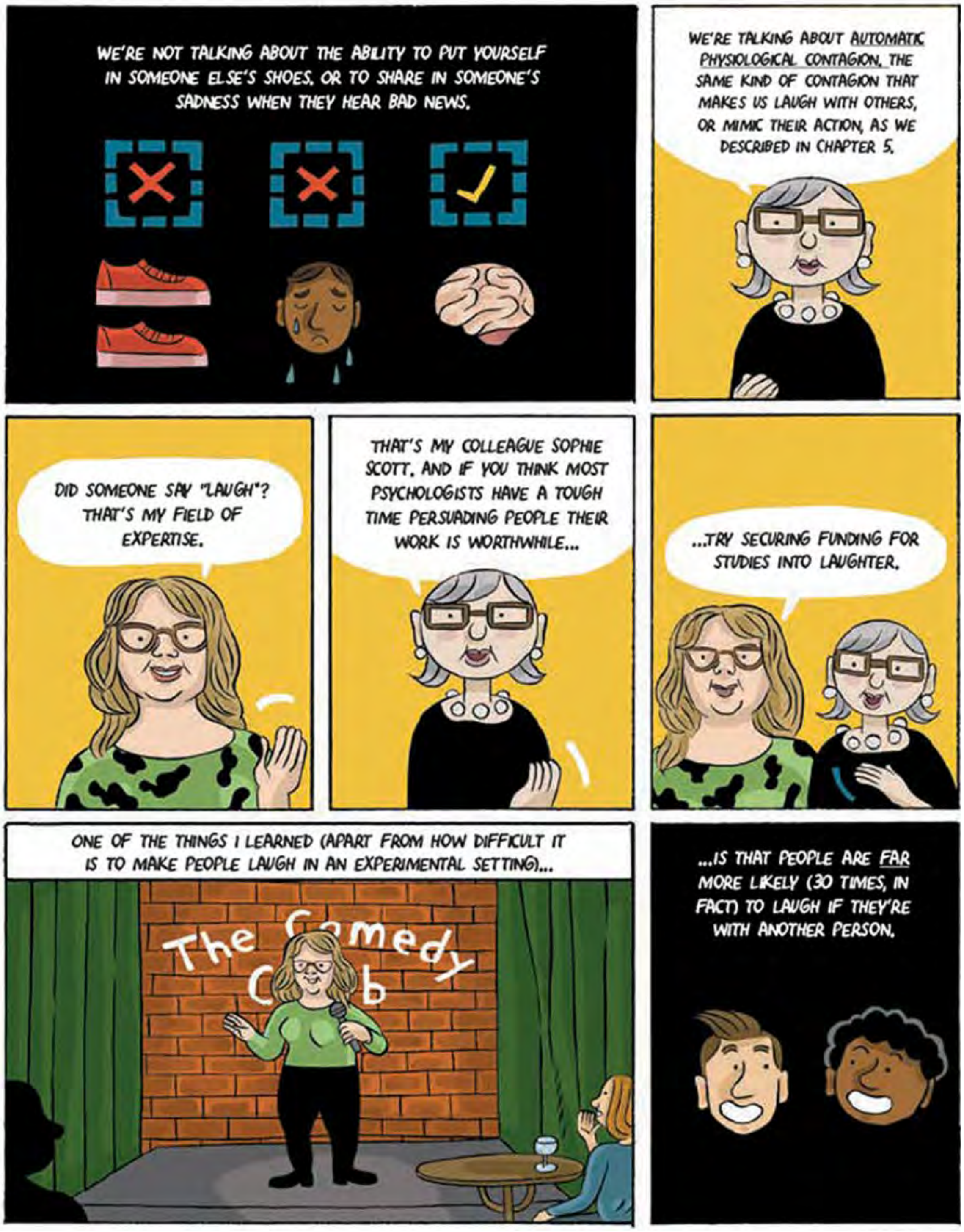

WHEN THIS TEST IS SIMPLY DESCRIBED, 93% OF PEOPLE SAY THEY'D GIVE ALL OF THEIR MONEY TO ENSURE THE SHOCKS STOPPED.
WE WERE THE FIRST GROUP TO PERFORM THIS TEST "FOR REAL" (USING ACTORS)...
...AND DISCOVERED THAT, IN FACT, 53% OF PEOPLE CHOOSE TO KEEP SOME OF THE MONEY.
THAT PEOPLE EXAGGERATE THEIR OWN KINDNESS IS NOT UNEXPECTED.
NOR, REALLY, IS THE COMMON JUSTIFICATION THE 53% REPORT:
I THOUGHT I COULD KEEP A LITTLE OF THE MONEY, AND HE COULD HAVE JUST A LITTLE BIT OF PAIN.
HERE'S A VARIATION ON THE TEST THAT HASN'T ACTUALLY BEEN CONDUCTED YET.
BEFORE YOU GO INTO THE BOOTH, HERE'S A PUZZLE TO SOLVE.
PLEASE WORK ON IT WHILE THE OTHER EXPERIMENT IS GOING ON.
AND HERE'S OUR HYPOTHESIS OF WHAT WOULD HAPPEN.
HERE, TAKE THE MONEY, I'VE GOT TO FIX THIS.
TURNS OUT, WHEN A BRAIN IS BUSY SOLVING A PUZZLE, IT HAS LESS CAPACITY TO PONDER MORAL DILEMMAS.*
AND THE DEFAULT POSITION IS TO BE NICE. WE PREDICT THAT ALMOST EVERYONE IN THIS SECOND TEST WOULD VERY QUICKLY PAY ALL THEIR MONEY TO STOP THE SHOCKS.
*PEOPLE ARE MORE SELFISH WHEN THEY HAVE TIME TO THINK.


SO PERHAPS HAVING FREE WILL ISN'T A GOOD THING...
...IF PEOPLE WHO HAVE MORE TIME TO THINK END UP MAKING SELFISH CHOICES.
BUT WE STILL LIKE HAVING FREE WILL! FOR EXAMPLE, LIKE MOST PEOPLE WE'D BE RELUCTANT TO GIVE UP FREE WILL WHEN IT COMES TO MONEY.
WE LIKE TO FEEL WE'RE IN CONTROL OF HOW WE SPEND IT!
IMAGINE YOU'RE BIDDING IN AN AUCTION.
NO, NOT THIS KIND.
THE KIND WHERE EVERYONE WRITES DOWN THEIR MAXIMUM BID, AND THE HIGHEST AMOUNT WINS.
IF YOU BID $500, BUT THE WINNING BID TURNS OUT TO BE $1,000, YOU'D LIKELY SHRUG YOUR SHOULDERS AND MOVE ON.
BUT IF THE WINNING BID WAS JUST $505, YOU'D EXPERIENCE GREAT PANGS OF REGRET FOR NOT HAVING BID A HIGHER AMOUNT.
IF PEOPLE IN THIS KIND OF "SEALED BID" AUCTION KNOW THAT THEY WILL FIND OUT WHAT THE WINNING BID IS...
...EVERYONE ENDS UP BIDDING A LITTLE BIT MORE – PRECISELY HOPING TO AVOID THE KIND OF REGRET MENTIONED ABOVE.
~~500~~
~~525~~
~~545~~
550

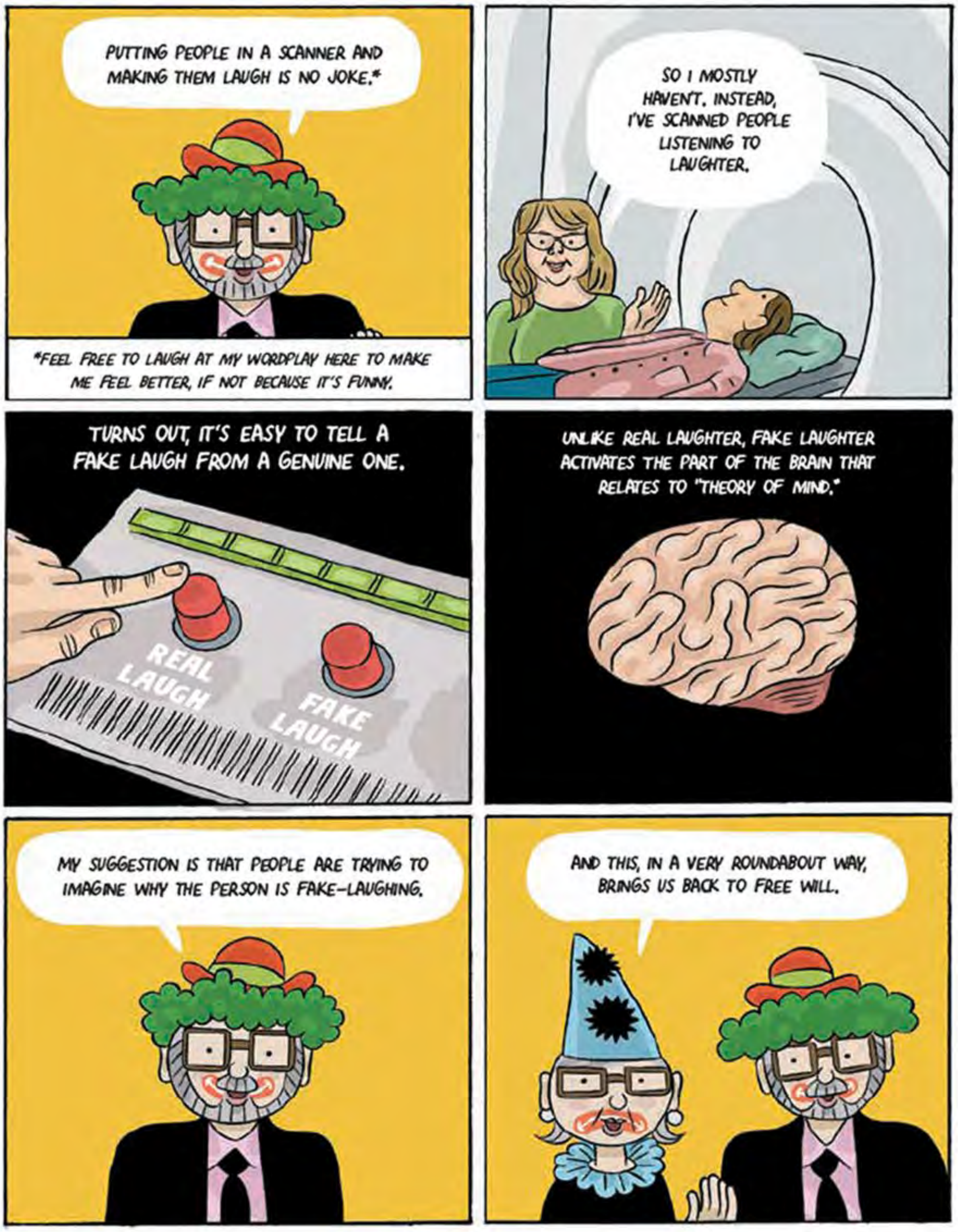

IT IS NOT INSIGNIFICANT THAT THIS EXAMPLE INVOLVES ONE PERSON DEALING WITH A GROUP OF OTHER PEOPLE.
11
12
IN THEORY, EACH INDIVIDUAL IS SIMPLY DECIDING HOW MUCH AN OBJECT IS WORTH TO HIM- OR HERSELF.
BUT IN REALITY, EVERYONE IS ALSO THINKING "HOW MUCH IS IT WORTH TO THESE OTHER PEOPLE?"
YES, IT'S RECURSIVE THINKING AT WORK AGAIN!
PARTLY BECAUSE THEY WANT TO WIN THE AUCTION, OF COURSE...
...BUT PARTLY ALSO BECAUSE ALMOST EVERYTHING TAKES ON GREATER VALUE WHEN YOU KNOW HOW MUCH OTHER PEOPLE COVET IT.
AND NOW WE'RE BACK TO THE MORE EXPLICIT FORM OF SOCIAL COGNITION.
IT'S THE KIND OF COGNITION WHERE EACH ONE OF US, BOTH CONSCIOUSLY AND UNCONSCIOUSLY...
...SPENDS OUR TIME THINKING ABOUT WHAT OTHER PEOPLE ARE THINKING ABOUT.

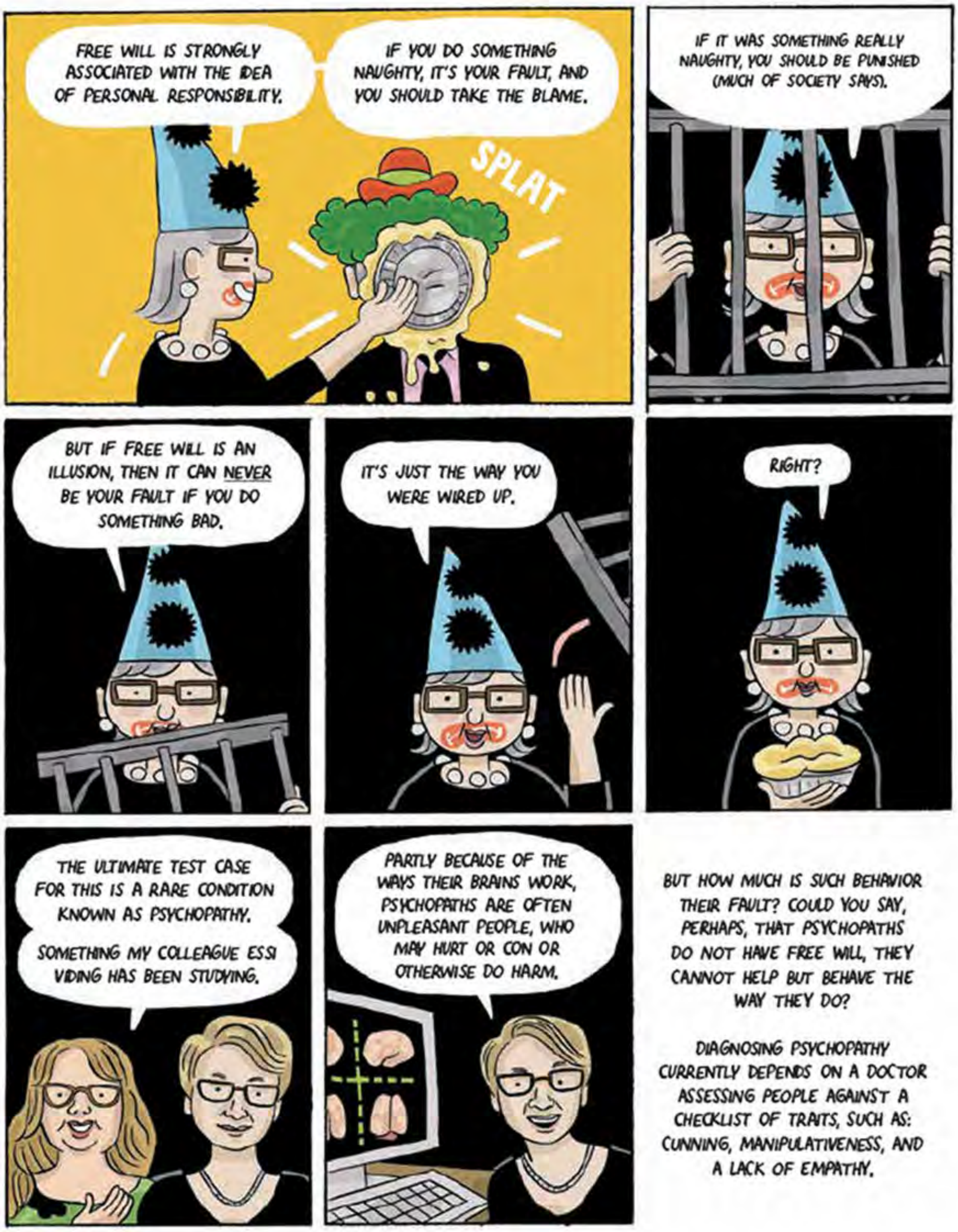

WHAT'S ALL THIS GOT TO DO WITH LEMONS, I HEAR YOU ASK.
NO YOU DIDN'T.
I'M CASUALLY BRINGING UP ONE OF MY FAVORITE EXPERIMENTS. YOU'LL SEE WHY WHEN I'VE DESCRIBED IT.
CASUALLY, SHE SAYS. THIS ISN'T TWITTER, WHERE ONE PRONOUNCEMENT HAS NO REASON TO LINK IN TO WHAT CAME BEFORE.
STOP BEING MEAN. I WANT TO TALK ABOUT THE LEMONS! I PROMISE IT'S RELEVANT.
AH, YOU MEAN THE INTRAVERT/EXTRAVERT* TEST?
WHERE INTRAVERTS SALIVATE MORE THAN EXTRAVERTS AFTER TASTING A DROP OF LEMON JUICE.
*EXTROVERT/INTROVERT SPELLING ALSO ACCEPTED.
THAT TEST IS RATHER OLD HAT, YOU KNOW.
I'M NOT TALKING ABOUT THAT! I MEAN THE LEMON EMPATHY TEST.
IT WAS DEVISED BY SWISS NEUROSCIENTIST FLORENCE HAGENMULLER IN 2014.

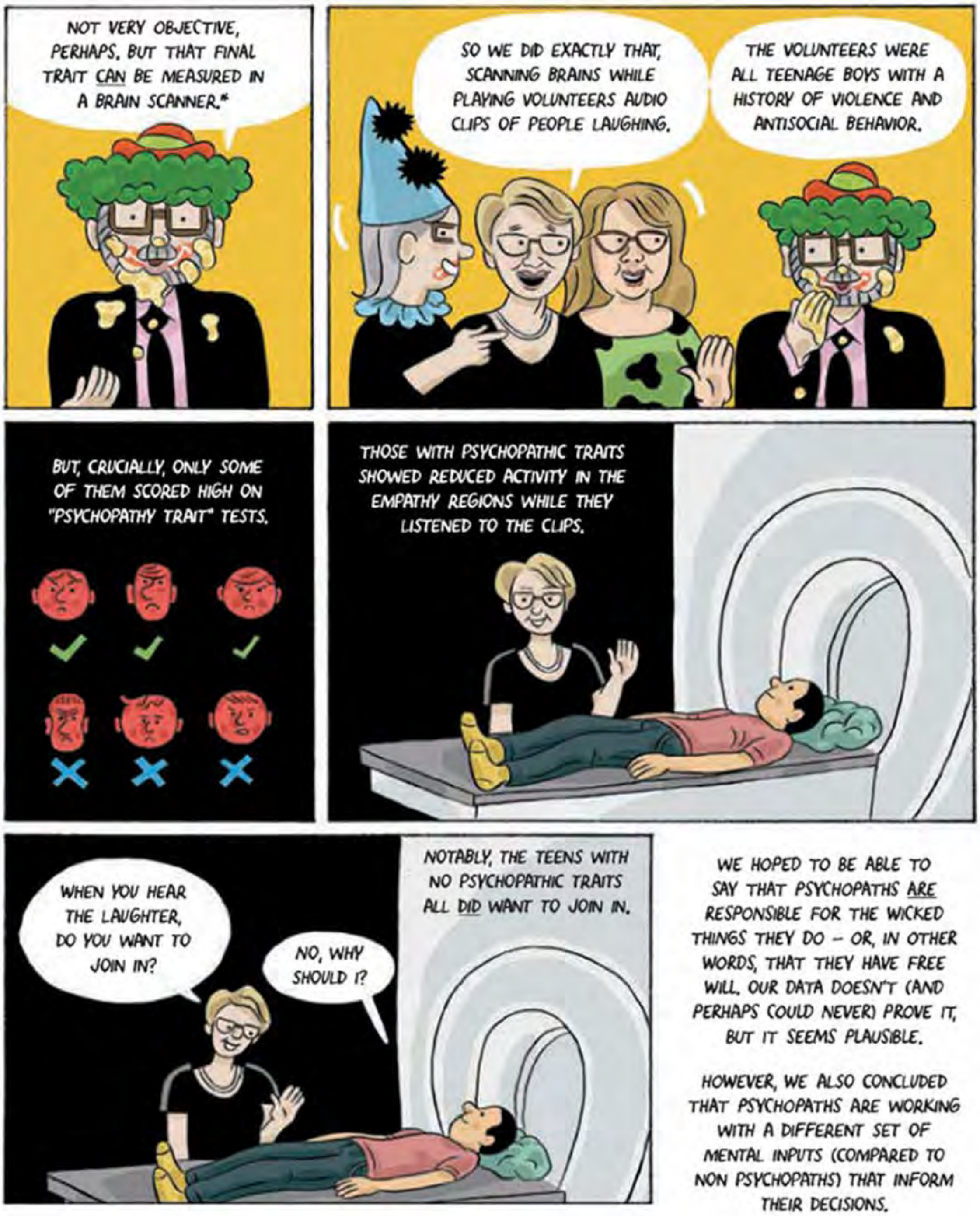

SHE ASKED PEOPLE TO SIT WITH ROLLS OF COTTON WOOL IN THEIR MOUTHS AND WATCH TWO SHORT VIDEOS.
VIDEO 1: A MAN EATS A LEMON.
VIDEO 2: A MAN TAKES BALLS OUT OF A BAG.
VHS
VHS
YOU WILL NOT BE AT ALL SURPRISED TO LEARN THAT AFTER WATCHING VIDEO 1...
...MOST PEOPLE HAVE PRODUCED A HEALTHY AMOUNT OF SALIVA.
WHILE AFTER VIDEO 2, THEY HAVEN'T.
THE GOOD BIT IS THAT THE AMOUNT OF SALIVA PRODUCED WHILE WATCHING THE LEMON VIDEO CORRELATES TO SCORES PEOPLE GET ON AN EMPATHY QUESTIONNAIRE.
PEOPLE WHO SALIVATED MORE SCORED "HIGHER" ON THE EMPATHY QUESTIONNAIRE – THEY'RE MORE IN TUNE WITH THEIR FELLOW HUMANS.
PLEASE NOTE, "EMPATHY" IN THIS CASE DOESN'T MEAN WHAT IT MEANS IN EVERYDAY CONVERSATION.

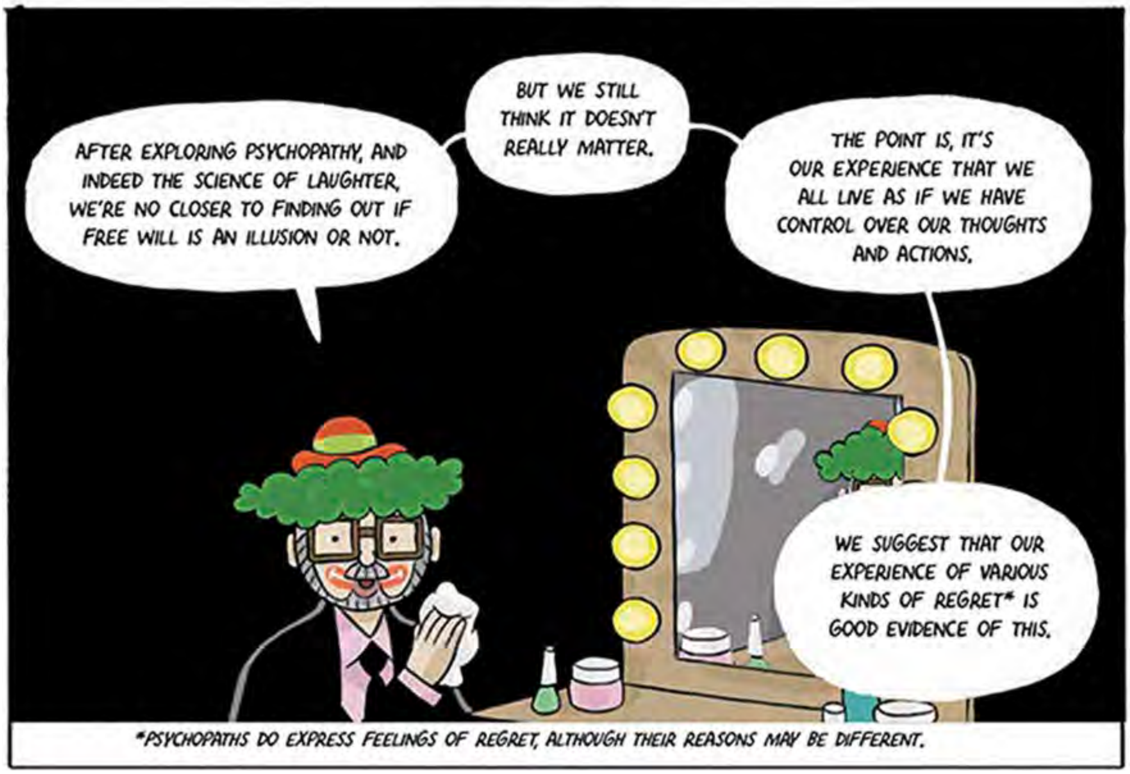

WE'RE NOT TALKING ABOUT THE ABILITY TO PUT YOURSELF IN SOMEONE ELSE'S SHOES, OR TO SHARE IN SOMEONE'S SADNESS WHEN THEY HEAR BAD NEWS.
WE'RE TALKING ABOUT AUTOMATIC PHYSIOLOGICAL CONTAGION, THE SAME KIND OF CONTAGION THAT MAKES US LAUGH WITH OTHERS, OR MIMIC THEIR ACTION, AS WE DESCRIBED IN CHAPTER 5.
DID SOMEONE SAY "LAUGH"? THAT'S MY FIELD OF EXPERTISE.
THAT'S MY COLLEAGUE SOPHIE SCOTT. AND IF YOU THINK MOST PSYCHOLOGISTS HAVE A TOUGH TIME PERSUADING PEOPLE THEIR WORK IS WORTHWHILE...
...TRY SECURING FUNDING FOR STUDIES INTO LAUGHTER.
ONE OF THE THINGS I LEARNED (APART FROM HOW DIFFICULT IT IS TO MAKE PEOPLE LAUGH IN AN EXPERIMENTAL SETTING)...
...IS THAT PEOPLE ARE FAR MORE LIKELY (30 TIMES, IN FACT) TO LAUGH IF THEY'RE WITH ANOTHER PERSON.


THEY'RE MORE LIKELY AGAIN TO LAUGH IF THEY'RE WITH A CROWD, ESPECIALLY A CROWD OF SIMILAR PEOPLE.
I ALSO FOUND STRONG EVIDENCE THAT LAUGHTER, EVEN RIOTOUS UPROARING LAUGHTER AT A DAD-JOKE...
HEH-HEH-HEH
WHY DID THE MATH BOOK LOOK SO SAD?
...IS MOSTLY ABOUT FITTING IN SOCIALLY, AND LESS ABOUT HOW FUNNY SOMETHING ACTUALLY IS.
HA-HA-HA-HA-HA
I'M SUPPOSED TO BE LAUGHING, AREN'T I.
BECAUSE IT WAS FULL OF PROBLEMS.


PUTTING PEOPLE IN A SCANNER AND MAKING THEM LAUGH IS NO JOKE.*
*FEEL FREE TO LAUGH AT MY WORDPLAY HERE TO MAKE ME FEEL BETTER, IF NOT BECAUSE IT'S FUNNY.
SO I MOSTLY HAVEN'T. INSTEAD, I'VE SCANNED PEOPLE LISTENING TO LAUGHTER.
TURNS OUT, IT'S EASY TO TELL A FAKE LAUGH FROM A GENUINE ONE.
REAL LAUGH
FAKE LAUGH
UNLIKE REAL LAUGHTER, FAKE LAUGHTER ACTIVATES THE PART OF THE BRAIN THAT RELATES TO "THEORY OF MIND."
MY SUGGESTION IS THAT PEOPLE ARE TRYING TO IMAGINE WHY THE PERSON IS FAKE-LAUGHING.
AND THIS, IN A VERY ROUNDABOUT WAY, BRINGS US BACK TO FREE WILL.


FREE WILL IS STRONGLY ASSOCIATED WITH THE IDEA OF PERSONAL RESPONSIBILITY.
IF YOU DO SOMETHING NAUGHTY, IT'S YOUR FAULT, AND YOU SHOULD TAKE THE BLAME.
SPLAT
IF IT WAS SOMETHING REALLY NAUGHTY, YOU SHOULD BE PUNISHED (MUCH OF SOCIETY SAYS).
BUT IF FREE WILL IS AN ILLUSION, THEN IT CAN NEVER BE YOUR FAULT IF YOU DO SOMETHING BAD.
IT'S JUST THE WAY YOU WERE WIRED UP.
RIGHT?
THE ULTIMATE TEST CASE FOR THIS IS A RARE CONDITION KNOWN AS PSYCHOPATHY.
SOMETHING MY COLLEAGUE ESSI VIDING HAS BEEN STUDYING.
PARTLY BECAUSE OF THE WAYS THEIR BRAINS WORK, PSYCHOPATHS ARE OFTEN UNPLEASANT PEOPLE, WHO MAY HURT OR CON OR OTHERWISE DO HARM.
BUT HOW MUCH IS SUCH BEHAVIOR THEIR FAULT? COULD YOU SAY, PERHAPS, THAT PSYCHOPATHS DO NOT HAVE FREE WILL, THEY CANNOT HELP BUT BEHAVE THE WAY THEY DO?
DIAGNOSING PSYCHOPATHY CURRENTLY DEPENDS ON A DOCTOR ASSESSING PEOPLE AGAINST A CHECKLIST OF TRAITS, SUCH AS: CUNNING, MANIPULATIVENESS, AND A LACK OF EMPATHY.


NOT VERY OBJECTIVE, PERHAPS, BUT THAT FINAL TRAIT CAN BE MEASURED IN A BRAIN SCANNER.*
SO WE DID EXACTLY THAT, SCANNING BRAINS WHILE PLAYING VOLUNTEERS AUDIO CLIPS OF PEOPLE LAUGHING.
THE VOLUNTEERS WERE ALL TEENAGE BOYS WITH A HISTORY OF VIOLENCE AND ANTISOCIAL BEHAVIOR.
BUT, CRUCIALLY, ONLY SOME OF THEM SCORED HIGH ON "PSYCHOPATHY TRAIT" TESTS.
THOSE WITH PSYCHOPATHIC TRAITS SHOWED REDUCED ACTIVITY IN THE EMPATHY REGIONS WHILE THEY LISTENED TO THE CLIPS.
WHEN YOU HEAR THE LAUGHTER, DO YOU WANT TO JOIN IN?
NO, WHY SHOULD I?
NOTABLY, THE TEENS WITH NO PSYCHOPATHIC TRAITS ALL DID WANT TO JOIN IN.
WE HOPED TO BE ABLE TO SAY THAT PSYCHOPATHS ARE RESPONSIBLE FOR THE WICKED THINGS THEY DO – OR, IN OTHER WORDS, THAT THEY HAVE FREE WILL. OUR DATA DOESN'T (AND PERHAPS COULD NEVER) PROVE IT, BUT IT SEEMS PLAUSIBLE.
HOWEVER, WE ALSO CONCLUDED THAT PSYCHOPATHS ARE WORKING WITH A DIFFERENT SET OF MENTAL INPUTS (COMPARED TO NON PSYCHOPATHS) THAT INFORM THEIR DECISIONS.

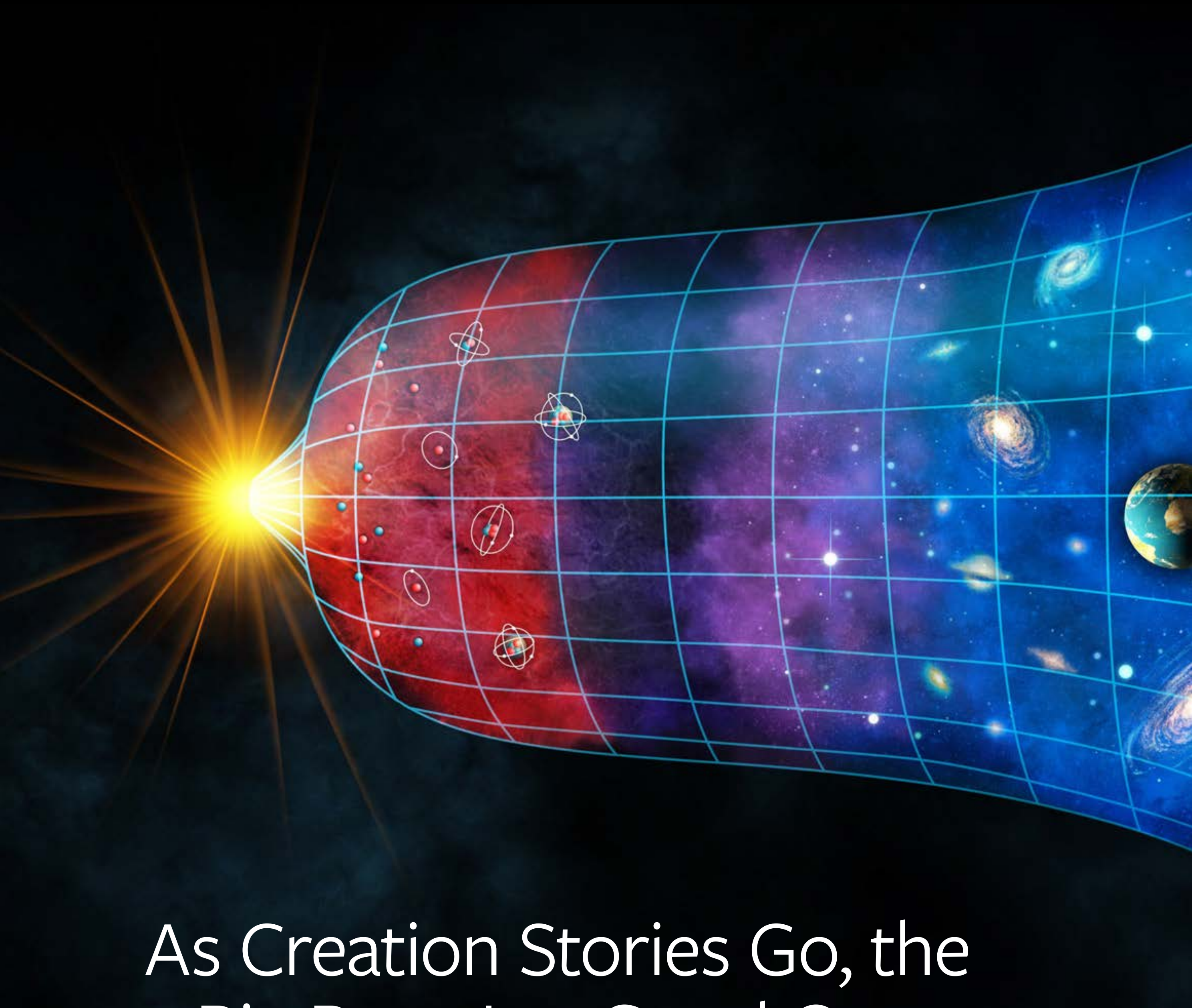


UTA FRITH is known for her research on autism and dyslexia. She was listed in 2014 as among the 200 most eminent psychologists of the modern era. She is Emeritus Professor of Cognitive Development at the Institute of Cognitive Neuroscience at University College London. She is a member of the Senate of the Leopoldina, the German National Academy of Sciences, and a Foreign Associate of the NAS. Uta was chair of the Diversity Committee at the Royal Society from 2015-2018 and has raised awareness of the value of diversity in making group decisions.

CHRIS FRITH is Emeritus Professor of Neuropsychology at the Wellcome Centre for Human Neuroimaging at University College London, Visiting Professor at the Interacting Minds Centre, Aarhus University, and Honorary Research Fellow at the Institute of Philosophy, University of London. He is a pioneer in the application of brain imaging to the study of mental processes. In 2016, he was listed among the top 10 most influential brain scientists of the modern era by *Science*. He is a Fellow of the Royal Society, of the American Association for the Advancement of Science, and of the British Academy.

ALEX FRITH has been a children's non-fiction author since 2005. Working exclusively for Usborne Publishing, he has written over 50 books.

DANIEL LOCKE is an artist and graphic novelist based in Brighton, United Kingdom. Since 2013 much of his work has been informed and shaped by the discoveries of contemporary science. He's worked with Nobrow, Arts Council England, The Wellcome Trust, and The National Trust.



As Creation Stories Go, the Big Bang Is a Good One

How science is like mythology when it pushes the boundaries of the known

BY PAUL M. SUTTER

DEEP IN THE DEPTHS OF TIME, there was the Ocean of Milk. The gods and demons both desired amrita, the nectar of immortal life, which could only be obtained from the great ocean. The supreme god Vishnu told them to use Mount Mandara as a churning stick, and to rotate the mountain with the giant serpent, Vasuki, as a rope. For a thousand years, they churned until amrita emerged. The gods and demons fought and quarreled over amrita until the gods prevailed. The churning produced other wonders: the physician of the gods Dhanvantari, the goddess of riches Lakshmi, the goddess of misfortune Jyestha, the white elephant, the seven-headed horse Uchchaisrava, and a wish-granting tree. And finally came the moon, Chandra.

More recently, modern scientists are churning the universe for another treasure. They are searching for the ripples in space-time, known as gravitational waves, leftover from the primordial Big Bang. Scientists believe that when our universe was less than a second old, it underwent a radical phase transition, dramatically inflating in size. That event shaped the future evolution of the cosmos, planting the seeds that would one day grow to become galaxies and clusters. That cataclysmic event, perhaps the most powerful episode the universe has ever experienced, left nothing else behind but the most subtle churning of gravitational waves. Scientists hope to find these gravitational waves because the earliest moments of the Big Bang are shrouded in mystery, and perhaps the only relics of that era are those faint whispers of gravity.

The first story comes to us from the Hindu mythological tradition, and the second from modern cosmology. Both are creation stories, the story that defines how everything—literally, *everything*—came into being. Creation stories are perhaps the most important stories of all. As the great German philosopher Martin Heidegger pointedly asked, "Why is there something rather than nothing?" The creation story explains why there is *this* rather than *not-this*. It separates us from the unknown, from the dark. Without creation, without cosmology, we are lost.

CREATION In a Hindu creation story, gods and demons churn the Ocean of Milk to bring forth amrita, the nectar of immortal life. The churning also gives life to the gods and goddesses of healing, riches, and misfortune.

COURTESY OF V&A MUSEUM / WIKIMEDIA

You might think the two stories don't merit comparison. One is a legend handed down through time, and one is based on the observational study of our cosmos. But the stories have more in common than we may want to let on. In particular, both propose some entity or act or form that already *exists*, and through some process the world as we know it emerges. In other words, all creation stories make some assumption about the (primordial) cosmos, and the story goes from there. This is as true for the Hindu tradition as it is for Big Bang cosmology, and all the stories struggle to move to a point before the beginning.

Viewed through the lens of this commonality—this struggle to explain the most primordial of primordials—the ideas in physical cosmology, which are technical and mathematical, take on a new character: They can be viewed as rehashes of the old mythological stories. Scientists are human, and they are all drawing from the same well of inspiration as everybody else. Mythological creation stories and the scientific Big Bang theory aren't in competition; in their shared attempts to explain the before-the-beginning, they are intertwined at a fundamental, human level, and it's here where science can gain its greatest inspiration.

> *"Why is there something rather than nothing?"*

HISTORIANS AND ANTHROPOLOGISTS have attempted to categorize the world's many creation stories, with some success. One category describes the universe as having come into its present form from some sort of primordial void or chaos, often by the will or actions of a divine being. The classic example is the story of Genesis in the Bible. In the beginning, there were two entities: the all-powerful God that initiated the act of creation, and the formless void-like "nothing" from which He could work. In these stories, there was a point in time in which our universe (as we know it) did not exist, and another point in time in which it did. From then, the usual machinations of nature led to the present day.

Another category sees the creation of our universe as merely the latest act in an infinitely long chain stretching back to eternity. As espoused in many Hindu mythologies, the destruction of the universe follows from its creation, and the cycle starts again. There may be variations—the present iteration of the universe isn't always like the last—and various divine agents may be involved in the act, but the cycle itself simply *exists*, a fact of reality, that enables the creation/destruction process to unfold.

Ideas in cosmology can be viewed as sequels to mythology.

Still other myths, such as many Native American stories, feature a diving creature swimming into a vast and featureless primordial ocean that draws up bits of land and flesh, or a divine being that divides itself into the components of the universe, or a primitive seed that bears the universe as its fruit.

The same themes played out when a new creation story emerged in the early 1900s, one born from modern science. Scientists were not the first ones to attempt to put cosmology—the study of the universe—on empirical grounds (science does not hold a monopoly on empiricism), but they were the first to utilize the machinery of modern astronomy to the study of the whole cosmos.

Most scientists in early modern Europe followed the prevailing religious views on creation: Genesis, Adam and Eve, a cunning serpent. But in the late 1800s evidence began to paint a different picture. The evolution of species, the formation of sedimentary layers, the existence of fossils, and even the first attempts to estimate the age of the sun all pointed to a universe far, far older than anyone had imagined.

At the turn of the 20th century, most scientists believed that the universe was simply *old*, possibly eternally so, and had not significantly changed in all that time. Sure, stars could move around and maybe even explode, species could appear or disappear, and the forces of wind and water could reshape the surface of our planet. But on the big—cosmological—scales, everything that is, has always been.

This view was so dominant that when Albert Einstein took his newly minted equations of general relativity and applied them to the whole entire universe (because why not), he found himself in a bit of a pickle. His equations naturally predicted a dynamic, evolving universe—one that changed with time—but this ran counter to his intuitions that the universe was static. He added a little fixer, an additional term to the equations known as the *cosmological constant*, to balance everything out and keep a static cosmos.

A few years later, in the late 1920s, the Belgian scientist and Catholic priest Georges Lemaître looked at that same set of equations and proposed the earliest version of what we now call the Big Bang theory: That our universe started as a small "primaeval atom" which expanded and cooled into its present form. Most scientists at the time rejected Lemaître's idea—it smelled a little too *biblical* for their tastes.

The debate simmered for a few more years until Edwin Hubble clearly demonstrated the expansion of the universe. Through careful observations he found that at the very largest scales, all galaxies, on average, are moving away from all other galaxies.

Lemaître's math came in handy to explain these observations. This was no trick of light. No alternative theory could account for all the data. Even Einstein dropped the cosmological constant from his equations (calling it his "greatest blunder"). The verdict was in: Our universe is getting bigger with time. And if it's getting bigger with time, that means that in the past it was smaller.

The Big Bang was off to a momentous start. Here we have the most modern creation story of all, the one told by physical cosmology, and it contains some wonderful and powerful statements. Statements like:

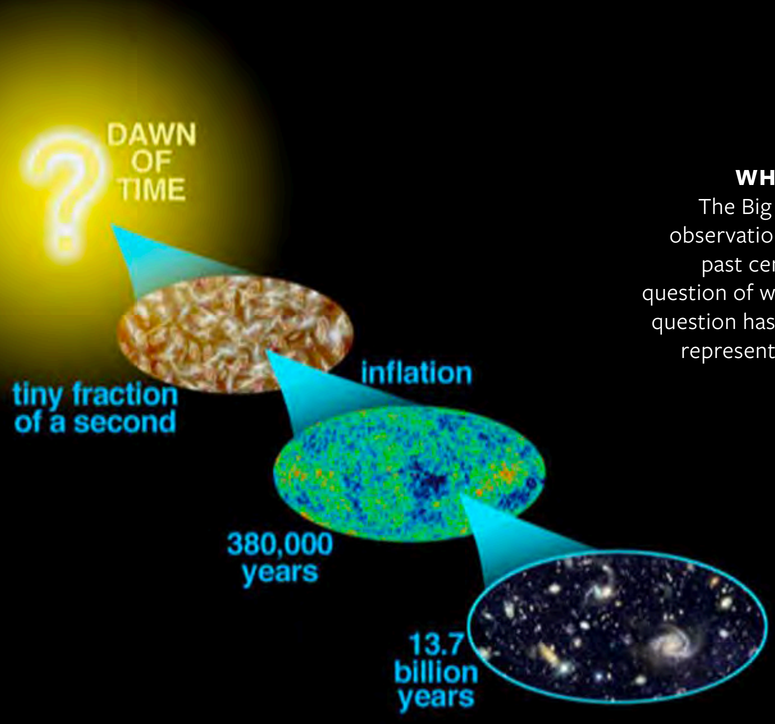
- We live in a dynamic, evolving cosmos, ruled by a set of physical laws that we can understand. The universe changes with time at the very largest scales. Nothing is fixed. The only constant is change.

- Approximately 13.8 billion years ago, our entire observable universe—every galaxy, every star, the entire contents of the cosmos—was crammed into a volume no bigger than a peach with a temperature of over a quadrillion degrees.

- When our universe was only 380,000 years old, the first atoms formed. The process released an invisible form of radiation that permeates the cosmos to this day.

- In its earliest moments, microscopic fluctuations—random wiggles in the quantum fields that suffuse all reality—imprinted themselves in spacetime, forming the seeds that would eventually grow to become the largest structures in the universe.

PAGES 82-83: ANDREA DANTI / SHUTTERSTOCK



WHAT CAME BEFORE?
The Big Bang theory, for all its observational successes over the past century, can't escape the question of what came before. That question has inspired theories that represent science at its boldest.

NASA

Perhaps the Big Bang never ended ... and never started.

As creation stories go, it's a good one. And like all other creation stories, the Big Bang struggles with the beginning. As Lemaître put it, the primeval atom of his theory started with the existence of "a day without yesterday," which was the aspect of his theory that most troubled his fellow scientists, because it implied an act of creation from nothing, which was decidedly not a very scientific-sounding idea.

And yet the Big Bang theory, for all its observational successes over the past century, cannot escape that conclusion. This is a feature of the mathematics of general relativity used to describe the very early universe. We now have a well-motivated and well-tested physical understanding of the universe when it was merely a few minutes old. At that age, the universe was hot enough and dense enough to fuse the first elements (mostly hydrogen and helium) with abundances that match observations.

Pushing earlier into the Big Bang, however, brings us deeper into the mists of unknown physics. Whether through the observations of the cosmos, the collisions of our most powerful particle colliders, or the most arcane mathematics of the chalkboard, we have little useful tools to understand the earliest moments of the history of our universe.

At the heart of it all lies the singularity. In general relativity, at one specific moment in our past, everything was crammed into an infinitely tiny point. We know that the singularity did not actually exist; it's an artifact of the math of general relativity, informing us that the theory is breaking down. To tell us what *actually* happened requires a theory of quantum gravity (a workable theory of strong gravity at very small scales), which we currently lack.

Put another way, we have no physical theory of the initial moments of the Big Bang. Indeed, since our understanding of the passage of time and the breadth of space is rooted in those very same theories, we have no way yet of knowing if our conceptions of spacetime even make sense at such extreme scales. It could be that our naive ideas like "before" or "beginning" simply don't apply.

It's here where speculation gets really wild. Perhaps there is some fundamental unit of spacetime—a chunk

Modern cosmologists are dreamers and storytellers.

that represents the smallest possible four-dimensional volume—and at one time our universe contracted and "bounced" at the scale of that chunk, repeating a never-ending cycle of Big Bangs.

Perhaps our cosmos is embedded in a higher-dimensional structure, with esoteric objects, known as *branes*, occasionally colliding. When they collide, their intersection point triggers a new Big Bang in that region of spacetime.

Perhaps the Big Bang never ended … and never started. Maybe the universe is far larger than we thought—perhaps infinitely large. And maybe the universe at those grand scales has never stopped expanding, but pieces of that "multiverse" can pinch off, isolating themselves as island bubbles adrift in an eternal ocean of the cosmos.

Lemaître, though he espoused a view that religion and science shouldn't mix, was certainly inspired by the creation story he was most familiar with. Repeated cycles of Big Bangs, stretching forward and backward to eternity, look a lot like many Hindu versions of cosmology. Extra-dimensional entities that interact, and through their interactions build a universe, would find welcome reception to cultures around the world.

This isn't a bad thing. Scientists are the latest in a long line of thinkers, mystics, philosophers, poets, and more who have interrogated the very nature of existence. The parallels and connections are manifest because they all spring from the same font of human creativity and ingenuity. And while scientists have learned a lot, they run into the same headaches as everyone else; namely, trying to explain what came before what-started-it-all.

In the millennia of recorded human history, we've asked a lot of questions and managed to come up with many answers. But some questions—like the ultimate origins of the universe—always seem to be just out of grasp. Perhaps this is the best we'll ever get: concrete, testable ideas going back to some finite point in our past, speculation beyond that, and unanswerable questions behind everything.

Or perhaps not. Modern cosmologists are currently trying to tackle some of the most perplexing aspects of the Big Bang theory, attempting to push past the point of the "primaeval atom" and into the deepest origins of the universe. They are trying to determine if time itself has an origin or is simply a manifestation of some other process. They are trying to find experimental clues to pre-Big Bang processes whose artifacts might remain in our contemporary cosmos, such as those effervescent gravitational waves that cosmologists eagerly hunt for. They are trying to discover a more fundamental set of universal laws that naturally give rise to the physics that we know and love.

Modern cosmologists are dreamers and storytellers. They are grounding their story of the Big Bang in evidence and reason, but they are seeking the same answers as all the dreamers and storytellers who came before them. They are trying to explain why there is something rather than nothing, and whether they know it or not, they are drawing from the stories and myths that surround them in the world.

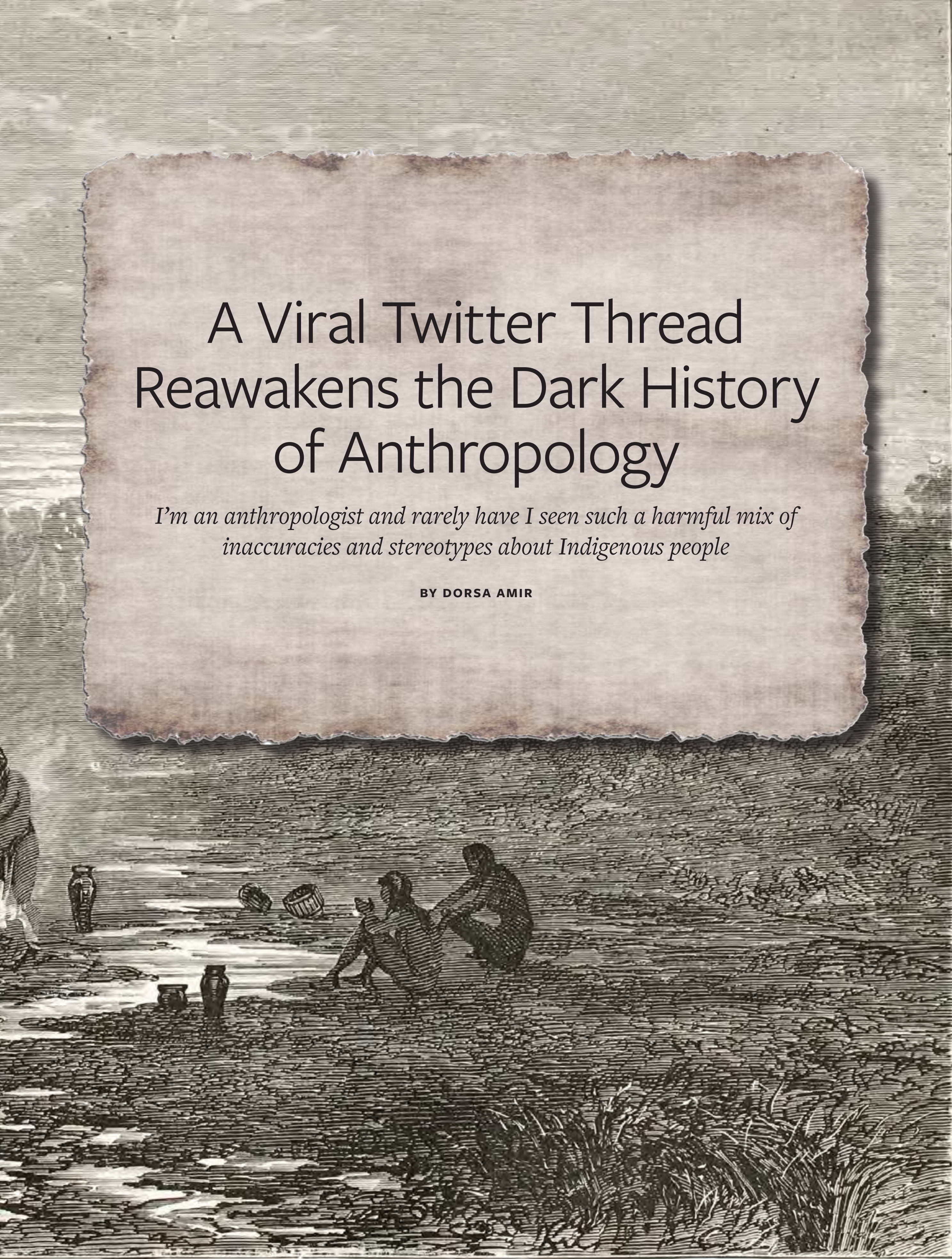
Here is where science can be its most beautiful, when it pulls hungrily from any source for a spark of inspiration to inform our knowledge of the universe, giving us a new tale to delight in. And here too is where science can be its most bold, when it finds the utmost boundaries of the known, a line once marked as impossible, and pushes unafraid into the dark.

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

A Viral Twitter Thread Reawakens the Dark History of Anthropology

I'm an anthropologist and rarely have I seen such a harmful mix of inaccuracies and stereotypes about Indigenous people

BY DORSA AMIR



IN MARCH, A DIET COACH named Anthony Gustin, founder of an online food store called Perfect Keto ("Empowering your health journey in a food system that doesn't care"), went viral on social media. The "clinician" and "food and fitness skeptic," as he refers to himself on Twitter, tweeted that he had recently traveled to Africa to spend time with the Hadza, a group of foragers in Tanzania, to learn more about living a healthy lifestyle. In a hunting trip set up for tourists, Gustin followed the Hadza as they went about their day, observing how they hunt, socialize, and make their living. In the viral thread, he favorably contrasts these "wild humans" with "chubby, modern humans" living in "manmade zoos." He calls studies of the Hadza a "LIE" and "mythical." A photo shows Gustin sitting alongside several Hadza men, appearing pensive. "I hunted, killed, and ate a wild baboon (brains and all) with the indigenous Hadza tribe in Africa," he tweeted. "Here are 13 things I learned about human health along the way."

In his tweets, Gustin makes some astonishing observations about the Hadza. They "barely eat any plants" or fiber. "The men dream about big game hunts. Not huge salads or leafy greens." Both the men and women only work for "3-4 hours a day." The Hadza create no waste. They rarely rush, stress, or worry. And, believe it or not, they "rarely drink water," opting instead for a "few sips of mud." Though "nearly extinct," the Hadza are still thriving in their "natural habitat."

As an anthropologist, I'm used to encountering misconceptions about hunter-gatherers in the media. But rarely had I seen such a harmful combination of tropes, inaccuracies, and stereotypes—at least, not from the 21st century. Initially, I didn't want to reply to the thread for fear of further amplifying it. But as the attention grew and multiplied, I felt compelled to correct the record. I replied to Gustin on Twitter, outlining not only the clear inaccuracies in the thread—the Hadza, for instance, eat an enormous number of plants[1]—but also explained how his claims had reawakened tropes from the darkest ages of anthropology. Gustin, who now has almost 23,000 followers on Twitter, called me a woke idiot and blocked me.

Almost every claim about the Hadza's diet—the lack of fiber, plants, and water—is wrong.

What Gustin doesn't seem to realize—and appears to be willfully evading—is how his narrative, and others like it, perpetuate damaging beliefs in the social sciences, beliefs that those in power regularly exploit to further marginalize already precarious populations. Though Gustin seems just aware enough of the Hadza's struggle over their sovereignty to fashion himself as the hero of their story: "The government was going to eradicate the Hadza's land," he says, "until they figured out tourists (like me) would pay to go to Tanzania to see them."

WHAT DOES GUSTIN GET WRONG about the Hadza and human health? Nearly everything. Gustin seems unaware that what he experienced on a short tour may not be representative of how an entire population lives when he's not there. Almost every claim about their diet—the lack of fiber, plants, and water—is simply wrong.

Years of careful ethnographic observations and interviews with community members reveal what a short tour cannot: The Hadza have a diverse diet of tubers, berries, meat, baobab, and honey. The relative importance of each fluctuates with the changing seasons.[2] Only about 15 percent of community members rely on hunting and gathering, with the majority opting for a predominantly agricultural diet.[3] (Digging for tubers, an important fallback food and continuous source of calories, is primarily a task for women and sometimes children, who are conspicuously absent in Gustin's narrative.)

What about the claim that the Hadza only work several hours a day? Once again, Gustin may be unaware—this time of how far he has tread into a decades-long debate in the field of anthropology. The proposition that hunter-gatherers live a life of leisure can be traced back most notably to anthropologist Marshall Sahlins, who referred to the way foragers live as the "original affluent society."

Using a sampling of activity data from the !Kung—a forager group living near the Kalahari Desert—Sahlins claimed that hunter-gatherers spent no longer than five hours a day on labor. But he failed to incorporate into his estimates other forms of work, such as food processing and preparation, which upped the estimate significantly. The most recent and rigorous investigation into this question suggests that those in non-industrial societies work full days, laboring somewhere between 46-54 hours a week.[4]

A HADZA FAMILY IN TANZANIA Anthony Gustin has resurrected the colonialist image of the Noble Savage, writes Dorsa Amir, and he employs language that is dehumanizing and strips Indigenous communities of their agency.

WIKIMEDIA COMMONS

More pernicious is the way Gustin's thread caricatures Hadza life as one of "extreme happiness and leisure." They spend most of their time "laughing, or telling stories," Gustin says. This whitewashes the true story of the Hadza, which is radically more complex and nuanced. Many members of the Hadzabe, like law student and activist Shani Mangola, regularly speak out against the sort of mischaracterizations Gustin amplifies about his community. "[People] disrespect us and ... use abusive language against us," Shani has tweeted, "as if we [are] not human beings." And there are plenty of legitimate stressors in their lives. "Land encroachment and environment destruction," he tweeted, "is [a] huge problem." He also shares that the Hadza lack enough resources. "We lose hope," he added, "and [the] future of our kids become[s] hopeless."

Beyond the scientific inaccuracies, what compelled me the most to respond to Gustin's tweets was his framing of the Hadza as an exotic curio, as "wild humans" trapped in the Stone Age. On his personal podcast, Gustin claimed, incorrectly, that the Hadza have "been more-or-less unaffected in their way of life for the last 50,000 years." They're a "window into the past," he said. Gustin's "adventure buddy" Paul Saladino—proponent of the dubious "Carnivore Diet"—chimed in: "The Hadza are the closest thing we have to a time machine." Gustin added, "These people want to live like this. They don't want to transition to a more 'civilized' way of life."

This type of argument is nothing new; it is a recurring motif in the pseudoscientific attempt to characterize human variation. The history of discourse around Indigenous populations has ranged from the explicitly violent to the benevolently racist. A common trope in this genre is that of the Noble Savage, a wild human uncorrupted by the evils of civilization, living in harmony with nature.

This idea is most commonly attributed to Jean-Jacques Rousseau, and has been invoked throughout the centuries as a way to draw distinctions between "civilized" and "primitive" man. It carries with it a deep paternalism, an idea that Indigenous groups are somehow naive, unspoiled, and innocent, in need of protection. The Indigenous are not the authors of their own lives, nor are they given permission to set their own agenda. No, Westerners are here to do that for them. They know better: The Hadza don't want their culture to be "spoiled by civilization." Never mind the fact that this means depriving them of the choice to access education, infrastructure, and healthcare.

So, what can biological anthropology say about living healthier?

Gustin may not realize his role in this story, but his ignorance does not absolve him of his complicity. On his podcast, he recounted the moment that his Hadza guide told him and Saladino that they're welcome back, but they should bring with them more *ugali*—a food made of maize meal. "In my mind, I thought, 'I'm not going to bring you *ugali*!' " Gustin said. " 'I'll bring you more arrowheads!' "

A more overtly malignant stereotype in the history of anthropology is that of the Indigenous as subhuman, on a rung between civilized man and his primate kin. On his podcast, Gustin is careful to note that the Hadza are, in fact, *Homo sapiens*. (Imagine needing to clarify that.) Yet he goes on to describe them as an "endangered species," saying, on his podcast, "Without tourism, they would have been wiped out completely by now."

This type of language—almost exclusively used to describe non-human animals—is dehumanizing, strips these communities of their agency, and sets the stage for persistent discrimination and exploitation. Though Gustin lionizes tourism as the solution to the Hadza's struggles, it can often have a devastating influence on Indigenous ways of life.

"The Hadza often find the steady flow of tourist arrivals to the settlement in Mang'ola tiresome," anthropologist Haruna Yatsuka writes in a 2018 report.[5] "[They] must strike a precarious balance between their own ways of life and the pressures to perform that way of life in the commodified context of the global tourist economy." Tourism gives Indigenous people "the impossible task," argues archaeologist Michael Rowland, "of acting out pre-contact stereotypes of themselves produced by the colonizing culture."[6]

The negative effects of the tourist trade on foragers' lives are well documented. The commodification of Indigenous culture often carries a steep cost. An infamous account comes from the Shuar, a forager-horticulturalist group in Amazonian Ecuador with whom I regularly work. The tourist trade that began in the late 19th century deeply affected their communities. The Shuar would ritually craft *tsantsa*, or shrunken heads, from the bodies of their fallen enemies. The Western interest in collecting *tsantsa*—which still line the exhibit halls of places like Ripley's Believe It or Not—set into motion a sharp rise in war raiding to satisfy the increasing demand of explorers and tourists, a trend which lasted for nearly 100 years and robbed countless lives.

When I hear that we "should eat like the humans of the Paleolithic," my initial response is: Which humans of the Paleolithic?

DESPITE THE INACCURACIES and stereotypes, Gustin's thread revealed interest in the insights anthropology can offer about human health. As it happens, biological anthropologists spend decades conducting rigorous and ethical research on these very questions. So, what *can* biological anthropology say about living healthier?

Let's begin with diet. Unlike our primate cousins, who have a relatively limited menu of foods to choose from, humans are tremendously flexible omnivores. The ability to thrive on an immense variety of food has helped us inhabit nearly every ecosystem on the planet and devise the cuisines that make up our rich culinary world. It is tempting to think that our bodies are in a state of evolutionary mismatch, such that the cultural and energetic environment has changed too rapidly for our genes to keep up. There is some truth to that, but as with all things anthropological, there is nuance to consider.

A simplistic—and incorrect—understanding of this evolutionary process would lead one to conclude that the best diet is the one that our "caveman" ancestors ate, as if our bodies were in a state of perfect health during the Pleistocene and simply stopped evolving in the following years. This shallow understanding of human evolution is pervasive, and yet it is the flawed foundation on which Gustin builds his argument. The idea that the "correct" diet is an ancient one is also the backbone of fads like the Paleo Diet, and "adventure buddy" Saladino's Carnivore Diet, which can, as his website claims, take us "back to our ancestral roots."

When I hear that we "should eat like the humans of the Paleolithic," my initial response is: *Which* humans of the Paleolithic? This epoch—which ranges from 2.5 million years ago to around 12,000 years ago—began with *Homo erectus* in Africa and ended with *Homo sapiens* everywhere. Which diet, exactly, are we supposed to be following? The Paleolithic Arctic Diet, composed mostly of marine meat? The Paleolithic Amazonian Diet, made of tubers and fish? Or perhaps, as Gustin and Saladino claim, we should order from the Hadza menu of baboon and honey.

While there is no single "correct" diet to emulate from the past, we can gain some insights by considering how human physiology varies from that of other primates. The patterning of our teeth—a combination of flesh-ripping incisors and fiber-grinding molars—are suited for an omnivorous diet of both animal meat and plant foods. The reduced size of our gut and the way our digestive system processes food supports the same conclusion. This does not mean that we *should* eat both animals and plants; that would be committing the naturalistic fallacy (just because something is found in nature, does not imply it must be good, or moral).

We can also pool data from extant foraging communities and look for similarities and differences. Here, however, there are far more differences than similarities. As anthropologist Herman Pontzer, who has worked with the Hadza for several years, states in a 2018 paper with his colleagues, "Dietary diversity among hunter-gatherers is so vast that dietary universals are few."[7]

A handful of similarities remain. Work by anthropologist Melvin Konner suggests that the diets of those in foraging societies are markedly lower in sodium and refined carbohydrates, and much higher in fiber and protein, than those of folks in industrialized settings.[8] Plus, all human groups cook their food, and that food is always a mix of both plants and animals. Beyond that, dietary diversity is the norm, and the data here suggest, as Katharine Milton argues, "that humans can thrive on extreme diets as long as these diets contribute the full range of essential nutrients."[9] These include macronutrients—things like carbohydrates, fats, water, and protein—and micronutrients, like vitamins. A person eating a diet rich in vegetables, fruits, and lean proteins will almost certainly have everything they need. "The range of 'natural' human diets is vast," Pontzer writes in his book *Burn*. "People eat whatever is available."

What about exercise? Surprisingly, the Hadza do not appear to be expending more energy than more sedentary and industrialized populations. That's strange, because accelerometry data—collected through devices that measure steps—suggest that the Hadza are extremely physically active: Women are walking an average of nearly 4 miles a day, while the men regularly walk double that.[7] And yet their measures of total energy expenditure—the number of kilocalories they burn in a day—are virtually identical to those of sedentary Americans.

In a 2017 *Scientific American* article, Pontzer writes, "It seems so obvious and inescapable that physically active people burn more calories that we accept this paradigm without much critical reflection or experimental evidence."[10] But what experiments reveal instead is a fascinating fact about human health: Our bodies adjust to higher activity levels and put a cap on the number of calories we burn each day. How? By taking away energy from other physiological tasks, like cell maintenance, and freeing those calories up for physical activity.[11]

This research has consequences for how we think about conditions like obesity. It has long been believed that the obesity epidemic is a result of both higher caloric intake and a sedentary lifestyle. And many people believe that weight loss is best achieved through diet *and* exercise. It's widely assumed that a calorie in is equivalent to a calorie out. Just treat it like arithmetic: Eat less than you burn. But it appears our bodies don't follow this rule so rigidly; they don't like to spend more than a certain number of calories a day and are willing to turn down functions, like cell maintenance, to do it. Perhaps the focus, then, should be less on burning energy through physical activity, and more on reducing the energy we take in through food. "The Hadza don't develop obesity and metabolic disease for the simple reason that their food environment doesn't drive them to overconsume," Pontzer writes in *Burn*. "The Hadza [showed us] a new way of understanding ourselves."

ON GUSTIN'S WEBSITE, he states that when he "started to learn more about science," he became "enamored with the thought of modifying diet and exercise." Who can fault that? Science can inspire us to pursue any number of passions. But it is important to recognize that it is imperfect. Anthropology in particular has been fraught with centuries of racism, colonialism, and imperialism, the effects of which still echo into the present and color how people talk about human variation. But like science more broadly, anthropology is self-correcting. My friends and colleagues in anthropology care deeply about the people with whom they work, the people who invite them into their homes and communities.

Some of them are working to redefine what ethical cross-cultural research looks like in the 21st century, paying attention to the impact their research can have on vulnerable populations. In a 2020 paper, for example, anthropologist Alyssa Crittenden and her colleagues write, "The growing appetite for including diverse populations in work on demography, health, wealth, cooperation, cognition, infant and child development, and belief systems raises unique scientific and ethical issues, independent of discipline or research topic."[12] Crittenden has also supported the founding of the Olanakwe Community Fund, a mutual-aid organization created by the Hadza, based on a strong desire among the community for greater access to educational opportunities and a seat at the political table. She is not alone in these endeavors.

I am intimately familiar with the joy of learning about humanity; I have built my career on it. And I see that same curiosity in others, eager to learn more about the human story and their role in it. We share this in common, along with the thousands of other quirks and nuances that make us human. Scientists and the public have a symbiotic relationship: The public supports our work, through grants, tuition, and their attention, and in return, we owe them the spoils of our research, helping to guide their thinking on what it means to be human. And sometimes that means setting the record straight on Twitter.

DORSA AMIR is an evolutionary anthropologist and postdoctoral research fellow at U.C. Berkeley. Follow her on Twitter @DorsaAmir.

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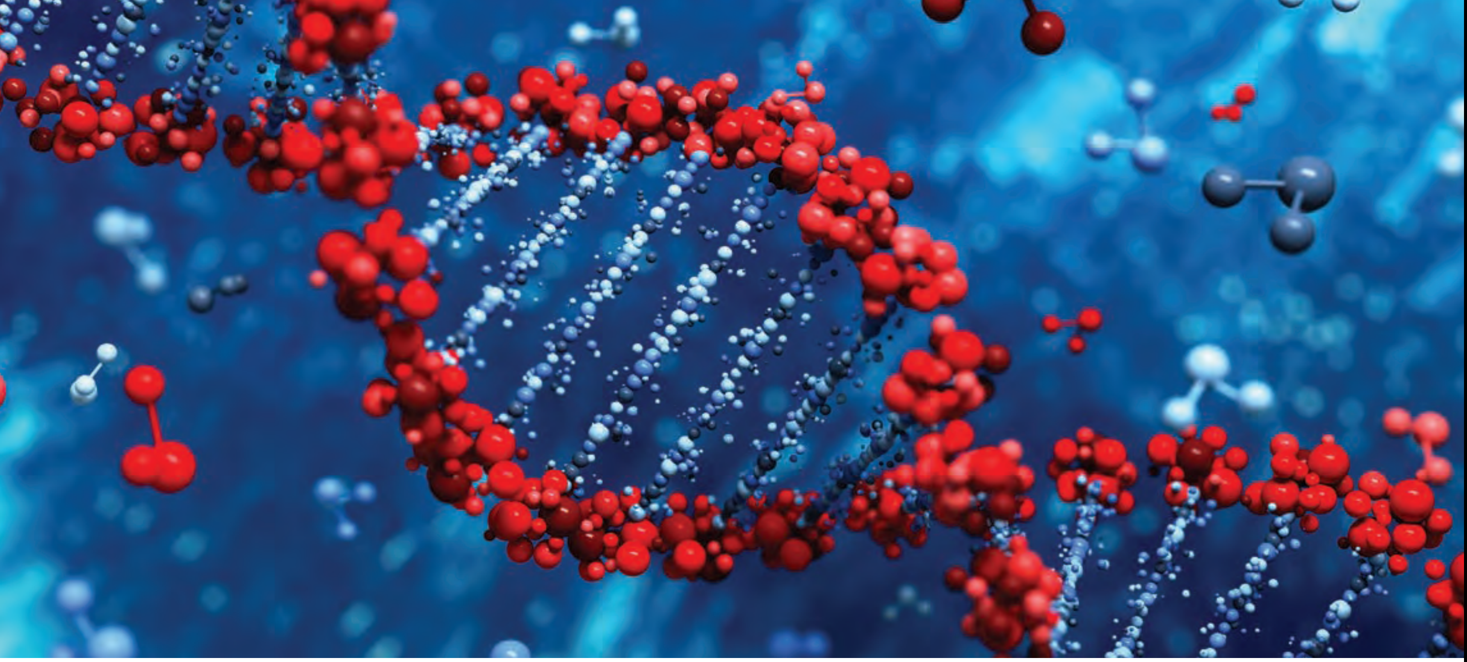

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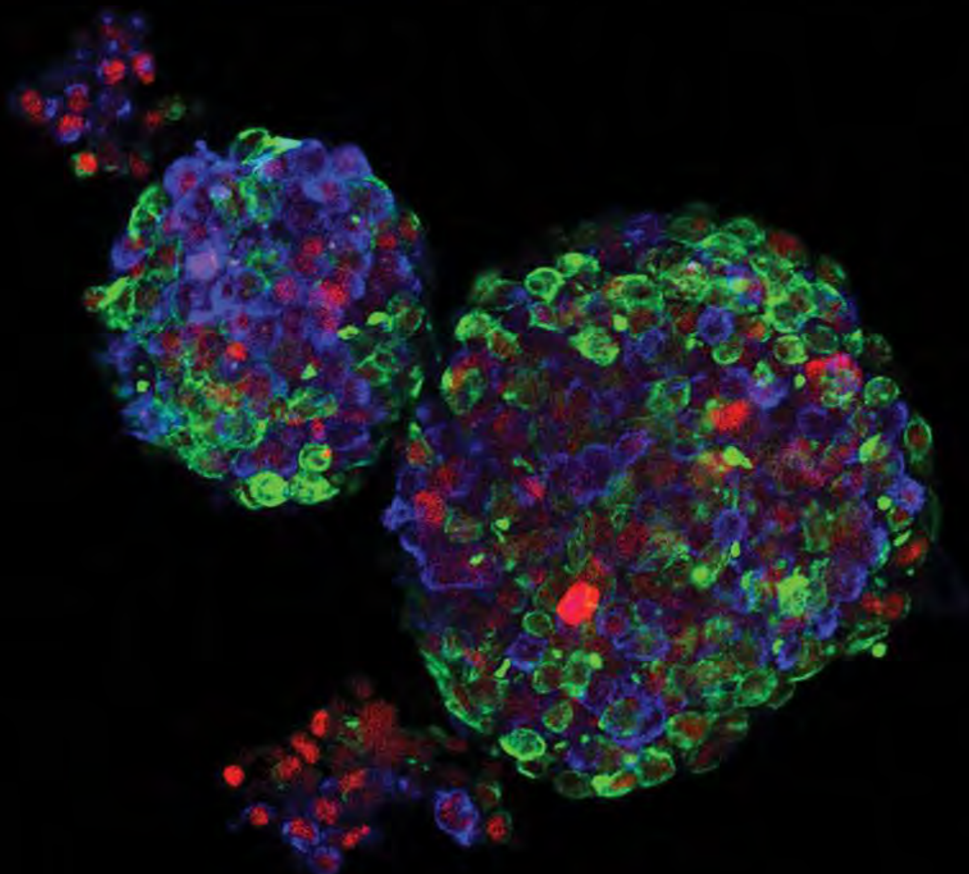

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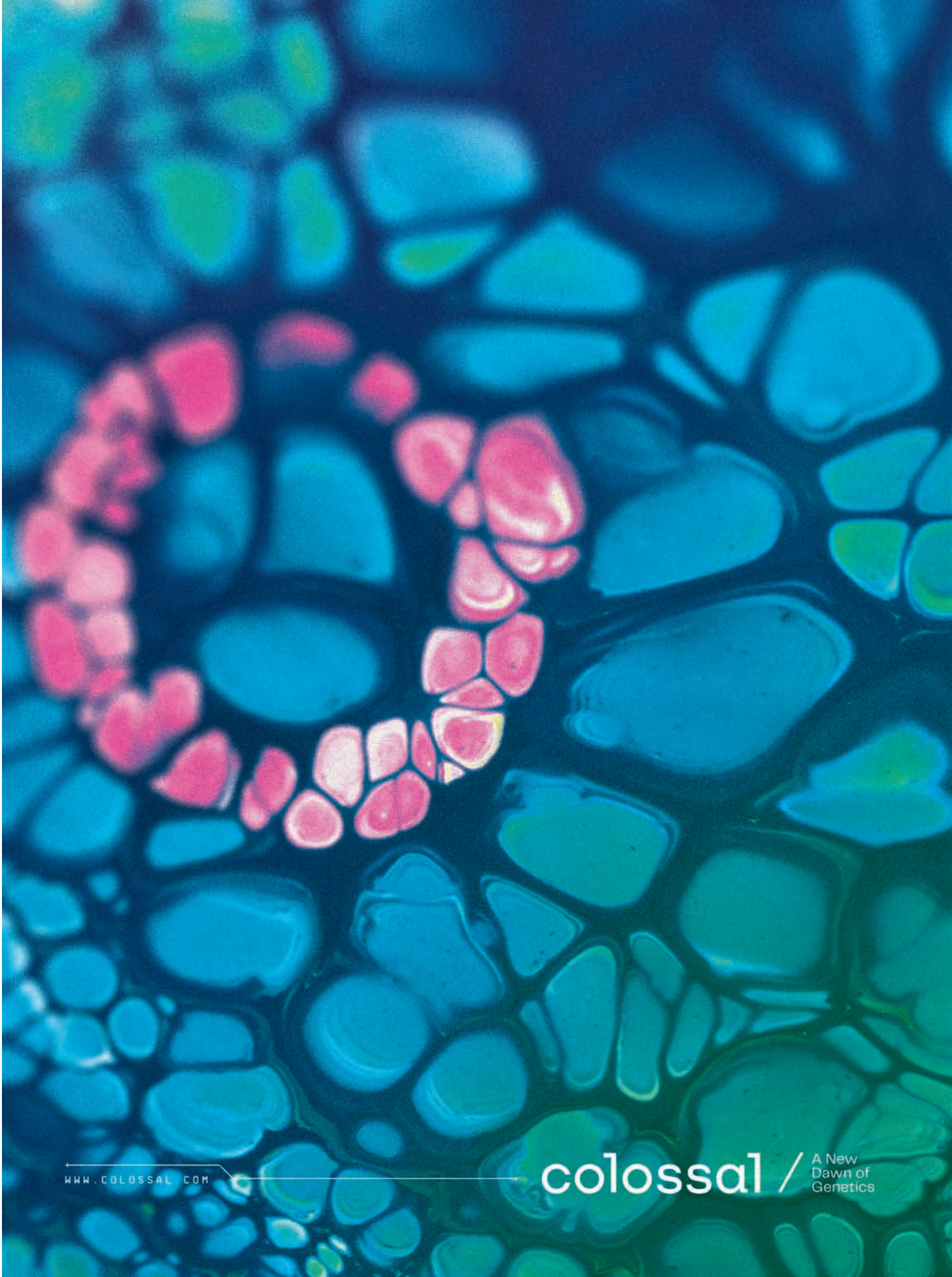
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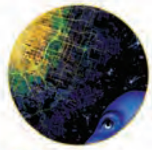

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Lindy Elkins-Tanton

The planetary scientist on rocks, gases, and planetary ingredients

INTERVIEW BY KRISTEN FRENCH

EXPLOSIVE ROCKS

Hundreds of people were working on this problem of the connection between the Siberian flood basalts and the Permian extinction, and a lot of them had solved little parts of the puzzle, but no one had really studied these explosive rocks. Their existence almost amounted to a rumor. They were in maps from Russia, but there were no scientific papers about them, except for this one that we found in Russian that was really about pollen contained in the rocks. And so, we were able to get some interesting successes of scientific measurement because our Russian colleagues figured out where the rocks were and how to get there. And then we had people from all different scientific fields and universities and countries applying their expertise to gathering the data and running it through climate models to ask, could the global effects of these exploding rocks have led to the Permian Extinction? And the answer was yes.

CLIMATE CHANGE ANALOG

The part that was so astonishing to me was that we could show how much sulfur dioxide and carbon dioxide was probably released by the exploding rocks, and how much acid was in the acid rain caused by these explosions. Together with colleagues from Oslo, we were also able to show that the rocks released naturally occurring chlorofluorocarbons, which had been thought of as just chemicals of our technological age, found in refrigerants. But the End Permian was a time when, through an amazing coincidence of chemistries and energies, chlorofluorocarbons were produced in the absence of human industrialization. Taken together, these gases and compounds removed the ozone layer and caused a huge amount of greenhouse gas-related warming. Jeffrey Kiehl from the National Center for Atmospheric Research, who was on our project, told me that he thinks that the End Permian is the closest analog that we have in the geologic record to what's happening today. That's quite sobering.

JON SIMPSON

THE ASTEROID PSYCHE AS EGGS OR FLOUR

Our leading hypothesis for our NASA mission to the asteroid Psyche is that it is at least part of the metal core of a planetismal, one of thousands of first forming tiny worlds composed of metal cores and silicate rock exteriors that crashed into one another to create our rocky planets, leaving behind a few remnants in the asteroid belt. Psyche might be a part of the very first generation of metal cores, and so seeing what it is made of, whether it was magnetized, what kind of rock it came with, will tell us the ingredients that went into our Earth with new fidelity. If the Earth and the other rocky planets are like cakes, then Psyche is maybe the eggs or the flour.

MYSTERY INGREDIENT

The interesting thing about Psyche is that there are just really very few objects that appear to be made of metal. And Psyche's the largest one. It's an outlier, it's a low likelihood event in our solar system and it's probably caused by other low likelihood events. My secret wish is that it would turn out not to be a core part of planet Earth, but something unusual, something surprising, something that would fill in a new part of our ingredients of planet story. That would be great.


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- Dona Bertarelli, Founder of Sails of Change
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