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COVER STORY & FEATURES

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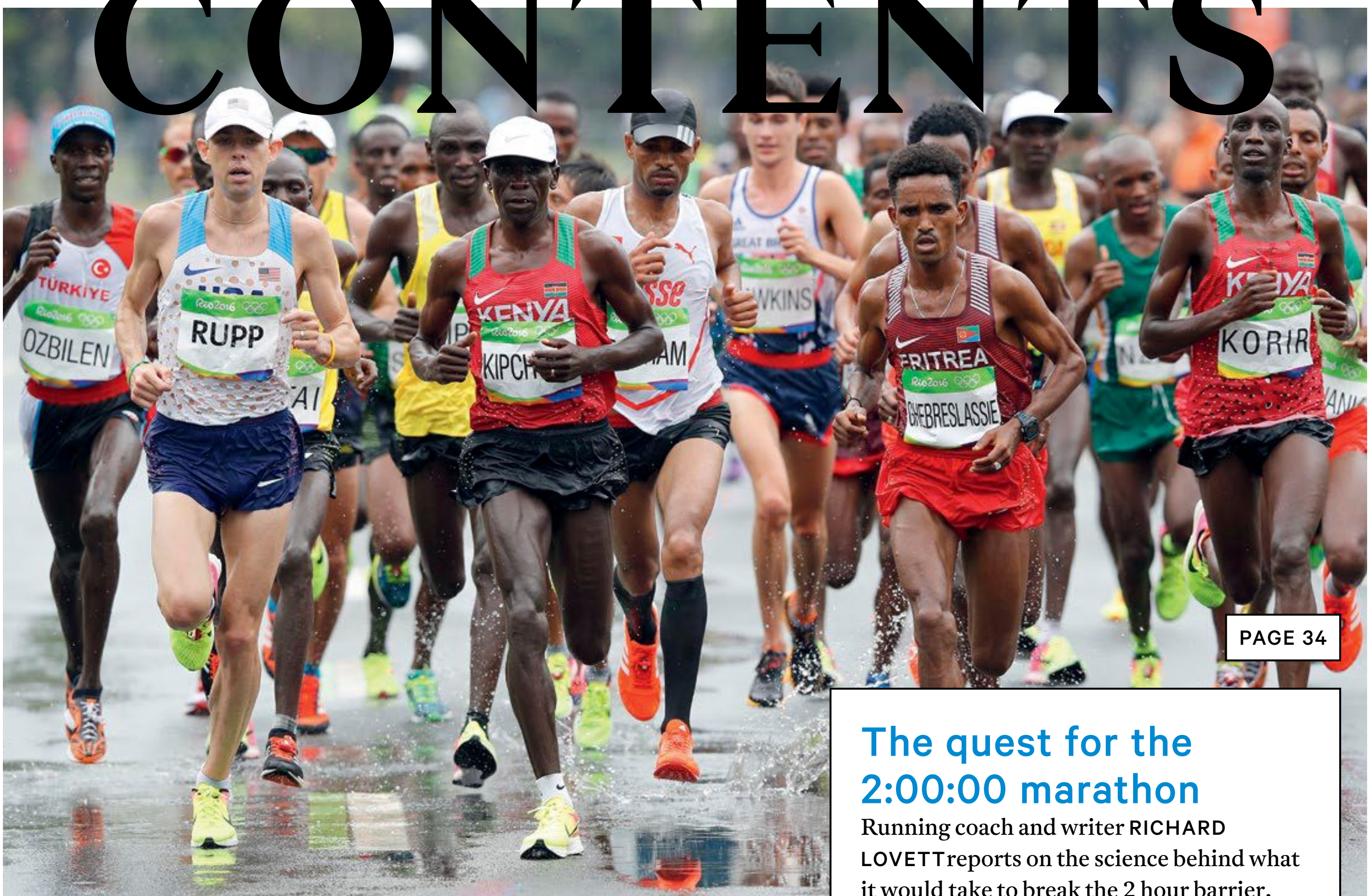

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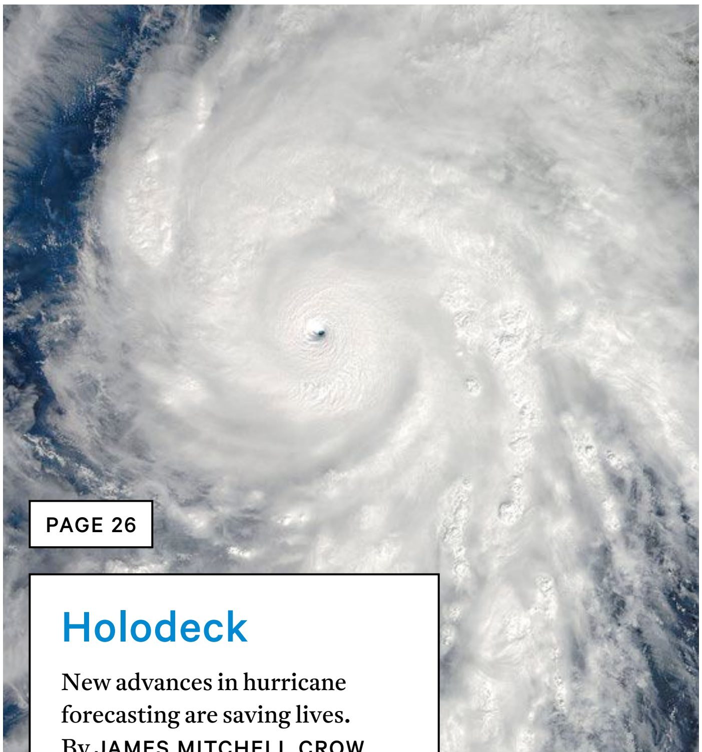

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Letters to the editor must include the writer's full name, address and daytime telephone number. They may be edited for clarity and length. Please do not send attachments.

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THE EARLY SOLAR SYSTEM

Would it be reasonable to assume that "ocean moons" like Jupiter's Europa once were icy minor planets from beyond Neptune that, in a younger solar system drifted towards the sun but were caught in the gas giant's gravitational field?

Could the elliptical orbit of Europa thereafter have caused the internal heating while the surface sublimed, leaving a crust that may crack to exude water vapour, or absorb some of the comets or meteors attracted by Jupiter – including, perhaps, "building blocks of life"?

— FRED WEYERMAN
Frankston, Vic

THE EDITOR REPLIES:

That's not the current thinking of astronomers, although no one is 100% sure of what happened all those years ago when the solar system was young.

There are some really small moons of Jupiter that are almost certainly captured asteroids and comets. However, the giant planet and its biggest moons behave a little as if they were a mini-solar system themselves. The moons become more icy and less rocky the further their orbit lies from the gas giant. In addition, they all orbit Jupiter in the same direction that the planet spins, suggesting they all formed at the same time.

In the outer solar system, one exception to this general orbiting rule is Neptune's largest moon Triton. It orbits in the opposite direction to Neptune's rotation – the only large moon in the solar system to do so – leading scientists to believe it must have been captured.

ELECTRONIC ELECTIONS

With respect to Alan Finkel's column "Finding a sure cure for election dysfunction" (Issue 70, page 28), I think that the recent fiasco of the on-line census suggests that we won't be seeing electronic voting here for some time yet.

Only when the system is bulletproof can we consider electronic voting for either federal or state elections.

— TONY CALLAWAY
Hoppers Crossing, Victoria

Alan Finkel's excellent and timely article on electronic voting (Issue 70, page 28) makes a strong case for its introduction and deals effectively with some common objections.

However, it is incorrect to describe voting as a "cherished right". In Australia it is compulsory, and no more a right than paying taxes. In the vast majority of democracies, freedom of speech includes the freedom not to speak at election time.

While Australian elections are as fair as most in the western world, they are not free, and voting is not a right but a legal obligation.

— ALAN NEEDHAM
Wanneroo, WA

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EDITOR'S NOTE

ELIZABETH FINKEL
Editor-in-chief

The debt of science to consuming passions

WHO CAN EXPLAIN a consuming passion? It's certainly beyond the bounds of science.

But scientists, it seems, are singularly susceptible to them.

That's the impression that has stayed with me from some of the stories in this issue of the magazine.

Take marine scientist Brad Norman, profiled on page 54. He was all set to be a vet. Then 22 years ago he took a swim with a whale shark at Ningaloo Reef in West Australia. Ever since, his every waking hour has been devoted to them.

That's just as well for the whale shark. Norman has been one of their chief protectors. Back in 1999, he sounded the international alarm about their vulnerable status, and last July, an assessment of the species he co-authored led the International Union for Conservation of Nature to update their status to "endangered". His work helped secure their protected status in Australia, and his organisation, ECOCEAN, has written the manual for responsible ecotourism. He has also educated whale shark tour operators all over the world on how to be part of a citizen science corps that monitors whale sharks.

Norman's story is poignant, not just because of the plight of the whale shark. He himself is "endangered". Notwithstanding his dazzling accolades (a 2006 Rolex Award for enterprise and being named a 2010 National Geographic Ocean Hero), he has no university tenure or regular income. It would be unthinkable if his operation was allowed to dry up.

One of the ways Norman carries out research on the smell of an oily rag is through collaborations with like-minded souls, often encountered at the biennial Rolex Award dinners. I spoke with one such fellow, Rory Wilson, and was similarly struck by the force of this man's driving passion — in this case, for penguins. Wilson invented what he describes as "Heath Robinson contraptions" to monitor their underwater activities. (Robinson is a cartoonist fond of wacky gadgets). Wilson has also built similar devices for Norman to track the underwater activities of whale sharks. "I decided there must be more to life than penguins", Wilson told me, quickly adding, "there isn't really".

Then there's Nerida Wilson, the subject of our Portrait on page 82. She was 16 when Cupid's arrow struck while diving off Mornington Pier in Victoria. The object of her affection: a sea slug. In truth, nudibranchs, as they are properly called, are breathtaking – a perfect example of Darwin's " endless forms most beautiful." This marine biologist has dedicated her life to studying their evolution.

And finally, there's Jurgen Otto, smitten by Australia's peacock spider. He expresses his passion for them through photography. Take a look at his stunning portrait in "Snapshot" on page 68.

Scientific passions may be inexplicable. But without them we would probably have no scientists. What else would entice a person to devote his or her life to a career notorious for its perilous funding and uncertain career path?

ISSUE 71

COVER
Is there any limit to the number of records that can fall before the limits of the human body become plain? We look at what the science says about beating the two-hour marathon barrier.
CREDIT: MICHAEL MULLER / CPI SYNDICATION / HEADPRESS

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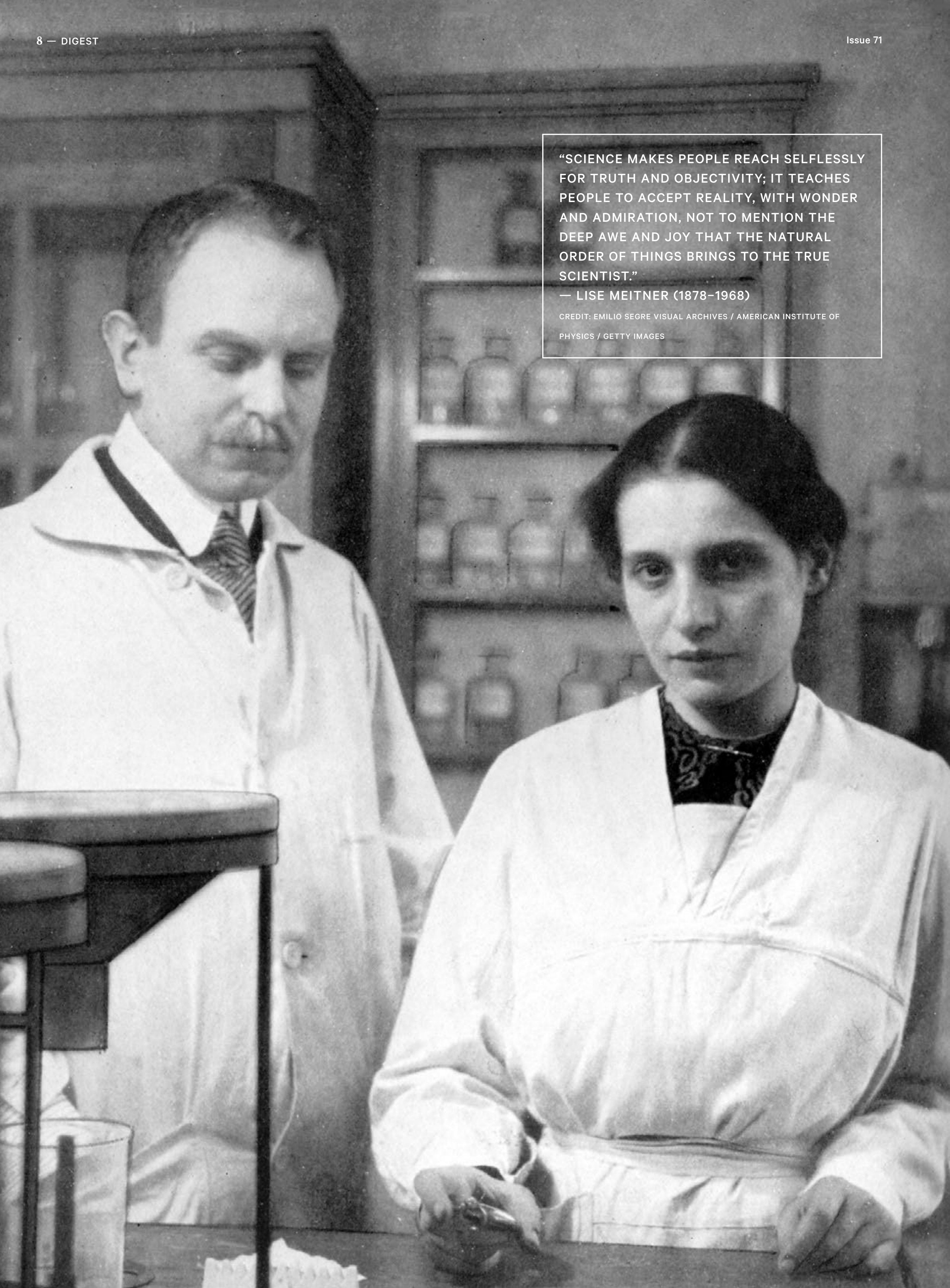

“SCIENCE MAKES PEOPLE REACH SELFLESSLY FOR TRUTH AND OBJECTIVITY; IT TEACHES PEOPLE TO ACCEPT REALITY, WITH WONDER AND ADMIRATION, NOT TO MENTION THE DEEP AWE AND JOY THAT THE NATURAL ORDER OF THINGS BRINGS TO THE TRUE SCIENTIST.”
— LISE MEITNER (1878–1968)

A CLOSER LOOK AT THE BIG STORIES

DIGEST

SPACE

Rocky exoplanet found in habitable zone of star next door

Proxima Centauri hosts an Earth-sized planet that is warm enough for liquid water to exist on its surface – and maybe life, too. BELINDA SMITH reports.

Extraterrestrial life may be as close as our nearest neighbouring star. Proxima Centauri, the star closest to the sun, seems to have a rocky planet in its orbit.

Dubbed Proxima b, it's 1.3 times the mass of Earth. It gets very up close and personal with its faded star, →

The planet Proxima b (shown here in an artist's rendering) orbits the red dwarf star Proxima Centauri. CREDIT: ESO / M. KORNMESSER

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→ placing it in the Goldilocks zone where it's not too hot, not too cold – just right for liquid water and perhaps life, according to a study published in *Nature* in August.

Discovered more than a century ago, Proxima Centauri is well studied. But, although only 4.25 light-years from Earth, it's a red dwarf which makes it too dim to see with the naked eye.

Telescopic observations from 2013 suggested it hosts a planet. Rocky exoplanets are too small to see with a telescope but astronomers can detect them by measuring a star's Doppler "wobble". An orbiting planet exerts a little gravitational tug on its star, which slightly expands or contracts the wavelength of light emitted by the star – enough for telescopes on Earth to detect.

THOUGH ONLY 4.25 LIGHT-YEARS FROM EARTH, PROXIMA CENTAURI IS TOO DIM TO SEE WITH THE NAKED EYE.

In the past few years, the High Accuracy Radial velocity Planet Searcher, or HARPS, at the European Southern Observatory's La Silla site in Chile, detected Doppler wobbles from Proxima Centauri, suggesting it might host a planet. But there wasn't quite enough evidence to say for sure – until this year. Guillem Anglada-Escudé from the Queen Mary University of London in the UK and colleagues trained the HARPS instrument onto Proxima Centauri almost every night between 19 January and 31 March.

Proxima Centauri, the closest star to the sun, as seen through the Hubble Space Telescope. CREDIT: NASA / ESA

At the same time, they observed the star with other telescopes in Chile to make sure the wobbly starlight wasn't the result of solar flares – red dwarfs are prone to such outbursts. Anglada-Escudé checked the wobble measurements daily. "The first 10 were promising," he says, "the first 20 were consistent with expectations, and at 30 days the result was pretty much definitive, so we started drafting the paper."

The timing and magnitude of Proxima Centauri's wobbles provided strong evidence for an exoplanet that whizzed around once every 11.2 days. Anglada-Escudé and colleagues pegged its mass at 1.3 Earth masses. It orbited its star at the intimate distance of only 0.05 astronomical units. By contrast the distance between Earth and the sun is one unit, twenty times greater.

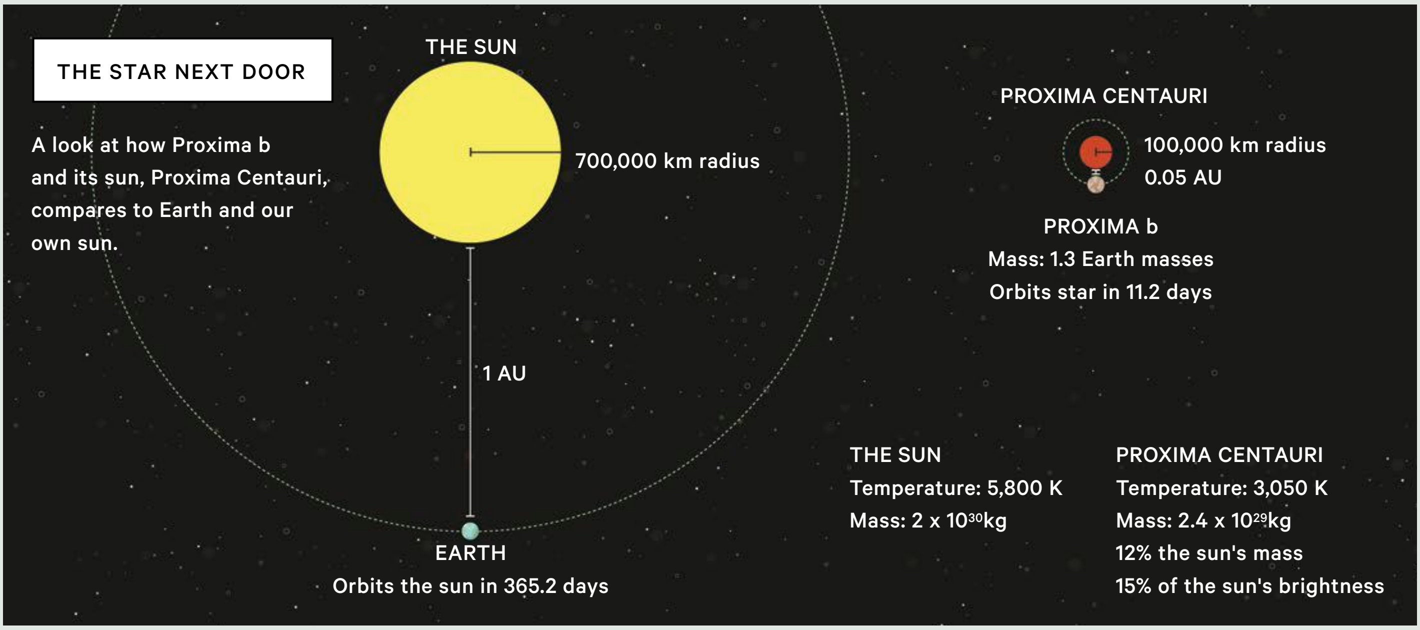
Because of the red dwarf's relatively cool temperature, this very intimate relationship puts it "squarely in the centre of the classical habitable zone for Proxima", the researchers say.

So what's Proxima b like? It's impossible to tell just yet, but the researchers say the history of how it settled in its orbit will shape the answer.

It may have formed further away from the star and migrated closer in; or it may have coalesced from smaller planet "pebbles" in the same orbit. If it formed from pebbles, the authors write, that would result in a much drier world than one formed by a migrating planet.

The next generation of telescopes, such as the Extremely Large Telescope in Chile, will provide more clues.

Red dwarfs are the most abundant stars in the Milky Way galaxy, and if only a small fraction hold planets in an intimate embrace, "our galaxy could be teeming with life", observes Artie Hatzes from Germany's Thuringian State Observatory.



TECHNOLOGY

Paraplegics regain feeling and movement, thanks to virtual reality

After a year of training, eight people paralysed from the waist down showed remarkable improvement. BELINDA SMITH reports.

When it comes to a spinal cord injury, the adage "use it or lose it" applies. Not only do unused muscles wither, but the brain areas that would otherwise be controlling those muscles become dormant, too. If they could be reawakened, would that aid recovery?

Yes, according to a study unveiled in *Scientific Reports* in August.

Eight people paralysed from the waist down regained partial sensation and movement in their legs after reawakening their brain using robotics and virtual reality.

Of the eight, five had been paralysed for at least five years and another two for at least a decade. After the treatment, four improved enough to upgrade from a diagnosis of complete to partial paralysis.

The research was carried out by a team led by Miguel Nicolelis at Duke University in the US and members of the Walk Again Project in São Paulo in Brazil.

When we watch others walking, our motor cortex also lights up. So the patients were shown an avatar of their feet walking in a virtual landscape, just the way our feet would look to us as we walk.

While they watched, an electrode cap recorded their brain activity. At first, their motor cortex failed to respond. But after a few months of weekly training sessions, they appeared to reawaken. "Basically, the training reinserted the representation of lower limbs into the patients' brains," Nicolelis says.

To encourage the reawakening of feeling in the patients' legs, subjects wore sleeves that vibrated differently depending on whether the avatar was walking on gravel, grass or sand.

Eventually, the subjects progressed from being seated in chairs to rigs that gave them the chance to express the slightest gestures of walking, such as harnesses that supported their weight and eventually to a robotic exoskeleton.

After 13 months of virtual reality training, a 32-year-old woman who had been paralysed from the waist down for 13 years was able to take step-like motions.

The work reported in the paper is only part of the story. The subjects are now more than two years into their rehabilitation and the researchers will continue tracking their progress, Nicolelis says.

Could the technique be even more successful if used in newly paralysed patients before their motor cortex shuts down? The team is designing a new trial to find out.

The findings offer patients with spinal cord injuries or stroke-induced paralysis new hope of regaining strength and control.

→ Watch a video on our website of a woman regaining movement after virtual reality training: bit.ly/VRparaplegia

A patient is strapped into mechanical supports that can aid in regaining movement.

CREDIT: AASDAP / LENTE VIVA FILMES

IN BRIEF

MEET THE OCTOBOT

The diminutive octobot is soft all over and autonomous.

CREDIT: RYAN TRUBY, MICHAEL WEHNER, AND LORI SANDERS, HARVARD UNIVERSITY

Inspired by its squishy aquatic counterpart, and standing two centimetres tall, it's the first self-powered robot printed entirely from soft, silicone gel.

Created by a team of Harvard University researchers, the octobot is controlled by a flexible brain circuit that directs a liquid fuel through channels in its eight legs.

The fuel, a hydrogen peroxide solution that reacts with a platinum-based catalyst, produces pressurized oxygen that inflates octobot's eight arms in a sequence of life-like movements that last up to eight minutes.

Octobot is the forerunner of robots that might one day squish into places metallic robots couldn't dream of.

→ Watch a video on our website of the Octobot in action: bit.ly/Octobot

PHYSICS

Have physicists discovered a fifth force of nature?

Claims of a "dark force" may have been premature, writes CATHAL O'CONNELL.

At first glance, the news is ground-breaking. In August a team of American particle physicists, building on Hungarian work, announced the "possible discovery" of a fifth fundamental force of nature. But peer a bit closer and the claim appears to be built on some shaky foundations.

Everything we can see is governed by four fundamental forces of nature: electromagnetism, the strong nuclear force, the weak nuclear force and gravity. The standard model of particle physics accurately explains the first three and predicts the existence of the particles that have been found to carry these forces: photons, gluons and W&Z bosons respectively. Einstein's general theory of relativity does a great job of describing gravity. Though the theory doesn't predict force carriers, some physicists believe there may also be "gravitons".

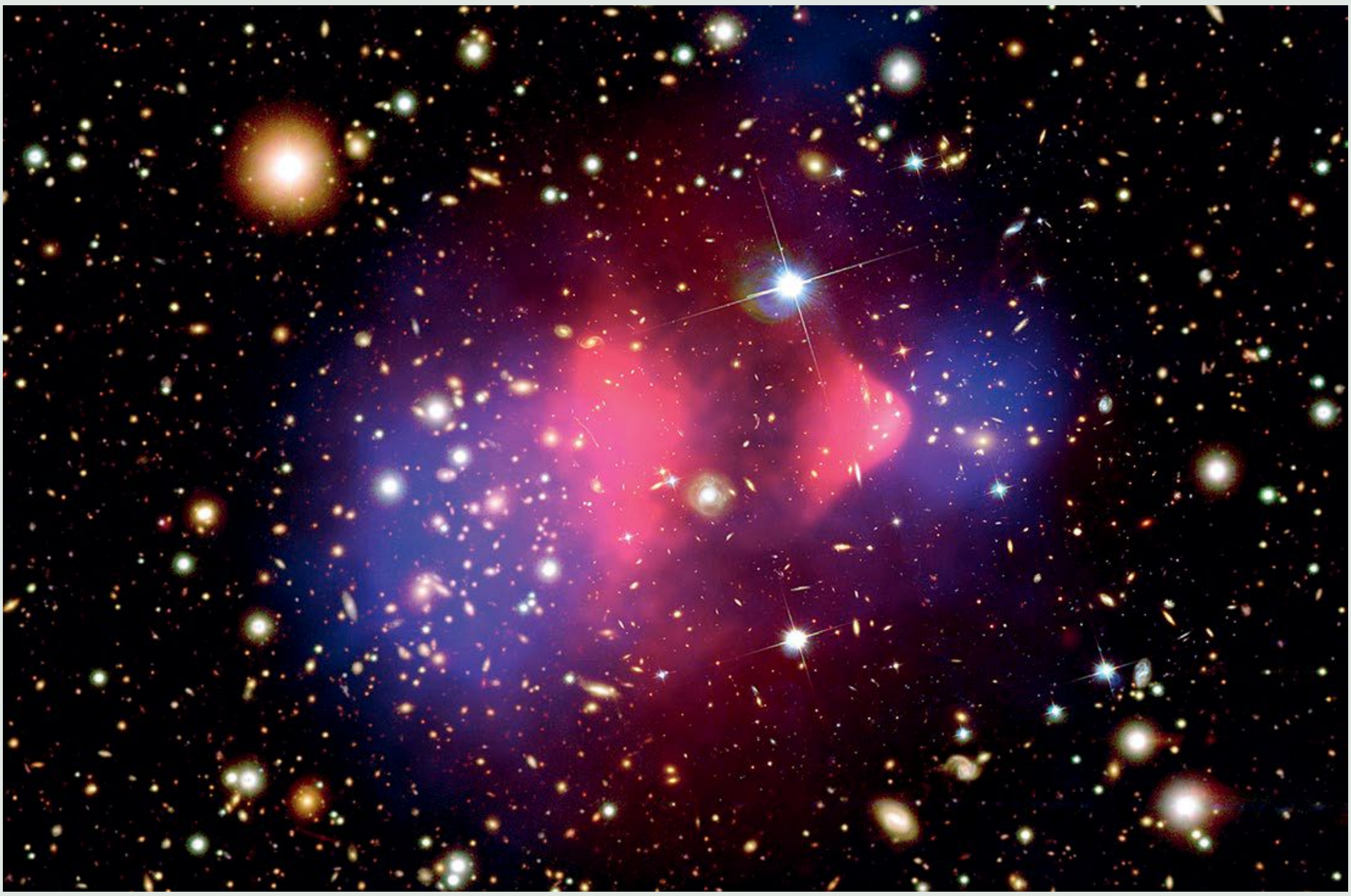
We haven't added anything to this list of forces in more than 60 years, but there's no theoretical reason for there not to be a fifth force.

A promising place to look is dark matter; we know it's strange – something outside of physics as we know it. Might it be associated with some kind of "dark force" too?

Last year a team of Hungarian physicists from the Institute for Nuclear Research in Debrecen went searching for the dark force by observing the decay of the element beryllium-8. It's a veritable factory for producing electrons and their antimatter partner, positrons. Like rigged billiard balls, they always ricochet off at the same angle relative to each other. According to some theories, a 'dark photon' carrying a dark force could interact with the electron and positron, nudging them slightly off course.

THERE'S NO THEORETICAL REASON FOR THERE NOT TO BE A FIFTH FORCE.

The Hungarians found evidence of just such a nudge. Occasionally the exit angle for the electrons and positrons



The researchers were looking for evidence of a dark matter force, and stumbled upon something else instead.

CREDIT: X-RAY: NASA/CXC/CFA/M.MARKEVITCH ET AL.; OPTICAL: NASA/STSCI; MAGELLAN/U.ARIZONA/D.CLOWE ET AL.; LENSING MAP: NASA/STSCI; ESO WFI; MAGELLAN/U.ARIZONA/D.CLOWE ET AL.

deviated. Was it the smoking gun they were looking for? Their calculations suggested the nudge was indeed the work of a new type of "dark photon".

But there was a glitch. The newfound force particle was extremely light – 16.7 megaelectronvolts, which is just 34 times the mass of the electron. Physicists have been searching in this featherweight range for more than 50 years. Why hadn't this particle turned up before?

This August, a team of particle physicists at the University of California, Irvine, led by Jonathan Feng, reanalyzed the Hungarian's data. Publishing in *Physical Review Letters*, Feng's team agreed that the Hungarians had identified a new force particle. But they disagreed as to its identity.

Rather than being a force particle associated with dark matter, they proposed it was a new force associated with *ordinary* matter. They dubbed it the "X boson". The reason it had eluded detection, they say, is that it doesn't interact with protons; it's also very weak and acts over a very short range.

THIS FIFTH FORCE DISCOVERY WILL ALSO LIVE OR DIE BY THE HAND OF MORE DATA.

So am I convinced that we've found the carrier of a fifth force? Not yet. A recurring lesson in particle physics is not to jump to conclusions.

The X boson has only been detected by one experiment; it needs independent confirmation. There are plenty of past examples to make me cautious. In 2008, the Hungarian group claimed discovery of a new boson at 12 megaelectronvolts, and in 2012 another around 13.5 megaelectronvolts. These disappeared as better detectors collected better data. What's to say the current 16.7 megaelectronvolts boson won't disappear too?

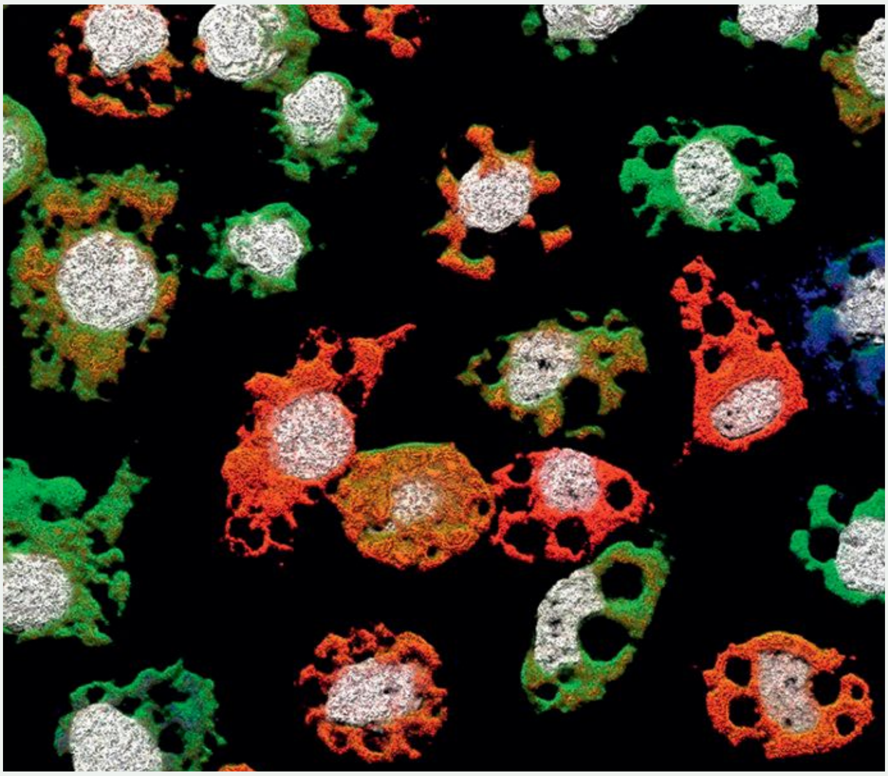
In December 2015, a result from the CERN's Large Hadron Collider also seemed to indicate the discovery of a new particle. Theorists published more than 500 papers explaining its origin. But by July, the blip had disappeared in the deluge of new data.

This fifth force discovery will also live or die by the hand of more data. In particular, the DarkLight experiment at the Jefferson Laboratory in Virginia will analyze the same energy range within a year.

The discovery of a fifth force of nature is an extraordinary claim, requiring extraordinary evidence. Right now, the evidence is ordinary at best.

CAPTURED

STRANGE NEW VIRUS FOUND



Viruses were long thought to be solo invaders, infecting their target in one fell swoop. But a newly identified "multicomponent" virus turns that assumption on its head.

Viruses typically have just a few genes all rolled up into a single viral particle, so all it takes is one particle to infect a target. But the Guaico Culex virus, discovered in several species of mosquitoes in central and south America, takes a multi-pronged approach. The virus consists of five different pieces of genetic material, and each viral particle contains just one piece. That means to successfully invade a host, multiple particles have to gain entry, rather than just one.

Scientists already knew that various plant pathogens work this way, but the new study is the first to identify a multicomponent virus that infects animals. The virus, described in the journal *Cell Host & Microbe* in September, does not appear to affect mammals.

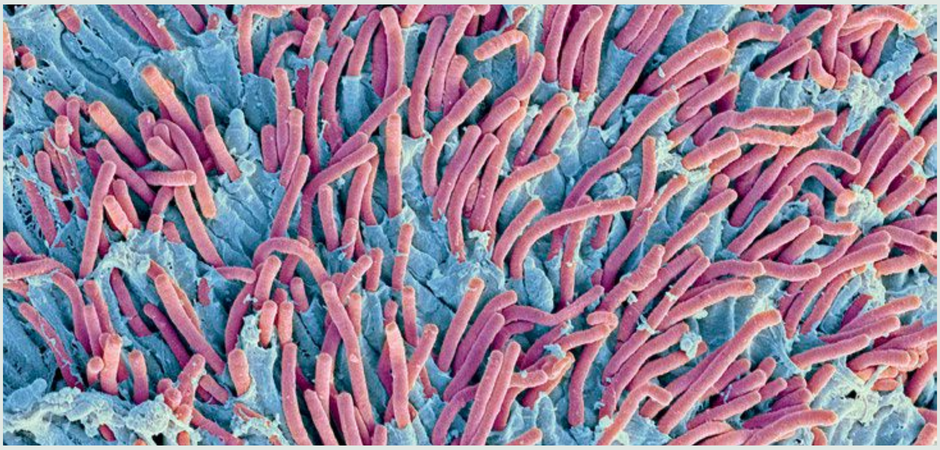
The research came out of a larger effort to seek out new mosquito-borne viruses in the wake of the Zika outbreak.

CREDIT: MICHAEL LINDQUIST / USAMRIID (US ARMY MEDICAL RESEARCH INSTITUTE OF INFECTIOUS DISEASES)

LIFE SCIENCES

Mouth microbes give colon cancer a helping hand

Dental bacteria hitch a ride in blood to fortify colon cancer. BELINDA SMITH reports.



Dental plaque, shown here in microscopic detail, consists of a film of bacteria (red) embedded in glycoprotein (blue). CREDIT: SCIENCE PHOTO LIBRARY / GETTY IMAGES

Bacteria are our guests. They occupy our body along with fungi and viruses in a community known as the microbiota. Sometimes those guests behave badly.

Take *Fusobacterium nucleatum*. It's a member of the oral microbial community and flies beneath the radar of the immune system. But it abuses its privilege. Not only does it cause dental plaque, it aids and abets the development of colon cancer. We don't know *why* the bacterium does that but biologists from the US and Israel have discovered *how*. Foiling it could offer new strategies for preventing and treating colon cancer.

The work was published in *Cell Host & Microbe* in August.

It's only in the past few years that cancer researchers have turned their attention to *F. nucleatum*. They've found colon cancers tend to have lots of the rod-shaped bacteria stuck to them while the surrounding tissue is pretty much bare. But the bacterium's preferred habitat isn't the gut; it's the mouth where it binds to other microbes to form blobs called biofilms. These masses of bacteria are the plaque that accrue on tooth enamel and the gum line. So how does *F. nucleatum* make the journey from mouth to colon? The obvious answer is that it's swallowed and travels through the gastrointestinal tract. But studies searching for it in the stomach and small intestine have largely drawn a blank.

Jawad Abed and Johanna Emgard from the Hebrew University in Israel and their colleagues thought the bacterium might hitch a ride in the bloodstream. To test the idea they injected fusobacteria into the veins of mice with colorectal

LIFE SCIENCES

New whale species identified

The animal eluded detection until now, but scientists have yet to see it in the wild. APRIL REESE reports.

When a trio of small dead black whales washed ashore in Hokkaido on the Japanese coast in 2013, Japanese researchers didn't know quite what to make of them. With their porpoise-like snouts, they looked similar to Baird's beaked whales, a species found in the Pacific. But these whales were smaller and darker.

The scientists suspected they might be a new species and sequenced their DNA. But with just three samples, they couldn't say for sure. Now, through a combination of good luck and sleuthing for more specimens, a team of biologists led by Phillip Morin at the US National Oceanic and Atmospheric Administration's Southwest Fisheries Science Centre are convinced that the mystery whales are, indeed, members of a new species.

The centre houses a large collection of tissue from marine species, and when Morin learned about the mystery whale specimens in Japan, he had a hunch that some of the centre's samples may have been misidentified and were actually the same species the Japanese team had found. "We thought it was possible, because they look so much like Baird's," he says. To find out, the team sequenced the DNA of about 50 samples in the collection, and found two that matched the DNA from the Japanese specimens. Then, as luck would have it, in 2014 fresh evidence washed ashore on an Alaskan island in the Bering Sea: a whale carcass similar to a Baird's beaked whale, but smaller.

AS LUCK WOULD HAVE IT, FRESH EVIDENCE WASHED ASHORE ON AN ALSAKAN ISLAND IN THE BERING SEA.

Genetic tests showed it, too, matched the DNA of the suspected new species. Morin and his collaborators, including Merel Dalebout, a beaked whale researcher at the University of New South Wales, Australia, found a few other tissue samples from museum collections that were also a match. "In all cases, they were extremely cancer. They found it didn't matter if the growths were precancerous or malignant – fusobacteria in the blood sought them out and stuck on tight. But they largely ignored the surrounding healthy tissue.

That suggested the cancer was somehow attracting the bacteria.

Using human and mouse cells, the team uncovered the attractant – a sugar on the surface of the cancer. Bacteria latched on via a protein on their surface called Fap2. Previous studies showed that once latched, Fap2 helps colon cancer cells fly under the immune system's radar, allowing the tumour to grow.

A drug that blocked Fap2 from latching to the cancer cells might allow the immune system to detect and destroy the cancer. Another key strategy is that oncologists could use Fap2 to design a guided missile. Toxic drugs guided by the protein would zero in on the cancer cells while ignoring the healthy tissue.

And will brushing teeth more often help minimize the risk?

"Based on our findings, it's too early to say whether we can prevent mouth bacteria from travelling through blood to the colon", says Gilad Bachrach, also from the Hebrew University and a senior author of the study. ⦿

different" from other beaked whale species, he says. The team described the new species in the journal *Marine Mammal Science* in late July.

The new whale, which will be named by the Japanese researchers who first singled it out, joins two others in the same genus: Baird's beaked whale, which inhabits the Pacific, and Arnoux's beaked whale, which lives in the Southern Ocean.

Most of the samples analyzed in Morin's study were from animals found around northern Japan and the Aleutian Islands, suggesting that the species lives in the North Pacific. But other than that, little is known about the elusive new beaked whale. The next step is to try to find it in the wild, Morin says. "Hopefully we'll learn more about it soon," he says. "Once we know where they are, we can target research to find out what they're doing and where they're going." ⦿

BY THE NUMBERS

OUR GALAXY'S MISSING MATTER

CREDIT: MARK A. GARLICK / CFA

150 TO 300 BILLION

The predicted mass of the Milky Way in terms of solar masses.

65 BILLION

The actual number of solar masses when you count all the stars and dust. *So where's the 'missing matter'?*

1 MILLION

The temperature, in degrees, of a gaseous 'fog' heated by the shockwave. That stupendously superheated gas may account for the missing matter.

40,000

The dimensions in light-years of a 'shockwave bubble' in the centre of the Milky Way. According to forthcoming paper in *The Astrophysical Journal*, it's a burp from our galaxy's supermassive black hole.

CLIMATE WATCH

A spiny chromis damselfish. CREDIT: REINHARD DIRSCHERL / ULLSTEIN BILD / GETTY IMAGES

LIFE SCIENCES

Changing the clock

A Great Barrier Reef fish reveals a surprising strategy for surviving climate change. APRIL REESE reports.

As CO_2 levels rise, more of the gas is dissolving in the oceans, where it turns into carbonic acid. Since industrial times, the ocean has become 30% more acidic.

How will marine organisms fare in this new life aquatic? Scientists are just beginning to find out, but the early evidence does not bode well for some species. The higher acidity can dissolve the shells of oysters and clams, for example, and scramble the chemical signals fish rely on to avoid predators. But the spiny damselfish (*Acanthochromis polyacanthus*) may be one of the lucky ones. In recent years, researchers found that some individuals within populations along Australia's Great Barrier Reef are resilient to acidification. A new study from a team led by Timothy Ravasi, a biologist with King Abdullah University of Science and Technology in Saudi Arabia reveals their secret. Surprisingly, it lies in their ability to change their circadian rhythms.

In coral reefs, CO_2 levels naturally rise as the sun goes down and seaweed and other marine plants shut down photosynthesis (which absorbs CO_2) for the night. Previous studies showed that damselfish have evolved the ability to tolerate these nightly spikes of CO_2 and the slight rise in acidity that follows. Subsequent research on the effects of higher CO_2 levels found that some individual fish are more resilient than others.

What is it about these fish, Ravasi and his team wondered, that makes them so tough? And what are their prospects for surviving future acidity levels as climate change worsens? To find out, they caught wild spiny damselfish from the Great Barrier Reef and divided them into two groups — one tolerant and one sensitive. Then they placed the fish in tanks of seawater with CO_2 levels raised to about 750 parts per million — the level expected by the end of the century if CO_2 emissions are not curtailed — and waited for them to reproduce.

To the team's surprise, some of the offspring hung on. "We thought they'd all die," Ravasi says. "But we found the baby fish seemed to be adapted."

Thinking some kind of genetic advantage might explain their adaptability, they mined a vast amount of data on the specific types of RNA and protein molecules (produced under the direction of specific genes) that were generated in the brains of the fish.

THE NEW RESEARCH ADDS TO THE TINY BUT GROWING BODY OF WORK ON HOW MARINE ORGANISMS WILL RESPOND AS CLIMATE CHANGE WORSENS.

The team, which included researchers from James Cook University in Australia, found that certain genes governing circadian rhythm went into overdrive. "Basically the offspring of the tolerant fish set their circadian clock [as if it were] always night," Ravasi says. The study, published in *Nature Climate Change* in August, found other genetic differences between the tolerant and sensitive offspring too, but the biggest was the change in the circadian rhythm genes in the tolerant juveniles.

While their resiliency is a hopeful sign that at least some marine fish are equipped with strategies that could help them adapt to a more acidic future, "we don't want to be too optimistic," Ravasi adds. "We don't know how other fish species will react. They might not be as strong as our little fish."

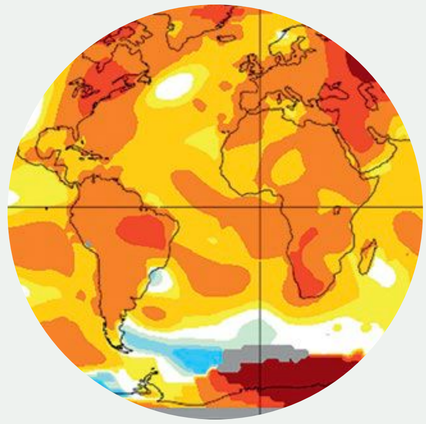
Giacomo Bernardi, a marine ecologist with the University of California at Santa Cruz, who was not involved in the study, says it adds some key insights to the tiny but growing body of work on how marine organisms will respond as climate change worsens. "This is a milestone, in that it puts together evolution, ecology and the molecular mechanisms that drive the entire process," he says. The bigger question is how individual genetic changes will affect the ways species interact with each other and their environment, Bernardi adds. "What will happen to the genes of the entire ecosystem — prey, predators, corals and plants?"

Ravasi and his team are now performing their cross-generation experiment on clownfish, another inhabitant of the Great Barrier Reef, and kingfish, a commercially fished species that lives in the open sea. Other research is taking the same approach with coral.

With conditions changing so rapidly, the work can't happen quickly enough, Ravasi says. "There's going to be a fast change in ocean chemistry," he says. "We really need to understand how marine organisms will react." ⦿

2016 shaping up to be the hottest year on record

The new data underscore the need to cut emissions. APRIL REESE explains.



August 2016 was .98 degrees Celsius above the 1951-1980 global average. Hottest areas are in shades of red.

CREDIT: NASA

If 2016 could be summed up in one word so far, it would be "hot." In July, scientists announced that the year was on track to usurp 2015 as the warmest on record. Earth's average global temperature for the first half of the year was 1.3 degrees Celsius warmer than when modern record-keeping began 136 years ago.

The month of July itself also smashed records, eclipsing the previous record-holders, July 2015 and July 2011. Then, in September, more bad news: August tied July for the hottest month on record. At .98 degrees Celsius above the 1951-1980 global average, it was the warmest August since 1880, according to NASA's Goddard Institute for Space Studies.

While El Nino had something to do with the rising temperatures earlier in the year, the record-breaking continued even after this cyclical warming event began dissipating. Most of the warming is because of heat trapped by rising levels of carbon dioxide and other greenhouse gases.

NASA's Gavin Schmidt cautioned that yearly rankings are not the whole story. "We stress that the long-term trends are the most important for understanding the ongoing changes that are affecting our planet," he said in announcing the August record in mid-September.

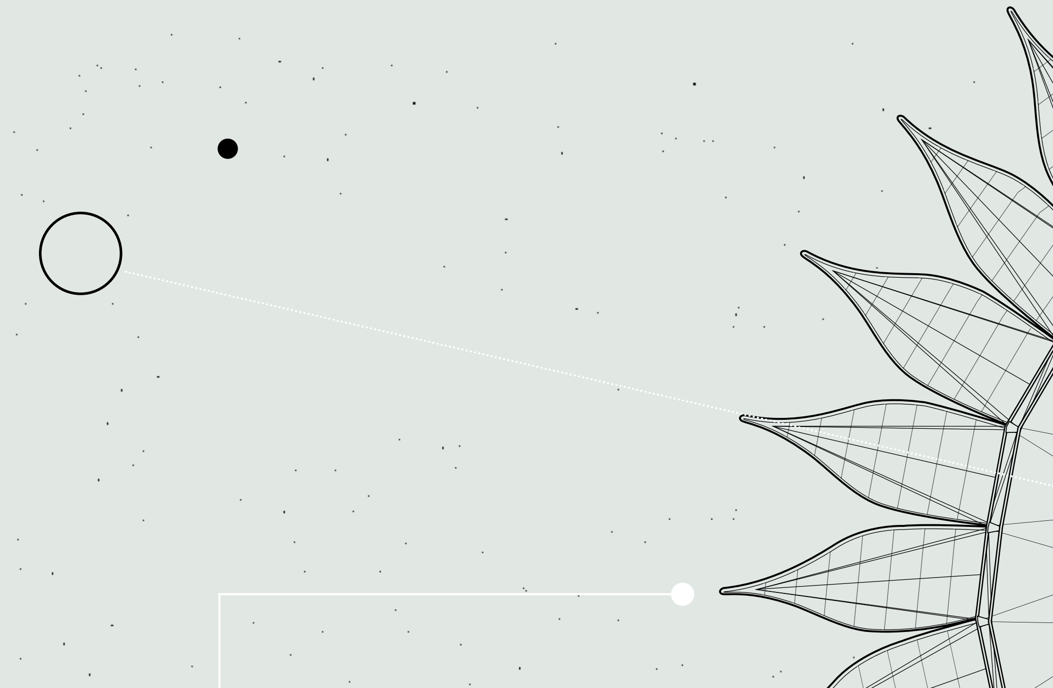
Those long-term trends show that the planet is on course for reaching climate scientists' projections for the coming decades. Computer models forecast an increase of between 2 and 6 degrees Celsius by 2100, depending on how successful the world's 7.5 billion people are at sticking to a carbon diet. Last year, the world's nations agreed to limit warming to below 2 degrees Celsius, with 1.5 degrees Celsius as the ideal target. But the unprecedented warming since industrialization shows how challenging it will be to meet it. The planet has already heated up by 1 degree Celsius since the 19th century.

If 2016 does turn out to be a record-hot year, it isn't likely to stay at the top for long. ⦿

TECHNOPHILE

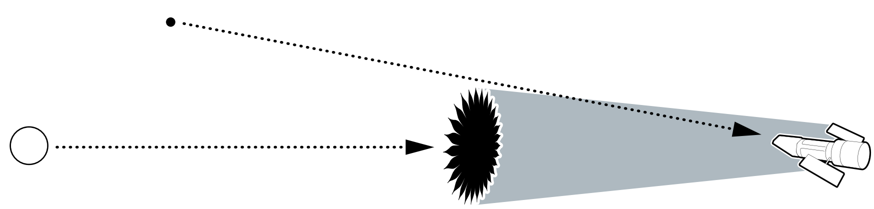
Alien glare

A flower-like starshade could give astronomers a direct look at planets orbiting distant stars. By CATHAL O'CONNELL.



STARSHADE

The starshade blocks the dazzling light from an exoplanet's star. The shade's "hypergaussian" petal arrangement causes waves of starlight spilling around the starshade to cancel each other out, making the exoplanet easier to spot.



Forty billion. That's the number of habitable, Earth-like planets in our galaxy. But do any of them host life? NASA has a far-out plan to find out: put a giant sunflower light-shield in space.

The 40 billion number is based on the thousands of exoplanets discovered so far by planet-hunters such as the Kepler Space telescope, which watches for the periodic dimming of stars as a planet passes in front of them. Researchers use the dimming effect to calculate the planet's size and orbital distance – but the technique gives no inkling as to what the planet is made of.

If only we could see one of these potentially second Earths directly. By analysing the light glinting off the planet, we'd be able to tell if it had liquid water. As the planet spun on its axis, the light would change, offering clues about how much of the surface was covered in ocean. We could look for oxygen in the planet's atmosphere, clouds in its sky, and possibly detect other molecules associated with life.

The problem is, we can't see these planets, as our telescopes are blinded by the parent star, which typically blazes 10 billion times brighter than the dim light reflected by Earth-like planets.

The starshade is a sunflower-shaped disc, half the size of a soccer field, designed to block that dazzling starlight. Flying in tandem with a space telescope, the starshade would use its own thrusters to position itself 50,000 kilometres in front of the telescope, where its 50-metre diameter disc would cover the target star, while leaving any planets visible.

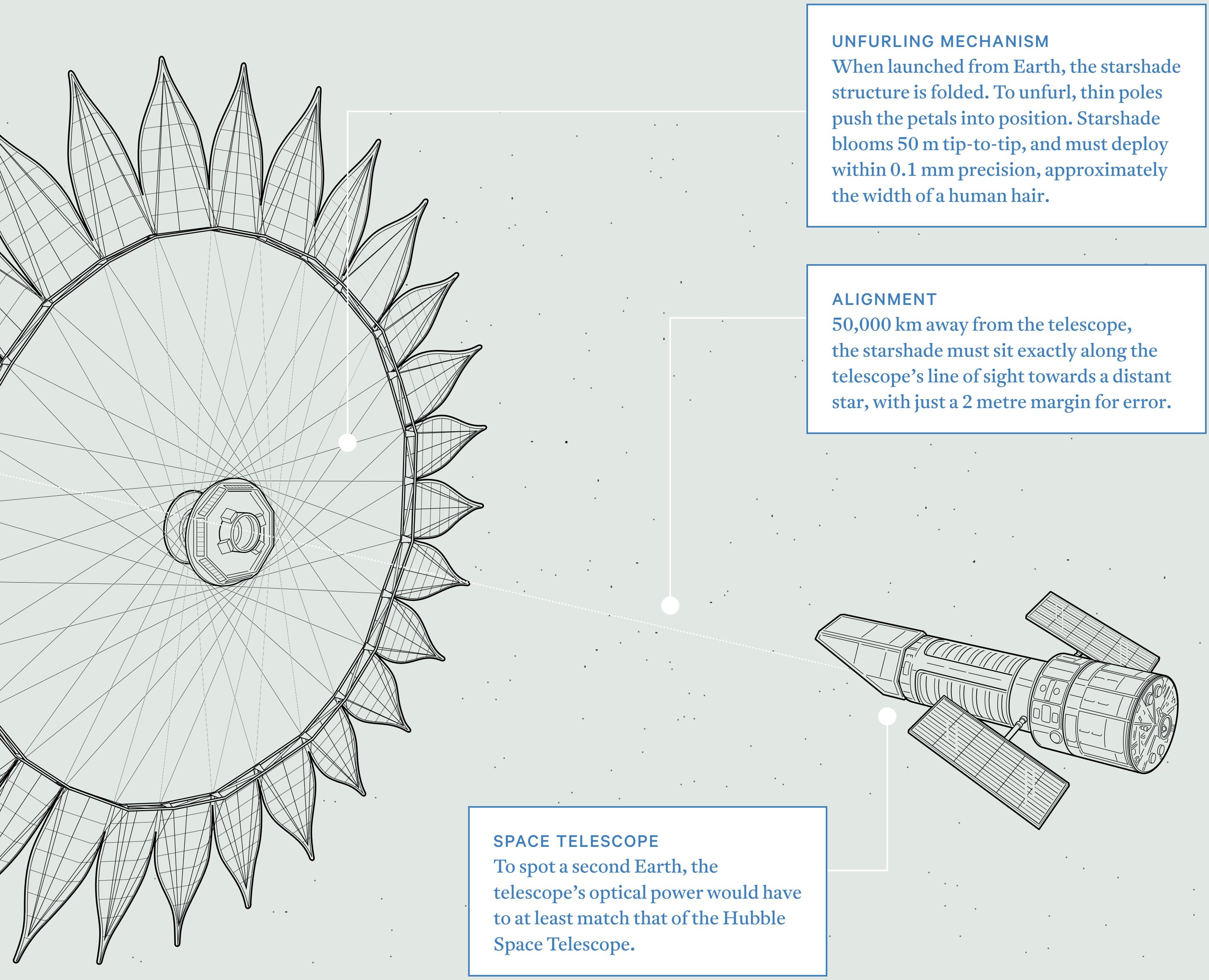
We're not talking close-up pictures here, explains Jonti Horner, an astrobiologist at the University of Southern Queensland. "The planets would still just be a single pixel, a tiny speck of light in the inky blackness of space. But if we could see that speck, then we could begin to analyse the light from it," he says.

The starshade idea harks back to Lyman Spitzer, the father of space-based astronomy. Back in the 1960s, he envisioned a simple disc to block the starlight. But the idea was shelved when reseachers hit the diffraction problem.

Any kind of waves, including sound, water and light waves, tend to diffract around an obstacle, their paths bending to follow its contours. That's why you can hear someone speaking from around a corner. And it's why a disc-shaped starshade could never work. Too much of the parent star's light would diffract around its edges, obscuring any planets within a bright halo.

The sunflower design solves this problem by directing the diffracted starlight onto special paths that cause neighbouring waves to overlap and cancel each other out, an effect known as destructive interference. So the brightness of the star could be reduced by 10 billion times – enough to reveal planets as close to their stars as Venus is to our Sun.

Astronomers at the University of



Colorado pioneered the sunflower design using mathematical models to figure out the optimum shape. They tested it in the Nevada desert at night by setting up a powerful light as the "star" and a feeble LED, a billion times less bright, as the planet. A telescope two kilometres away was initially blinded by the "star", but when the starshade was positioned in front, the "planet" was revealed.

The team then equipped the McMath Solar Observatory in Arizona with their starshade and pointed the telescope at the star Vega. The starshade blocked Vega's glare so effectively that several stars previously invisible to the telescope popped into view.

These early successes got the attention of NASA, which put its Jet Propulsion Laboratory on the case – figuring out how to make the starshade's delicate petals, then fold it up inside a rocket and unfurl it in space. It's a challenge, Horner admits – but not an insurmountable one.

The starshade is still in its early stages of development, but it could see a mission sooner rather than later. The Wide-Field Infrared Survey Telescope (WFIRST), scheduled to launch in 2025, could be equipped with one, if NASA can find the extra billion dollars it would cost. WFIRST would be a perfect partner for a starshade because the telescope will be highly manoeuvrable in its stable solar orbit. After examining one planetary system, starshade and WFIRST could reorient towards another system and continue the search for life.

And with up to 40 billion chances, who'd bet against them?

→ See the sunshield unfurl here: bit.ly/cos71sunshield

ILLUSTRATION: ANTHONY CALVERT

OPINIONS, IDEAS & PERSPECTIVES

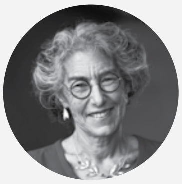
VIEWPOINT

"ANOMALIES ARE THE PATH TO REAL PROGRESS"

KATIE MACK — ASTROPHYSICS

NORMAN SWAN
BODY TALK

KATIE MACK
ASTRO KATIE



LAURIE ZOLOTH
PHILOSOPHER'S CORNER

ALAN FINKEL
INCURABLE ENGINEER

NORMAN SWAN is a doctor and multi-award winning producer and broadcaster on health issues.

BODY TALK

Let's get physical

Extra exercise might offset the harmful effects of sitting for too long.

SITTING HAS BEEN ACCUSED of being as toxic as obesity and smoking. Those concerns have spawned a whole new line in office furniture: the standing desk. At my organisation, the Australian Broadcasting Corporation, we even have standing studio consoles and head sets that allow twitchy broadcasters like me to walk around gesticulating while on air.

Just focusing on the amount of time you spend sitting each day, however, ignores the amount of exercise you get when you're not sitting. It also doesn't take into account what you're doing while sitting. Watching television for prolonged periods is considered a risk factor in its own right for obesity and premature mortality.

So just how bad is sitting for you? A recent series of studies in the *Lancet* aimed to find out. The researchers analysed sitting time, TV time and physical activity in relation to premature mortality.

They looked at data from previous studies that had followed groups of people for several years to document lifestyle and physical activity. The studies also took into account obesity, age and prior illness – factors that could confound any direct link between sitting and disease. After eliminating poor quality or inappropriate studies, they ended up with information on more than a million people who had been followed for up to 18 years.

Physical activity was measured in metabolic equivalent of task (METs), which reflect the intensity of exercise over time. Crudely speaking, the more METs in your life, the better. For instance, regular walking for an hour is around three METs, moderate exercise around four METs and vigorous exercise around seven METs.

They confirmed what everyone already knows: physical inactivity is linked to early death from all causes. People in the lowest activity groups had up to a 59% increased risk of premature mortality when compared to people who didn't sit much and who had over 35 METs a week.

But when it came to sitting, the results were actually quite comforting. You could abolish the deadly effects of sitting by taking additional exercise. People who sat for eight hours a day needed to take 60-75 minutes of physical activity daily, amounting to more than 35 METs per week to abolish the risk. Now, that didn't need to be an hour and a quarter bashing away at the weights at the gym. Those gains could be accumulated as semi-structured exercise like walking the dog. While 75 minutes a day sounds a lot, in fact data from Australia suggest 25% of adults over 45 years old already take that amount. Then again, there's another 25% who take fewer than five minutes a day.

When it came to television sitting time, the story was somewhat different. Watching television for three hours a day was associated with higher chances of dying prematurely regardless of your level of activity, except for the most active people (more than 35 METs a week) who could get away with five hours in front of the box. So the ill effects of prolonged sitting in front of the TV, as opposed to other types of sitting, are far harder to counteract with exercise.

How do you explain all this biologically?

In specific studies where researchers intervened with exercise rather than just watching people's behaviour over time, they found that one hour of moderate intensity exercise helps you to metabolise your blood sugars more effectively after a meal. In looking at people with type 2 diabetes, they found that cycling at moderate intensity for 45 minutes after sitting for 10 hours improved their sugar metabolism. There is also evidence that interrupting sitting time with physical activity helps reduce the blood levels of glucose and fats.

PEOPLE IN THE LOWEST ACTIVITY GROUPS HAD UP TO A 59% INCREASED RISK OF PREMATURE MORTALITY.

TV viewing is more complicated. Adults who watch most of their television after dinner are also more likely to snack while doing so. We already know that our body handles food intake differently at night – eating in the evening is more likely to lead to unhealthy high blood sugar levels. There's also some evidence that TV advertisements may encourage people to consume more junk food.

Bottom line: don't become too paranoid about your sitting time. Just make sure not too much of it is in front of the television, and get as much moderate exercise as you can at other times.

KATIE MACK is a theoretical astrophysicist who focuses on finding new ways to learn about the early Universe and fundamental physics.

ASTRO KATIE

Love and loss in the time of colliders

Even the most promising data can let us down.

ISAAC ASIMOV ONCE SAID, "The most exciting phrase to hear in science, the one that heralds new discoveries, is not 'Eureka' but 'That's funny'". While the popular representation of scientists is that they are focused, single-minded workers jumping from discovery to discovery, the reality is a lot more complicated. Finding something strange in the data, rather than having a "eureka" moment, is usually what leads us to a new or more complete theory.

That's why physicists around the world got so excited when, in late 2015, they detected a small but tantalising bump in a plot produced by the Large Hadron Collider (LHC).

In particle physics, confirming a theory is an important (and very satisfying) step, but anomalies are the path to real progress. The Standard Model of Particle Physics – the fantastically successful framework for all particle physics seen so far – has passed every experimental test we've thrown at it. But it has some major theoretical problems. Theories such as supersymmetry and string theory are designed to solve those problems, but to know if we're on the right track, we need to see something in the lab that doesn't fit with what the Standard Model predicts.

The plot that got everyone excited last year looked like it might show just such a disagreement.

The LHC works by colliding protons together and collecting information about what comes out. Sometimes, collisions produce, among other debris, two photons (particles of light). In general, if you chart the number of collisions producing two photons, you'll see that low-energy photons are produced much more often than high-energy ones, and the transition between low and high is a nice smooth curve. That's what the Standard Model predicts. But what physicists saw in the plot was not a smooth curve, but one with a bump – a high-energy "excess" registering 750 giga electronvolts (about 750 times the energy of a single proton at rest).

When the results were announced, the particle physics community erupted in speculation. A bump like that could mean the LHC had produced a new particle, one the Standard Model didn't include – a sure sign of new laws of physics at work. The "diphoton excess" became the talk of the town. New theories were created, papers were published, and old theories were tweaked to "predict" the excess after the fact.

But there was a catch. Particle colliders count the number of events (in this case, photon pair productions) above a background level of random production of particles from other kinds of events. That background is always present, and we know what it is on average, but sometimes there's more and sometimes less. A bump could be just random chance. The diphoton excess certainly looked significant: early estimates said there was only a small chance of it being a fluke. Still, in a long running experiment, low likelihood events do occur once in a while. Scientists needed more data to know for sure whether the blip was, in fact, a new particle or just an unfortunate coincidence in the background events.

In early August, LHC scientists had their answer, and the news was not good. The diphoton bump had vanished back into the noise. It was a random fluctuation after all. That meant that more than 500 papers now contained detailed dissections of a signal that did not exist.

On the new Netflix series *Stranger Things*, a science teacher quips, "Science is neat, but I'm afraid it's not very forgiving." Even more apropos is a quote from H. L. Mencken (slightly reworded): "For every complex problem, there is an answer that is clear, simple, and wrong." As scientists, we always have to accept the possibility that a new and exciting development will be mercilessly killed by the next batch of data, and when that happens, we have to adapt. No matter how elegant our theory, or how well we thnk it solves some long-standing problem, if the data don't agree with it, we have to let it go and move on.

IN PARTICLE PHYSICS, CONFIRMING A THEORY IS AN IMPORTANT STEP, BUT ANOMALIES ARE THE PATH TO REAL PROGRESS.

At the moment, that means setting aside our diphoton theories and going back to the data to see what else we might find to challenge the Standard Model.

The next time something goes bump in the night, we'll still be here, and we'll be ready. ©

LAURIE ZOLOTH is a professor of medical ethics & humanities at Northwestern University, Chicago.

PHILOSOPHER'S CORNER

Swatting the malarial mozzies

"Gene drives" might be up to the task.

MALARIA THREATENS half the world's population. Last year it infected 200 million people and claimed 438,000 lives, mostly small children in sub-Saharan Africa – more than 1,000 die each day in their parents' arms. The malaria parasite has a knack of rapidly developing resistance to drugs. The best way to vanquish it is to target the mosquitoes that spread it. Researchers came close in the 1950s with massive DDT campaigns. But DDT was banned in the US in 1972 because of the potent pesticide's detrimental effects on wildlife and human health.

Now there's a new approach that's chemical-free. It works by tinkering with the DNA of the mosquito. That in itself is not new – researchers have been trying to make mosquitoes resistant for decades. The problem is that changing the DNA of an entire population is a slow and uncertain process. This new technique is faster, more reliable and more precise.

The technique, called a "gene drive", works by manipulating the mosquitoes' DNA to interfere with the development of females. That's key because adult females spread the disease by feasting on human blood before laying eggs.

The "driver" in the gene drive is an unusual bit of DNA code that can copy itself from one chromosome to another. While a gene is normally passed on to 50% of the next generation, if it carries a driver it's possible to transmit it to 100% percent of the next generation.

Austin Burt and colleagues at Imperial College London have attached gene drives to bits of DNA that hijack and destroy genes crucial to the development of female mosquitoes. According to mathematical models, within 20 generations, or about two years, the gene drive would spread through the population, eliminating females.

The effects of the gene drive can be limited to the species that transmits malaria; the main culprit in sub-Saharan Africa is *Anopheles Gambiae*.

Burt's team of molecular biologists, population geneticists, anthropologists, policy makers, and community outreach experts has been working for over a decade in three African countries deeply affected by the disease. They work with partners in Africa as a part of Target Malaria, a non-profit organisation.

When I met with Burt's team this summer, I was impressed with the iterative way they plan to develop the gene drive mosquitoes, using strict containment measures – first in Britain, then in Africa, mapping out a slow and careful path towards that moment when a bucket full of male mosquitoes carrying the gene drive is taken to a village. They have taken every conceivable safety precaution. Of course, even the safest team can make mistakes, and they will need to closely monitor the effort.

Besides safety, though, there are other ethical issues to be considered.

If gene drives are successful, the benefits to humanity would be enormous. But there could be possible harms.

These concerns range from unintended consequences when a species is eliminated from an ecological niche to the deep unease about the power of science to create and destroy. Ethicists also wonder whether we have the right to eliminate a species.

But should these fears get in the way of using this tool?

I don't think so. In the 1960s, the world agreed that smallpox was a species worth eliminating. We should feel the same way about *Anopheles Gambiae*.

And isn't deploying a gene drive that specifically targets the mosquito species that carries malaria far better than using chemical sprays, such as pyrethroids, organochlorines and DDT (still used in some countries) that indiscriminately target any insect?

Finally, who should make these decisions?

Mosquito-borne diseases are no longer just an issue for the poor of tropical countries. With global warming, mosquitoes are expanding their range and with them, the diseases they ferry including malaria, dengue and Zika.

Westerners tend to be preoccupied with the dangers of meddling with the status quo. But if you have lost baby after baby to wrenching fevers, you might think that protecting the status quo is the most unethical choice imaginable.

Gene drives may come to represent one of the most moral gestures scientists have ever made.

ALAN FINKEL is an electrical engineer, neuroscientist and the chief scientist of Australia.

INCURABLE ENGINEER

Good science takes time

Research is more of a long and winding road than a straight superhighway.

IT CAN SEEM LIKE discoveries are made overnight. But those "overnight successes" usually conceal a saga of victories and setbacks played out by a large cast of characters over decades.

Take lasers. It would be hard to imagine modern life without them. They're in the barcode scanner at the supermarket checkout, the surgery, your laser printer, driverless cars and guided missiles. Beyond these worldly uses, they've just allowed us to detect gravitational waves, giving us a new tool to probe the universe.

Lasers are also lucrative. Global annual sales run at about US$10 billion. But that's a narrow valuation. Our internet is built on a freeway of optical fibres in which laser light efficiently zips data around the planet. The economic value of lasers would have to be counted in the trillions.

Lasers are everywhere, but few people realise the idea for this lynchpin of modern civilisation was conceived a century ago, by none other than Albert Einstein.

To retrace the path, we need to step back and explain how laser light differs from ordinary light. Sunlight bounces around in all directions with a range of energies – it's like the choppy waves in a swimming pool full of splashing toddlers. But get the toddlers out of the pool and turn on a wave generator. Now all the waves are moving in one direction with the same height and energy. That's how laser light behaves. It's coherence – all that energy moving in the same direction – and the ability to focus to a fine point that makes the laser the most powerful and precise tool ever made.

The key to developing a laser was to realise that sometimes light could be emitted in discrete packets of energy. Einstein came to this insight in 1905. In 1917 he theorised it should be possible to excite electrons so they all produce exactly the same size packets of light energy or photons. It was the foundational idea for the modern laser.

Over the next forty years other scientists added bits and pieces to that foundation, including those in the former Soviet Union and Bell labs. In 1957 Gordon Gould, a Columbia University PhD student, put the bits and pieces together and described a method to stimulate electrons to produce light moving in synchrony with the same energy. He named it "Light Amplification by Stimulated Emission of Radiation", or "laser" for short.

A few years later, Theodore Maiman at the Hughes Research lab in California built the first practical laser by using a flash light to excite electrons in the atoms of a ruby crystal. Each excited electron released a photon that went on to excite another electron. This triggered a chain reaction where all the photons of light had exactly the same energy, though bouncing around in all directions. To capture only those moving in the same direction, he placed mirrors at either end of the ruby so only those photons moving parallel to the mirrors were reflected back and forth. It was these perfectly in phase photons of equal energy that were captured at one end of the crystal as a laser beam of pure red light.

It wasn't until 1977 that the first laser-based optic fibre communications system was installed, in Chicago. Music CDs debuted in 1982 with a Billy Joel album, and in 2009 the largest, highest-energy laser in the world, known as the National Ignition Facility, was switched on to explore the possibility of controlled nuclear fusion. Today's internet would be impossible without the extraordinary efficiency of lasers in optical fibres.

LASERS ARE EVERYWHERE, BUT FEW PEOPLE REALISE THE IDEA WAS CONCEIVED BY ALBERT EINSTEIN.

So the next time you log on, spare a thought for the epic journey that brought you laser technology.

It began with an ingenious idea, followed by a struggle to demonstrate that idea, failure, incorporation of new theories, more struggling, another idea, until finally the next genius in line turned the theoretical advance into an overnight marketplace success.

Transformational invention starts with fundamental science followed by ingenious technological development.

It takes time.

HOLODECK:
COMPILED BY JAMES MITCHELL CROW

STORM WARNING

KATRINA WAS THE DEADLIEST hurricane to hit the US in a century.

On the morning of 29 August 2005, it lashed New Orleans with near-200 kilometre per hour winds that drove a storm surge up to eight metres high and flooded 80% of the city. Across the region at least 1200 people died.

Hurricanes are notoriously unpredictable. But science is catching up, and helping to save lives. Ten years after Katrina, a sophisticated meteorological forecast gave the people of southwest Mexico five days to prepare for Patricia. When the most powerful hurricane in North America's history struck, only two people were killed by the storm.

CREDIT: DAVID J. PHILLIP / AFP / GETTY IMAGES

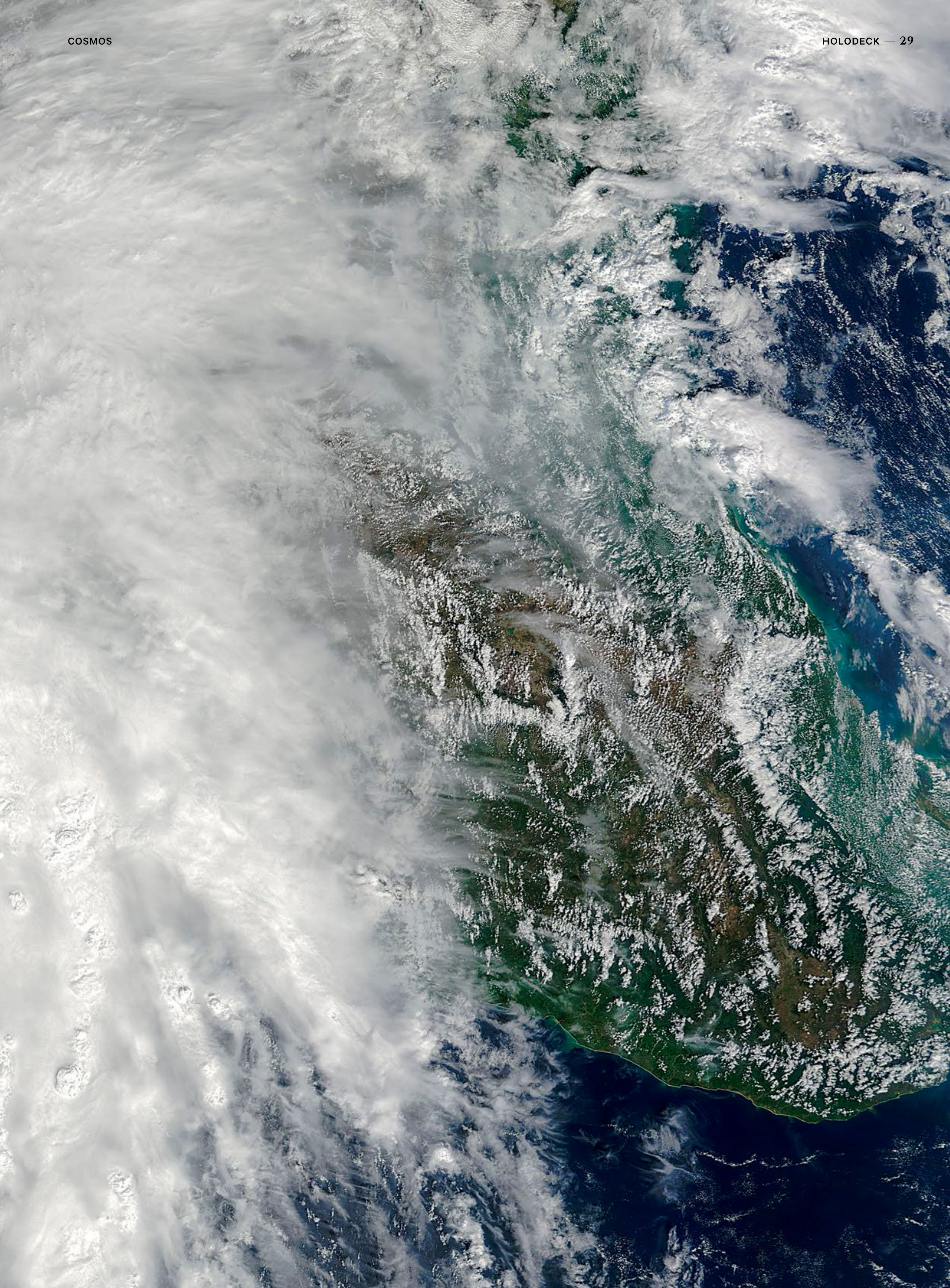
PATRICIA APPEARS

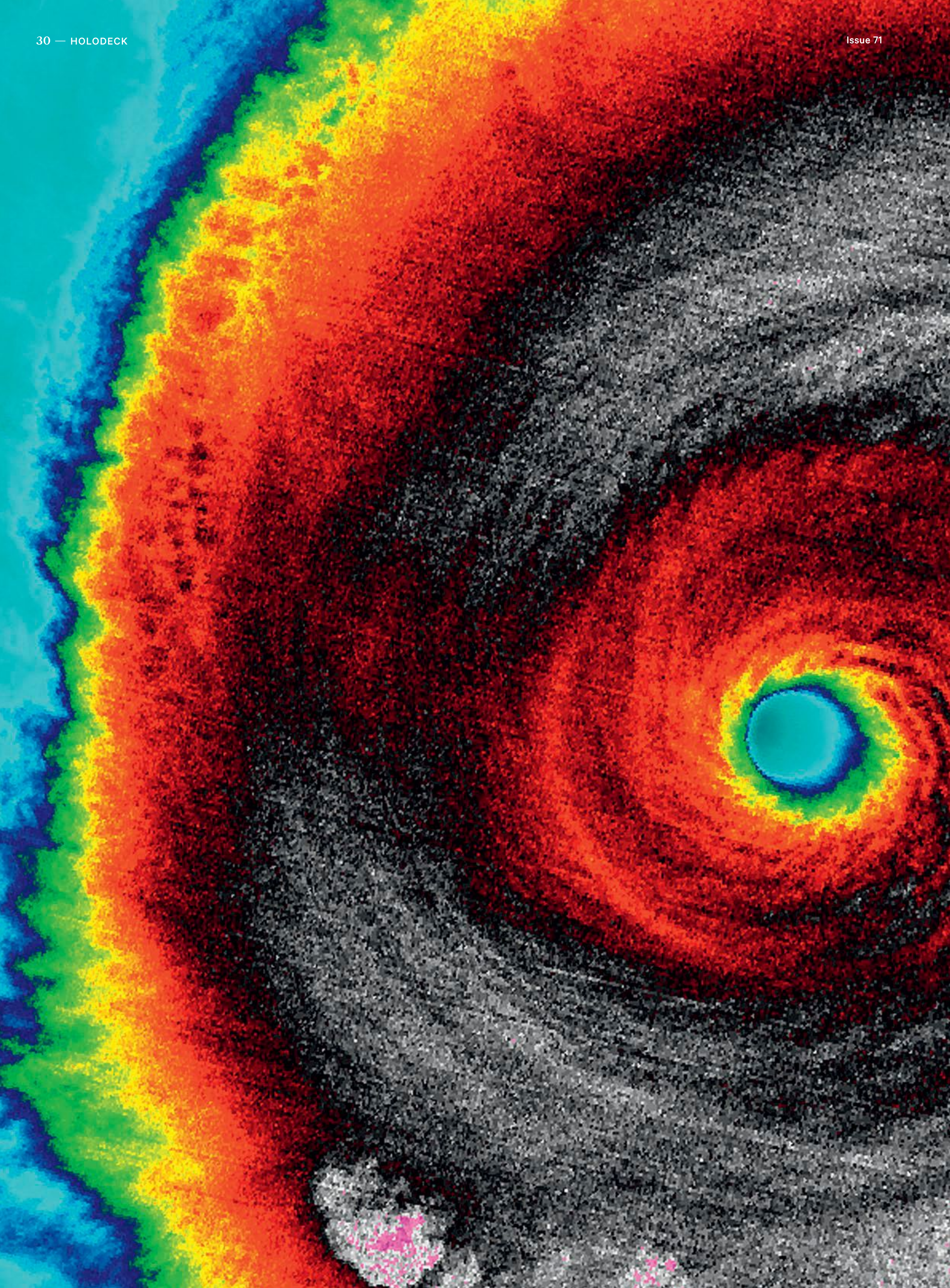
A Terra satellite captured this ominous image of Patricia on 23 October, 2015, just hours before the hurricane made landfall. But satellite images from almost a week earlier had foreshadowed what was in store.

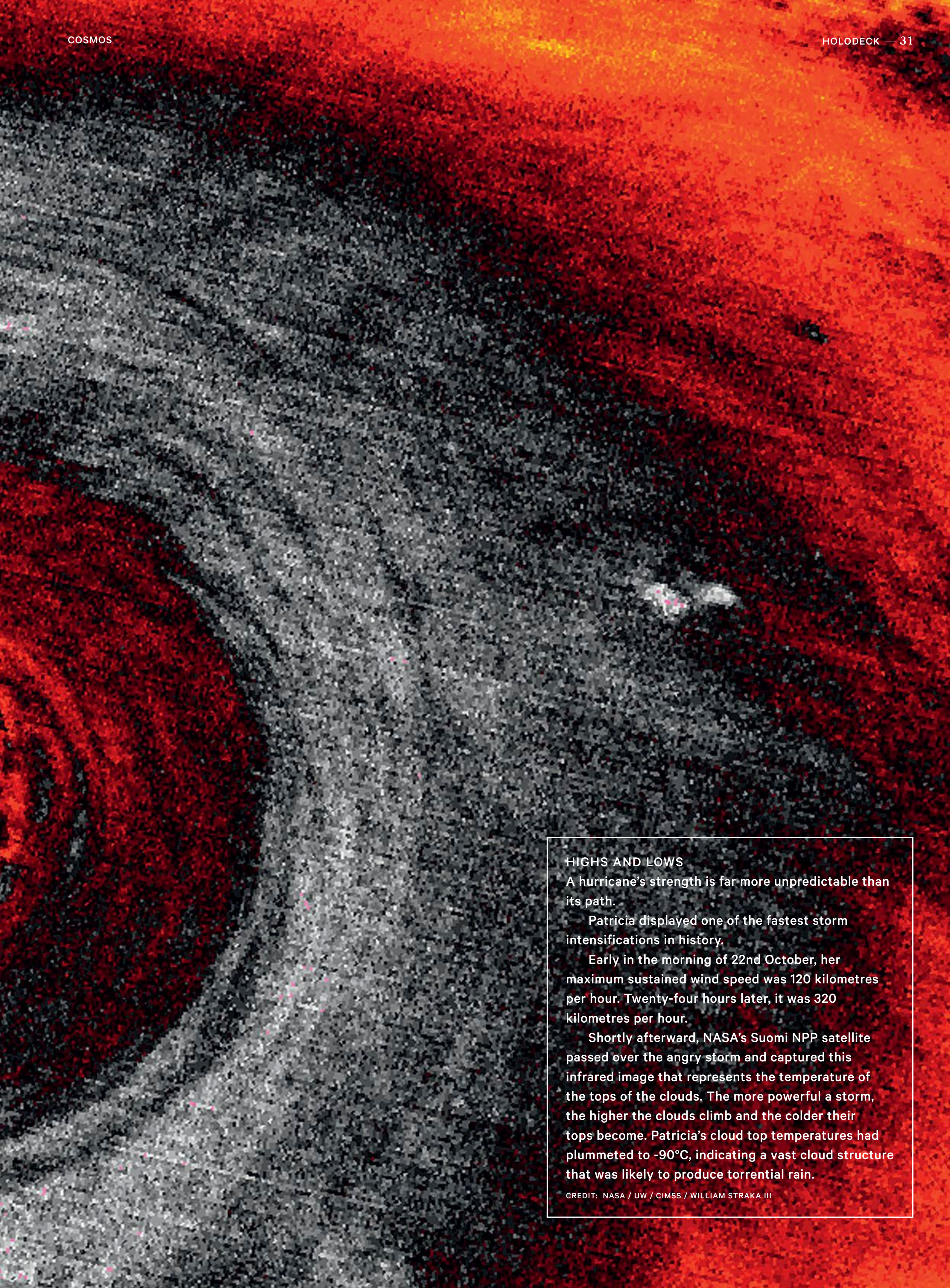
As the storm developed, Hurricane Hunter aircraft flew in for a closer look, dropping devices called dropsondes to measure the interior barometric pressure and wind speed.

All those data were relayed to supercomputers. Season after season, the more data we feed them, the better their predictive power. In 2005, they could predict a hurricane's track to within a range of some 250 kilometres three days in advance. Today they can track them to that level of accuracy five days in advance.

CREDIT: JEFF SCHMALTZ / LANCE / EOSDIS RAPID RESPONSE / NASA EARTH OBSERVATORY MAP







HIGHS AND LOWS

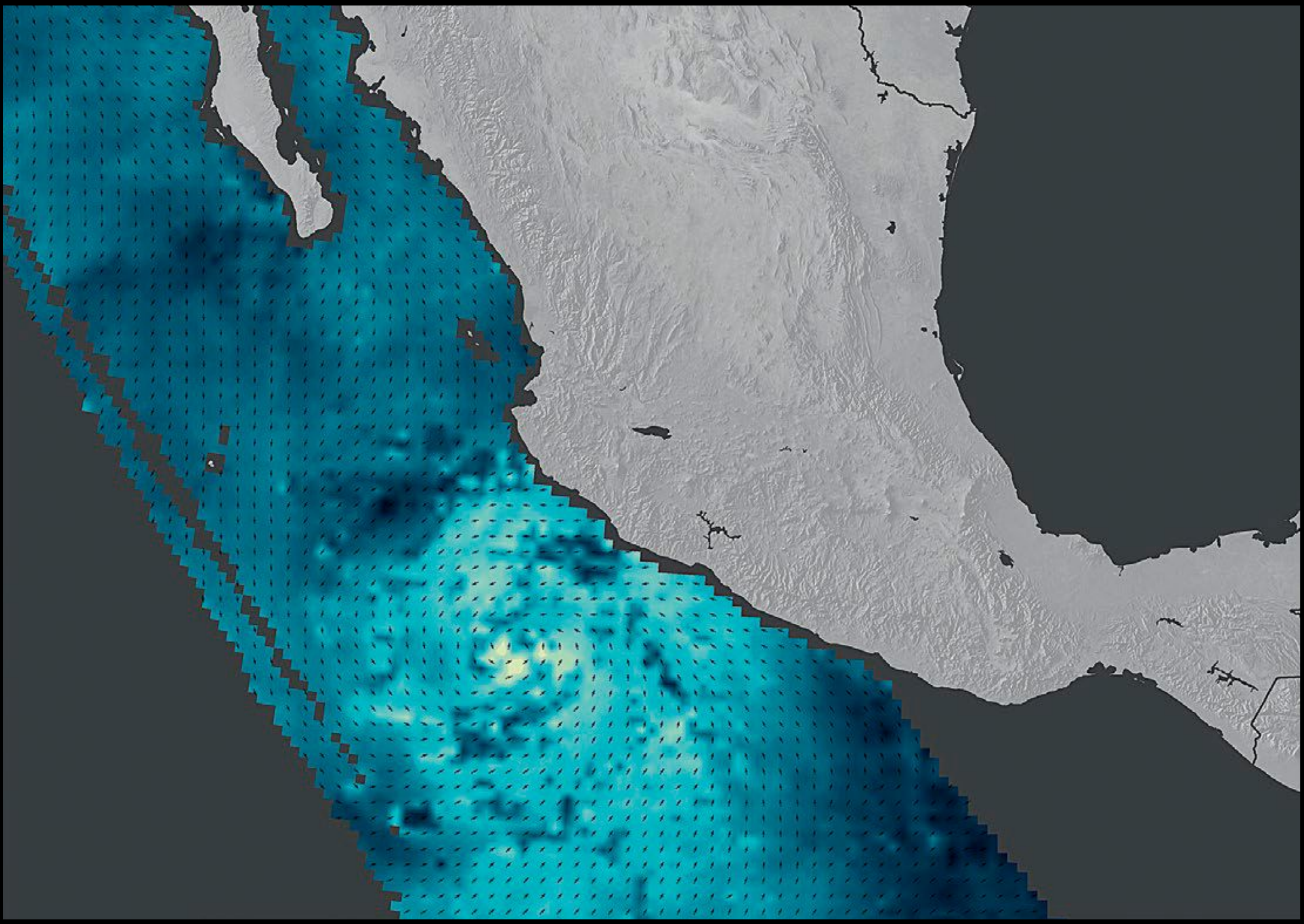
A hurricane's strength is far more unpredictable than its path.

Patricia displayed one of the fastest storm intensifications in history.

Early in the morning of 22nd October, her maximum sustained wind speed was 120 kilometres per hour. Twenty-four hours later, it was 320 kilometres per hour.

Shortly afterward, NASA's Suomi NPP satellite passed over the angry storm and captured this infrared image that represents the temperature of the tops of the clouds. The more powerful a storm, the higher the clouds climb and the colder their tops become. Patricia's cloud top temperatures had plummeted to -90°C, indicating a vast cloud structure that was likely to produce torrential rain.

CREDIT: NASA / UW / CIMSS / WILLIAM STRAKA III



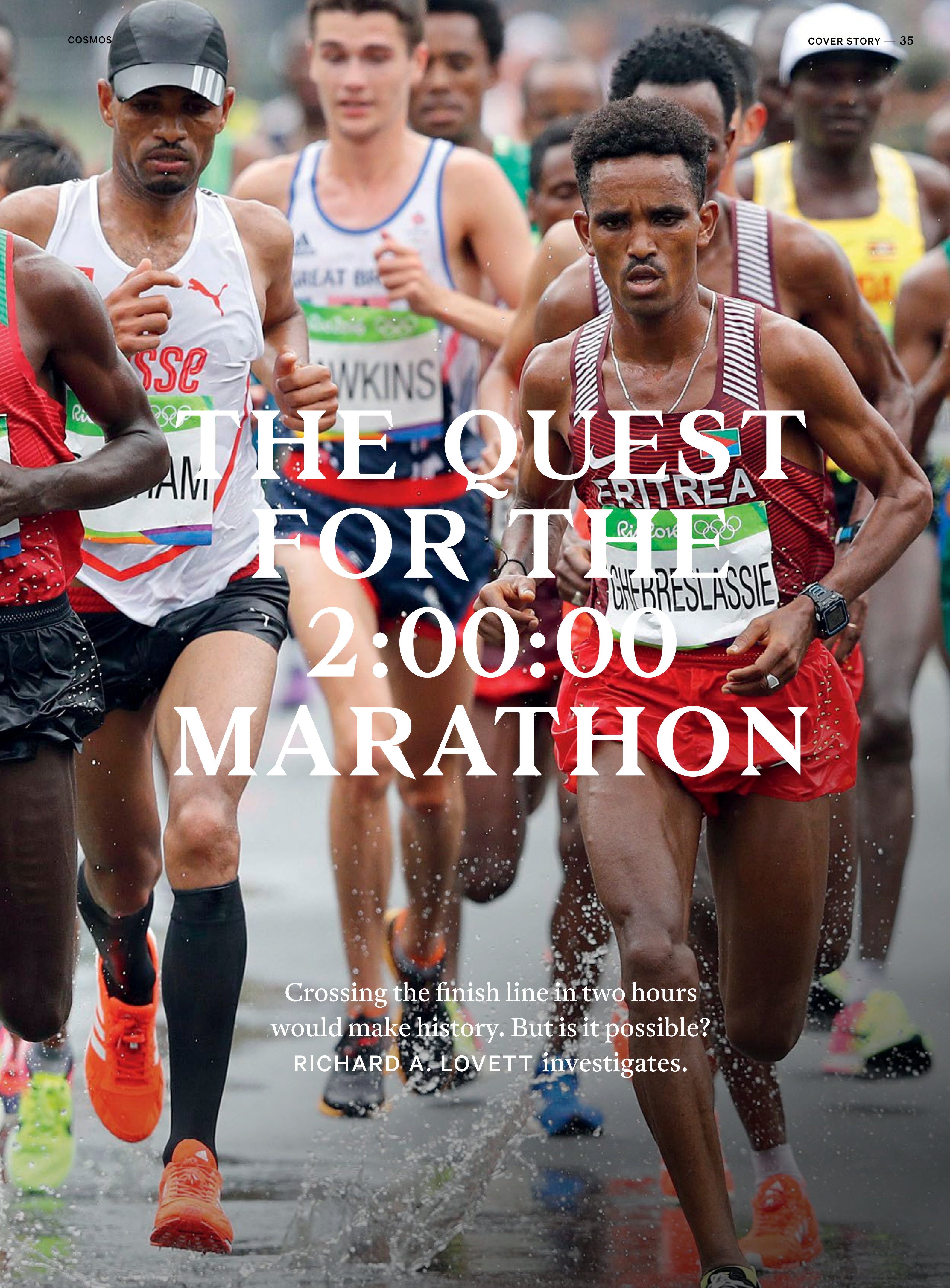
LANDFALL

Installed on the International Space Station in 2014, the ISS-RapidScat Instrument can see right through a storm. By bouncing microwaves off the ocean surface, it uses the echo strength to measure ocean surface roughness and calculate wind speed and direction. In this 23 October 2015 image (above; lighter colour represents faster winds), Patricia's surface wind speeds exceeded 110 kilometres per hour.

Less than 24 hours later, Patricia made landfall. Luckily, the hurricane weakened even faster than it had intensified, dropping to Category 3 status just before touching the shoreline. Even so, the damage was severe (right). But the long-range forecasting gave people time to get out of harm's way.

CREDIT: (LEFT) JOSHUA STEVENS, USING RAPIDSCAT DATA FROM THE JET PROPULSION LABORATORY; (RIGHT) MARIO VAZQUEZ / AFP / GETTY IMAGES

01
Runners compete in the men's marathon at the 2016 Olympic Games in Rio de Janeiro on August 21. Eliud Kipchoge of Kenya (middle) took the gold.



THE QUEST FOR THE 2:00:00 MARATHON

Crossing the finish line in two hours would make history. But is it possible? RICHARD A. LOVETT investigates.

IN 490 BCE, the legend goes, a courier named Pheidippides ran 40 kilometres from the Fields of Marathon to the city of Athens to deliver some very good news: the Athenian army had won a decisive victory over the invading Persians. "Victory," he gasped, before dying from exhaustion.

A SUCCESSION OF RUNNERS HAS PUSHED THE RECORD DOWN BY MORE THAN 55 MINUTES.

IT MAKES A GREAT STORY. But just how fast did Pheidippides run that day? More than 2,000 years later, in 1896, at the first Olympic marathon held in his honour, another Greek named Spyridon Louis covered the distance in 2:58:50. Though the official marathon distance was extended to 42.195 kilometres, a succession of runners has pushed the record down by more than 55 minutes. At the 2014 Berlin Marathon, Kenyan Dennis Kimetto clocked 2:02:57– a record that still holds.

Until recently, running that far that fast would have seemed fantastical—a sure prescription for suffering the same fate as Pheidippides. But today, people are seriously asking: is it possible for someone, someday, to cross the finish line in two hours?

As recently as 2012, Glenn Latimer, chief executive of World Marathon Majors, told *The Daily Mail* that a 2:00 marathon wouldn't occur in his lifetime, and "perhaps never". (Since then, however, the marathon record has dropped twice, by a total of 41 seconds.)

"I know without a doubt it's possible," counters America's fastest marathoner, Ryan Hall (2:04:58, Boston, 2011). "And while I can't say when it will happen I really believe I will see it in my lifetime."

"Sub-2:00 sounds far-fetched," adds another American, Ryan Vail, who holds a personal best of 2:10:57. "But I have been very surprised the last few years at how quickly the world record has dropped, so it would be crazy to rule it out."

Two-hour marathon hopefuls point out that a few decades ago, experts scoffed at the idea of a four-minute mile – and were proven wrong. When medical student Roger Bannister crossed the mile finish line in 3 minutes 59.4 seconds, 62 years ago, he immediately became the most famous distance runner in history. Incredibly, within weeks of Bannister's accomplishment, Australian John Landy clipped another 1.4 seconds off the mark, and since then the record has fallen all the way to 3:43.13.

No elite racer is openly talking about running a 2:00 marathon. Announcing such a goal would tip off rivals who may try to get there first, and it would be considered a bold move, bordering on arrogance. But surely there are secret dreamers who look at today's 2:02:57 world record and wonder what it would take to reach 2:00. Carving just 4.2 seconds off each kilometre would do it. It sounds like so little—that's about as much time as it takes to enter your PIN into a bank machine. But those 4.2 seconds mean the difference between being great and going down in history with Roger Bannister.

For the right type of dreamer, it's got to be an enormously tantalising vision. But what would it take to get there? And is the body even capable of such a punishing feat?

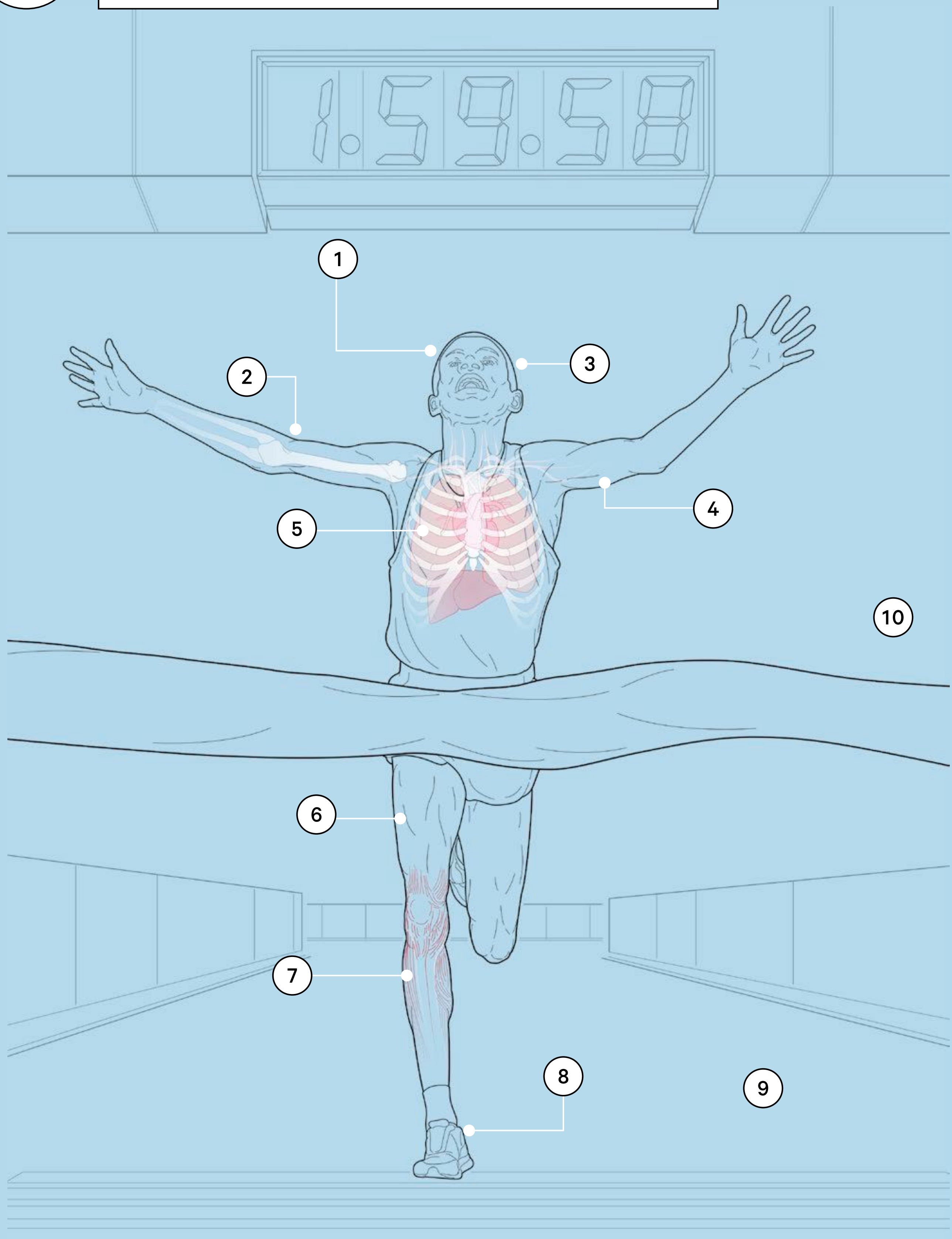
Most of the improvement on Spyridon Louis's 1896 mark came in the early years, as runners and coaches learned the basics of training and competing in a race that long. But twice in recent history, runners have lopped substantial chunks off the marathon record.

Ned Frederick, a biomechanics expert at Exeter Research Inc in Brentwood, NH, describes these people as marathoning "geniuses". The most recent was Australia's Derek Clayton (the first to run sub-2:10) who, in a pair of races in the late 1960s, chopped nearly 3.5 minutes off the world record. But the greatest of all may have been British runner Jim Peters. In a series of four races between 1952 and 1954, he lowered the record by a spectacular 8 minutes (from 2:25:39 to 2:17.39.4).

02
Roger Bannister, the first man to break the four-minute mile, leads Australia's John Landy to win the Mile event in 3 minutes 58.4 seconds at the 1954 British Empire Games in Vancouver.

A CLOSER LOOK

THE 2:00:00 MARATHON – WHAT IT WOULD TAKE



1 AGE —

Our secret dreamer is likely to be in his early 20s to mid 30s. Age-based performance data compiled by the World Master's Association suggests that the optimum age for male marathoners is 23-35 (though a 36-year-old would experience only a trivial, 7-second handicap). Dennis Kimetto was 30 when he set the current record. Australian Robert de Castella was 24 when he set the mark at 2:08:18, in 1981. The marathon is a race that rewards both talent and the discipline that comes with experience, allowing youngsters and seasoned veterans to contest on even footing over a fairly wide range of ages.

2 BUILD —

Marathoners tend to be lean and fine boned. A well-known rule of thumb is that each unneeded kilogram of body weight costs about two extra seconds per kilometre. Even upper-body strength, once thought to be an advantage for biomechanical efficiency in running form, may come at a cost in muscle strength. In the months leading up to the Rio Olympics, the US's top hopeful, Galen Rupp, reduced his upper-body strength training and cut muscle mass from his pecs, abs and biceps, according to John Brant, co-author of the 2013 autobiography of Rupp's coach, Alberto Salazar. Apparently it worked: Rupp won bronze in a strong field.

3 GENETICS —

Our secret dreamer is likely to come from a family of accomplished runners who not only inspired him, but also bequeathed him the perfect genetics.

The mother of America's top female finisher in the Rio Olympics, Shalane Flanagan, once held the women's world record in the marathon, and both parents represented the US in international cross-country competition. Family members tend to have similar body builds, but the shared heredity may also affect physiology. In 1992, scientists in the US and Canada put more than 600 sedentary people on training programs and discovered that there was a wide difference in how well they responded. Some made enormous leaps in fitness; others actually got less fit. This indicates that genes are important, especially those that enhance the body's ability to adapt with training.

4 MUSCLE COMPOSITION —

Human muscles contain two types of fibres, slow-twitch (Type I) and fast-twitch (Type II) – the names refer to how quickly they can contract. There are also two basic types of fast-twitch: Type IIA and Type IIB.

Fast-twitch fibres, especially Type IIB, are best suited for explosive activities such as springing and powerlifting. But they fatigue quickly. Slow-twitch fibres aren't as good for sprinting, but have much more endurance, while Type IIA fibres sit in the middle, with both speed and a higher degree of endurance than Type IIB.

Our secret dreamer's legs will need to be composed mostly of Type I fibres, probably augmented by a nice admixture of Type IIA. To a large extent, this will be another hereditary factor, like his build and the ability of his body to adapt to training, but he will want to do the right things in training to develop the fibres he has, and avoid bulking up on useless Type IIB fibres. Luckily, the training that does this is the same training he needs for building his aerobic system.

5 VO2 MAX —

VO2max is a measure of the amount of oxygen your body can process at peak effort: a gauge of the power of your aerobic engine, with all the parts – heart, lungs, capillaries, and muscles – working at their best. A 3:20 marathoner – the type who might see significant success in local races – might have a VO2max of 45 to 50. (Units are mL of oxygen/min/kg of body mass.) Elite marathoners tend to have values in the 80s, and our special dreamer would definitely want to be in that range.

Many people equate aerobic power with having a strong cardiovascular system. And that's definitely part of it. A sedentary person's heart might be able to pump two litres of blood per minute, but an elite's can pump 40 litres per minute, says John Halliwill, an exercise physiologist at the University of Oregon. But high VO2max also requires large numbers of capillaries supplying blood to the muscles, plus muscle cells well stocked with mitochondria – the subcellular powerhouses that turn fuel and oxygen into energy.

To a large extent, our secret dreamer's VO2max will be determined by his heredity; if his parents gave him the wrong genes, he has little chance of developing an elite VO2max, no matter how determined he is. Even with the right genes, he'll reach a point where he will have elevated his VO2max as far as his genes allow. In a 2005 study in the *Journal of Sports Medicine and Physical Fitness*, a team led by Alejandro Legaz Arrese of the University of Saragossa, Spain, tracked 33 elite Spanish runners through four years of intense training. At the end, the runners' VO2maxes were essentially unchanged. "In a nutshell," Halliwill says, "VO2max reaches a plateau." Training is still needed to keep from backsliding, "but further gains in speed have to come from somewhere else".

6 RUNNING ECONOMY —

That "somewhere else" begins with efficiency. However high our elite dreamer's VOmax might be, it's not going to do him much good if he hits aerobic max at a pace others would see as a brisk jog. It would be like driving a racecar in sand. His engine might be able to blow an enormous amount of energy, but he won't set any speed records.

Part of the solution involves detailed attention to running form. Bouncing, overstriding, leaning too far forward, or leaning too far back can all squander energy.

Our dreamer must also have strong legs, because strong muscles more effectively function as springs that store and release energy with each stride. In a 2015 analysis in the *Journal of Strength and Conditioning Research*, a team led by Carlos Balsalobre-Fernández of the University of Madrid found that a mix of weight lifting, bounding exercises, and short sprints improved running economy by 2-3% in serious but not world-class athletes.

7 BLOOD LACTATE —

Lactate is a molecule produced from the initial steps of the muscles' breakdown of glucose for energy. It makes up about half a glucose molecule, says John Halliwill, an exercise physiologist at the University of Oregon. Runners have long blamed its buildup in the blood for the onset of fatigue, but that's incorrect. Research by George Brooks, an exercise physiologist at the University of California, Berkeley, has found that the body uses the blood to ship lactate – which can be thought of as a lower octane fuel than glucose – to lesser-working areas that can easily use it, such as the heart, brain, liver and arm muscles, sparing high-octane glucose for the legs.

Italian coach Renato Canova, who has trained some of the world's best Kenyans, is notorious for following runners around on training runs and drawing blood, just to check lactate. Nike coach Alberto Salazar, who in 1981 ran the world's then-fastest marathon at 2:08:13, remembers having his lactate levels taken so many times via finger-prick tests that he complained of running out of unpricked fingers. Our secret dreamer may or may not subject himself to this many blood tests, but he and his coach will know that when it comes to marathon training, "lactate" is the name of the game.

8 SHOES —

There is a well-known relationship between shoe weight and running economy: each 100 grams of unneeded weight removed from the shoes means a 1% improvement in efficiency.

Modern shoes are already light, but it may be possible to shave off another 50 grams, says Ned Frederick, a biomechanics expert at Exeter Research Inc. in Brentwood, NH – enough to give our secret dreamer a "free" 30 seconds.

Historically, runners have simply tried out different types of shoes until they found what they liked, but Kramm thinks it's possible to use treadmill tests to match runners to their perfect shoes. It might also be possible to match the shoe to the course, perhaps by designing shoes that change cushioning and flexibility as the runner tires. "Individually tuned shoes won't trump talent and training, but could easily add up to the necessary seconds," Frederick says.

If our secret dreamer is thinking of dumping his shoes entirely, as some runners have, he may want to reconsider. In a 2012 study in *Medicine & Science in Sports & Exercise*, Jason Franz and Roger Kramm of the Locomotion Laboratory at the University of Colorado put experienced barefoot runners on a treadmill and discovered that however fond of barefoot running they might be, their oxygen consumption was 3-4% less efficient barefoot than shod.

9 THE COURSE —

Currently the fastest courses on the planet are those used for the Berlin, London, and Chicago marathons, but ideally our runner's marathon would be run on a track. The 10,000-metre record on the track is 26:17.53, versus 26:44 for roads, due in part to the track's perfect, ideally cushioned surface. A comparable effect in a marathon would be nearly two minutes – almost two-thirds of what our secret dreamer needs.

The 1968 Mexico City Olympics, run at an elevation of 2,200 metres above sea level, showed that high elevation slows down distance runners, by about 1% per 300 metres of elevation. If the reverse effect applies below sea level, a race held at the Dead Sea (-420 metres) might give a whopping 90 second advantage. If someone were to build a track there, our secret dreamer would be very much in business.

10 RACE DAY —

However well trained our secret dreamer is, he'll need good weather to make his big mark on race day: no wind and not too hot. In fact, he'll want temperatures most people would view as downright chilly.

Recreational runners are often told that the ideal temperature for a race is between 10°C and 13°C, but a 2007 study in *Medicine & Science in Sports & Exercise*, led by Matthew Ely, then a scientist at the US Army Research Institute of Environmental Medicine in Massachusetts, found that even at temperatures of 10°C-15°C there was a 1-2 minute drop in performance.

One thing our secret dreamer likely will not see on race day is a pacer. Marathon world-record attempts are generally assisted by runners in whose slipstreams the anointed stars glide for as much as 30 or more kilometres into the race. But who is going to pace an attempt at a sub-2:00 marathon? asks American marathoner Ryan Vail. "Those guys would be the very ones attempting the world record," he says.

It's possible he could have done even better: in the 1954 Commonwealth Games, he entered the stadium on pace for a 2:07 finish, but repeatedly collapsed in the final 400 metres and failed to finish. (He was later hospitalised, unconscious.) Had he been a little less aggressive, could he have beaten the times set by Clayton the following decade? He'll never know. The Commonwealth Games were his last race. "I was lucky not to have died that day," he later said.

03

Britain's Jim Peters struggles toward the finish line at the 1954 Commonwealth Games.

Since then no other such breakthrough racers have surfaced, but the record has continued to fall. Since 2000, it has dropped seven times, totalling 2 minutes and 45 seconds. If that rate of progress continues, a 2:00 marathon could happen sometime in the 2030s.

Who might that super marathoner of the near future be? Since long-distance runners tend to peak in their late 20s or early 30s, our secret dreamer could be a teenager today. But he could also be older, maybe already making his mark on the road-racing scene. Some observers think a crescendo of interest – fed by a rise in sponsorship money, prize-money incentives and ever-more sophisticated training methods – could produce a sub-2:00 marathon much sooner.

Yannis Pitsiladis, a professor of sports and exercise science at the University of Brighton, England, is one of the believers. Pitsiladis, the lead contact for the Sub2 Project (sub2hrs.com), has said he thinks an investment of $30 million in technology and incentive prizes could make it happen. His project's website proclaims that it's "no longer a matter of if but when".

Geoffroy Berthelot, a specialist in informatics and algorithmics at the National Institute of Sport, Expertise, and Performance in Paris, France, thinks that "when" may arrive sooner than expected. "Who knows if a 'Usain Bolt' marathoner might not come along next year?" he says, referring to the Jamaican sprinter who won three gold medals in the 2016 summer Olympics in Rio de Janeiro, Brazil.

Our secret dreamer knows that getting to 2:00 will take a rare combination of talent, toughness, perseverance and training. In the marathon, much of that training centres on improving three physiological variables: VO2max, lactate threshold, and running economy. (See infographic on pages 46-48.) If the highest known values of all three of these were ever combined in a single person, that person should be able to break two hours – with several minutes to spare, says Michael Joyner, MD, an exercise researcher at the Mayo Clinic, Minnesota, who examined the question in a 2010 paper in the *Journal of Applied Physiology* and in subsequent unpublished research.

But hitting the mark will also be, to some degree, a matter of luck. It will require "everything going perfectly – weather, pacing, preparation, etc," says Dathan Ritzenhein, the US's third-fastest all time marathoner (2:07:47, Chicago, 2012). "It's very hard to put all the pieces together, but I do think it will happen."

IF THE CURRENT RATE OF PROGRESS CONTINUES, A 2:00 MARATHON COULD HAPPEN SOMETIME IN THE 2030s.

RICHARD A. LOVETT is a Portland, Oregon-based science writer and science fiction author.

IMAGES
01 Adrian Dennis / AFP / Getty Image
02 Popperfoto / Getty Images
03 Allsport Hulton / Archive / Getty Images

ILLUSTRATIONS
Anthony Calvert

INVASION OF THE TOADS

As Asian toads infiltrate Madagascar, the island nation hopes to learn from Australia's cane toad defense.
By EDWARD CARVER.

→
TOXIC AND INVASIVE, the Asian toad is a recent arrival to Madagascar. It poses a grave threst to the country's unique native species.

01

IN EARLY 2014, biologist Jonathan Kolby was working with a group of amphibian researchers in Madagascar when they received a surprising email from a man living outside of Toamasina, the country's major port city. He'd attached a picture of a brown toad never before seen on the tropical island nation known for its rich biodiversity.

INTRIGUED, THE RESEARCHERS found the man's house, just next to a nickel refinery, but they didn't expect to find the toad. The man assured them that wouldn't be a problem. "Wait 10 minutes," he said.

Shortly afterward, as dusk fell, they stepped outside and immediately saw half a dozen Asian toads. "Big, fat breeding-size adults," recalls Kolby, a PhD candidate who studies amphibian diseases at Queensland's James Cook University. "We were like, 'Shit, this is bad'."

Two years on, that's still the scientific consensus. This bumpy, toxic toad from Southeast Asia, *Duttaphrynus melanostictus*, is disrupting Madagascar's fragile ecosystems, imperilling its unique wildlife and threatening its people. The poison in the toad's skin can kill animals and even children. If it continues to spread, the toad could spell serious trouble for some of the island's most iconic species of lemur and fossa (the lemur's predator, which looks like a small puma), animals already threatened by habitat loss.

Now a group of herpetologists and invasive species experts is pushing to eradicate the rapidly reproducing toads before it's too late. With some four million toads to kill, it would be one of the largest attempts ever made at stomping out an invasive amphibian. The campaign would likely cost anywhere from US$2 million to US$10 million, money the scientists don't have. They've asked for help from a mining company whose shipping containers may have provided the pathway for the invasion, but the company – while generally co-operative, and helpful in first identifying the toad as a problem – has declined so far, citing a lack of hard evidence that it was at fault and choosing to defer to the government on a direction forward.

Even if the scientists raise the funds, there's no guarantee the eradication campaign will work. But experts say failing to take action would have even greater costs.

"I cannot imagine how decision-makers in Madagascar could sleep at night if they simply said, 'Sorry, it's going to cost too much to deal with this. The cat's out of the bag already'," says Pete Lowry, a biologist at the Missouri Botanical Garden and a board member of Madagascar Fauna and Flora Group, which is helping to co-ordinate the eradication effort.

"The potential consequences are devastating," he says. "Madagascar is one of the hottest biodiversity hot-spots." About 70% of the island's roughly 250,000 plant and animal species live nowhere else on Earth.

Earlier this year, the group released a feasibility report that makes the stakes clear. "Eradication is the only option that has a definitive end point," the report explains. "All other responses would need to be carried out in perpetuity."

The threat has special resonance because of what happened 9,000 km away in Australia, starting in 1935 when 100 cane toads were imported from Hawaii by sugar farmers hoping to control beetles that were destroying their crops. The toads ran amok, spreading across much of the continent and causing severe reductions in the populations of some predators who died after eating them. In many habitats, cane toads have contributed to the decline of lizards such as the goanna, and marsupials such as the quoll, which are top-of-the-food-chain predators that keep ecosystems functioning. Eight decades on, Australians are still working to contain the toads. Scientists are developing fences that keep the toads away from breeding grounds and chemicals that trap the tadpoles. Backpackers touring Australia can even earn visa points helping to fight the toads' spread.

The Asian toads could turn out to be just as destructive as the cane toads have been in Australia, according to James Reardon, a zoologist with New Zealand's Department of Conservation and co-author of the report. "I absolutely know that if we could go back to a time when cane toads were limited to a small area in Australia – as Asian toads currently are in Madagascar – that we would throw everything at an eradication attempt," he says.

In Madagascar, the matter is urgent because scientists expect the toads to spread quickly. Currently they occupy about 120 km² near the Pangalanes Canal, a perfect conduit for amphibians that runs down the tropical east coast of the island.

Lemur expert Patricia Wright of Stony Brook University worries the toads will travel down the canal to the city of Mananjary and then move inland to Ranomafana National Park, a biodiversity haven she has worked to protect for more than three decades. The toads may already have arrived on a narrow strip of water leading into the canal, the scientists worry. Letting the toads reach the main body of the canal is "like building them a highway to the rest of the country", says Christopher Raxworthy, a herpetologist at the American Museum of Natural History.

Since the island has no other toads, its predators and prey are particularly vulnerable to the unfamiliar invader, the report warns. The tenrec, a hedgehog-like creature found mainly in Madagascar, is one of many animals that could eat the toad and die from the toxins. The voracious Asian toads are also likely to prey on the hundreds of colourful frogs and other amphibian species on the island – 99% of which are found nowhere else – and they could eat leaf chameleons or hatchlings from any species, says Raxworthy.

The threat is just as real to people. Children in Laos have gotten sick and, in at least one case, died from consuming the Asian toad, and the risk to Malagasy people, less familiar with the toads, may be even greater. The report also says that snakes are dying after eating the toads; a decline in snake populations could cause black rat numbers to surge, and more rats could mean more sanitation issues in a country that already battles the plague.

Scientists have three important reasons to hope that an environmentally friendly eradication is possible. First, the infested area contains no rare or native species that could be harmed during the attempted eradication. Second, male toads convene around bodies of water at night, calling females, so there's a convenient place to capture or kill them. Finally, recent testing reveals that spraying a citric acid solution – with a concentration similar to lemon juice, according to Raxworthy – kills toads through rapid dehydration without doing serious harm to other animals.

As a next step, members of the working group hope to do a "mini-eradication" along the southern edge of the incursion zone, in order to restrict the toad's expansion into the canal and further refine killing methods. But even this small effort would cost about US$400,000, and the scientists are still looking for the funding.

"We're essentially operating on a shoestring budget," Reardon says. "It's been a sort of ragtag collection of donations from the international conservation community."

This raises the question: who should pay to handle invasive species such as the Asian toad in Madagascar?

02

Researchers gather intelligence on the age and gender of Asian toads to aid eradication efforts.

THIS BUMPY, TOXIC TOAD IS DISRUPTING FRAGILE ECOSYSTEMS, IMPERILLING WILDLIFE AND THREATENING PEOPLE'S HEALTH.

To invoke corporate responsibility, scientists like to refer to the transport of invasive species as "biological pollution". A seminal 1998 study led by David Wilcove, now an ecologist at Princeton, cites invasive species as the second leading cause of extinction in the US after habitat loss.

James Carlton, a marine biologist at Williams College in Massachusetts, has proposed that a "polluter pays" model be adopted for invasive species control. Petroleum companies have used such a system since the Exxon Valdez disaster:

NICKEL AND COBALT COMPANY AMBATOVY MAY HAVE ACCIDENTALLY TRANSPORTED THE TOAD TO MADAGASCAR

when their tankers take to the water or their pipelines begin pumping crude, they pay a few cents per barrel into a fund for future cleanups. But right now, companies at risk of shipping and transporting invasive species pay no such fee, so there is no fund for control or eradication.

Calling the current system "ecological roulette" because of the lack of regulation, Carlton writes, "Industries that play a fundamental role as vectors transporting non-native species should bear more of the costs of prevention, control, and research."

In the absence of such a comprehensive system for dealing with invasive species, experts are left to sort out responsibility on a case-by-case basis – a difficult task. Scientists in the working group suggest that nickel and cobalt company Ambatovy may have accidentally transported the toad to Madagascar in a shipping container. The company was bringing equipment and supplies into the incursion zone to construct a large refinery about the same time the working group believes the first toads arrived.

Sherritt International, the Canadian mining corporation that owns 40% of Ambatovy and operates the plant, says that 170,000 containers pass through the port in Toamasina every year, many from Asia, and less than 5% are for its business. "In terms of identifying a specific container or a specific entry point, it's incredibly difficult to do that," company spokesman Scott Tabachnick says.

However, Reardon, the New Zealand zoologist, says statistics from the port are not relevant because the toads were not released at the port – in fact, they still haven't reached it. (But, as with the canal, he worries the toads will soon reach the port, a domestic and international shipping hub, and hop into another container.)

"We've got no hard proof, but it's highly likely the toads are in Madagascar because of Ambatovy's activities," Reardon says. The company has a direct rail link from the port to its plant, where containers are unloaded.

But it's impossible to know for sure how the toads arrived, especially since there are two other importers of goods in the area: Malgapro, a general import/export business based in the core of the incursion zone, and SolCiment Callidu, a company located on the periphery.

"From the point of view of managing Madagascar's biodiversity and managing this crisis, it doesn't make any difference who introduced the toad," says Pete Lowry, who also has an unpaid position on Ambatovy's scientific advisory panel. "The point is not to look back and say who's guilty. Time that gets spent doing that is time taken away from acting on this critical issue."

No matter how the toad problem arose, Lowry hopes Ambatovy will be part of the solution. "There's a ticking clock," he says. "Everybody who has something to contribute needs to step up to the plate and get started – now."

After a December meeting, Lowry's advisory panel – a group of scientists separate from the one that completed the feasibility report – recommended the company "take the lead" on toad eradication efforts, acknowledged Ambatovy spokesperson Vony Ramahaleo in an email. But the company points out that it already sits on the committee set up to deal with the invasion, along with government ministries and conservation organisations. "As the government of Madagascar has appointed a committee to lead this fight, we cannot substitute for them," writes Ramahaleo.

Without major donations, eradication efforts are on hold. But local people are still eager to get rid of the toads, which they call *radaka boka* ("leprous" or "scaly" frogs) or *radaka Dynatec* (which translates roughly to "frogs from Ambatovy's refinery"). Mikahely, a side project of the popular Malagasy music group Mika & Davis, recently released a song, *Radaka Boka*, about the invasion. Even the country's three telecom companies have teamed up to help; they've started a free text message system so people can report toad locations.

Still, Kolby regrets that more has not been done in the two years since he first spotted the toad. "Right now it's still worth going forward with eradication," Kolby says. "At some point it will become infeasible. The longer it's delayed, the less likely it is to succeed. Without a doubt, we're running out of time."

EDWARD CARVER is an environmental reporter who spent four years in Madagascar working on development and conservation projects.

CREDIT
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IMAGES
01 James Reardon
02 James Reardon

LESSON FROM AUSTRALIA: KNOW YOUR ENEMY

FOR 80 YEARS, Australia has waged a war on cane toads. Now it's winning some minor victories that may help Madagascar defend against its own amphibian invader.

It began innocently enough: In 1935, Australian officials brought in a hundred South American cane toads to control Queensland's sugar cane beetles. But this "solution" quickly became the problem. The toads multiplied and marched westward to colonize new tropical habitats, covering 45 kilometres per year. By the time officials realized there was a problem, it was too late. Australia had invited in an enemy, and nothing could conquer it: not trapping, poisoning or a burgeoning market for toad leather. Many of Australia's unique native species suffered, mostly large ones with catholic appetites. The largest and fastest-moving toads broke new territory in the richly biodiverse wetlands of Kakadu National Park. Toads grow disproportionately more poisonous as they get bigger. Predators big enough to eat them, like goannas and quolls, had no chance to get an education. They dined and died.

The good news is that while their numbers plummeted -- the goanna population dropped by more than 90%, for example -- these species did not go extinct. Following the initial incursion, toads bred and toadlets appeared – distasteful to predators but not deadly. As predators have grown wiser, numbers have started to recover.

That's just one of the surprises revealed in the Australian invasion. "It underlines the first rule of warfare: know your enemy", says evolutionary biologist Rick Shine at Sydney University.

Two successful control strategies have emerged from that knowledge.

It turns out that cane toads gravitate to disturbed environments – farmers' ponds rather than natural waterholes. A female lays a clutch of up to 40,000 eggs, creating an instant crowd. So cane toads are their own biggest competitors. Shine's lab discovered that tadpoles dine on newly-laid egg sacs. Poisons seep out of the sac, repelling every other type of tadpole, but attracting cane tadpoles who are resistant to its effects.

The discovery is the basis of a safe new eradication strategy. Traps laden with the poison are placed in dams, attracting and snaring tens of thousands of tadpoles. By developing a commercial product readily available in local shops, Shine hopes to see a large impact on toad numbers.

Melbourne University biologist Ben Phillips has made use of the toads' natural dependence on seasons to plan his strategy. The next area under threat is the Pilbara, an arid region of immense biodiversity on Australia's northwest fringe. To reach it, the toads must use farmers' stock dams as their highway, their only chance of survival in the dry season. That's when Phillips' campaign to make the dams toad-proof will roll out.

The South American cane toad was a solution that became the problem.

CREDIT: EDELMAR / GETTY IMAGES

Will any of this war history be useful for fighting Madagascar's Asian toad invasion?

At last count, there were four million Asian toads spread over 100 square kilometres. Compared to Australia's 1500 kilometre sprawl, it sounds containable.

But in Madagascar, it's a different toad and a different ecosystem. What works in one place may not work in another. "You can't cut and paste", says Phillips.

One thing the Australian scientists are sure about is that more research must be done, and quickly. They've discovered that every generation of invading cane toads gets faster and faster: the individuals at the leading edge of the invasion are the speediest, and they tend to breed with each other.

Madagascar had better get moving.

— ELIZABETH FINKEL

FRACKING'S STRANGE ORIGINS

The recent energy boom owes much to a 60-year-old discovery by an American geologist named M. King Hubbert. MASON INMAN reports.

→

FRACKING RIGS like this one at a Statoil site near Williston, North Dakota, allow more oil to be pulled from the ground.

01

In the 1950s, geologist M. King Hubbert, known as "the father of peak oil", warned that crude oil production would eventually peak and then decline. But ironically, he also figured out the mechanics of a technique that would one day expand the life of global oil reserves: hydraulic fracturing. "Fracking," as it's often called, spurred an energy boom in the US and is increasingly used in Australia to tap coal seam gas, but its environmental costs have prompted local officials in both countries to ban the practice. In this excerpt from *The Oracle of Oil: A Maverick Geologist's Quest for a Sustainable Future*, author Mason Inman recounts Hubbert's discovery.

AT A 1954 CONFERENCE, two US oil companies – Stanolind on one side, Atlantic Refining on the other – got into a fierce debate about the physics behind hydraulic fracturing. This relatively new method involved pumping fluid into a well until it opened fractures in the rock surrounding the well, yielding more oil. The two sides "got a dogfight going that lasted nearly all afternoon", Hubbert recalled, laughing. Neither side's explanation made sense to him. Nonetheless he stayed "on the sidelines just kind of enjoying the show".

Stanolind had introduced the new technique in 1948, under the name "the hydrafrac process" – soon shortened to simply "fracking". The technique had been an immediate hit. In its first several years, it was applied more than 30,000 times, helping extract more oil, especially from older wells.

However, even after its use had become widespread, no one knew exactly how hydraulic fracturing worked. Since it was put to use at the bottom of wells, thousands of feet underground, there was no easy way to see the results of the technique. Why did the rock fracture at a particular pressure? And why did the required pressure vary so much from well to well and place to place? No one was sure.

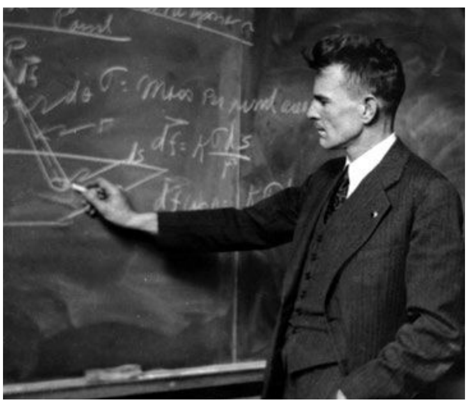
The debate Hubbert observed at the 1954 conference was over a seemingly esoteric point, but it was central to understanding how the fracking process worked. Stanolind argued the fractures were horizontal, like pancakes. Atlantic said the fractures were vertical, along the length of the well, like the fins on a rocket. Each company had its own reasoning – and Hubbert thought they were both wrong.

Soon after that contentious conference, Shell gave Hubbert a new assignment: figure out how fracking worked.

HUBBERT HAD FIRST encountered hydraulic fracturing in 1946 – although rather than trying to put it to use, it was a problem Shell wanted to avoid. The company's engineers had come to Hubbert to see if he could solve a mystery that had arisen as they drilled offshore in the Gulf of Mexico. As with almost every oil well, these engineers were using a concoction called drilling mud – a slurry of clay and other minerals. They pumped it down the hole, where it flowed around the drill bit, cooling it, and also clearing out chips of rock from the bottom of the hole. The mud served an additional, particularly crucial, purpose. As it flowed back up the hole, the mud put pressure on the walls of the well, holding back oil and gas under high pressure, which otherwise might unexpectedly blow out. In decades past, such gushers – the iconic black fountains erupting from oil derricks – had been a cause for celebration. But they were wasteful and dangerous, and so had been mostly tamed through careful use of drilling mud.

The Shell engineers told Hubbert how, in drilling along the Gulf Coast, they'd gone down some 6,000 feet using very light, watery mud without encountering any problems. But in a span of one or two hundred feet, they'd encountered a zone with much higher pressure that required heavier mud to supply enough pressure to hold back the fluids in the rock. They'd worried that if they waited too long to use heavy mud, they'd risk a blowout. Yet when they put in the heavy mud too early, they suffered another problem, known as "lost circulation", in which the drilling mud simply disappeared down the hole. This lost circulation was a major problem for drilling in this area, slowing down the process and driving up costs. Some wells suffered lost circulation so chronically that they were abandoned before they struck oil. Not sure of the dynamics underground, the Shell engineers couldn't determine how to prevent lost circulation.

02



Geologist M. King Hubbert figured out the complex physics behind hyrdaulic fracturing.

Hubbert's first thought was that they must have hit a limestone layer that had cavernous holes in it. But the engineers told him there was no limestone in that area. Then they explained there was another aspect to the mystery. When they sent down mud at high pressure, the mud disappeared. But when they eased off the pressure, the circulation returned. The engineers and Hubbert agreed that the pressure from the heavy mud must be opening up fractures surrounding the well.

However, the pressure wasn't enough to lift the overburden – the weight of all the rock pressing down from above – and that puzzled the engineers. Hubbert realised the engineers were imagining the fractures as pancake-like horizontal openings in the rock – and for such cracks to open, they'd have to lift the weight of all the rock above. Hubbert told them it was far more likely that the fractures were vertical, so to open up they'd only have to push neighbouring rock sideways, which would usually require much less force. It was like the difference between trying to lift the heavy door of a bank vault off its hinges, compared with simply swinging the door open.

Hubbert had solved the problem. His explanation of the underlying physics allowed the engineers to adjust their drilling mud to avoid lost circulation and drill more efficiently.

MEANWHILE, STANOLIND had also discovered hydraulic fracturing and devised a method for putting it to use. At first it had been experimental, using a fluid that was cheap to buy. "Due to availability and price, war-surplus napalm has been used in the majority of experiments to date," Stanolind reported in 1948. They mixed sand into the napalm – also known as "jellied gasoline" – which carried the sand along with it, enabling the sand to lodge deep within the newly opened fractures. Then they pumped down another fluid that dissolved the jelly, and much of the napalm flowed back to the surface. But the grains of sand remained stuck in the fractures, propping them open, allowing oil and gas to escape from the rock.

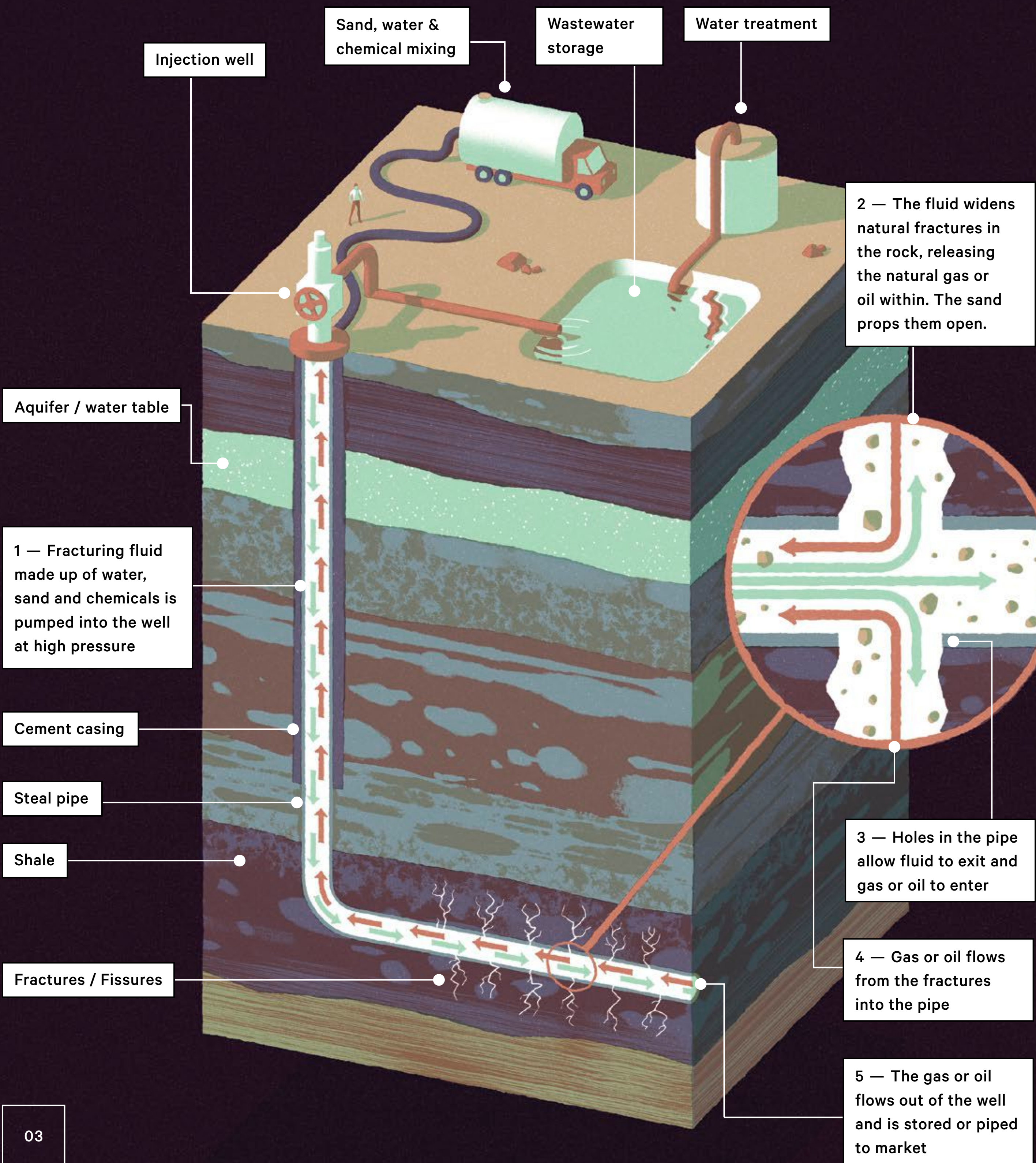
The technique quickly caught on, and companies advertised their fracturing services and equipment in industry magazines such as *Oil & Gas Journal* and *World Oil*, commonly showing drawings of horizontal, pancake-like fractures. Stanolind had based this on evidence drawn from a few shallow test wells and had assumed that all fractures, even those deep down, would likewise be horizontal. This explanation was "accepted almost universally, with rarely a dissenting voice", as Hubbert saw it. But to him, that explanation made no sense. They'd got the physics wrong. In 1953 he had published a short commentary in the journal *Petroleum Transactions*, arguing that Stanolind's explanation was mistaken and the fractures were likely vertical. At the 1954 conference where the "dogfight" broke out over fracking, both sides had explanations that differed from Hubbert's. Although the technique was in widespread use, there was still disagreement over how it worked, and its application remained hit or miss. There was clear room for improvement.

By the time Shell tasked Hubbert with

HUBBERT'S EXPLANATION OF THE UNDERLYING PHYSICS ALLOWED ENGINEERS TO DRILL MORE EFFICIENTLY.

A CLOSER LOOK

HOW FRACKING WORKS



explaining how fracking worked, "we had the records of several thousand fracturing jobs, with varying degrees of reliability in their data", he recalled. "We had to smoke out useful information."

Hubbert had recently hired a new assistant, David Willis, who had just completed his doctorate in geology at Stanford. In the fall of 1954, Hubbert and Willis developed a theory that described the forces at work when fluid was pumped into a well at high pressures. They worked on this intensively for a few months, writing up the results for a high-level conference to be held the following summer at Royal Dutch Shell's lab in Amsterdam. Hubbert and Willis found that in some special conditions – in shallow wells, or along faults under sideways stress, like California's San Andreas Fault – the fractures would lie horizontal. But their analysis suggested that in most cases the fractures would be vertical, along the well's shaft.

When Hubbert presented the results at the Amsterdam conference, "it was very well received by the highest level technical people," he recalled, "accepted completely, with no significant criticism". After this vote of confidence, Shell organised training sessions on the new analysis for its field engineers. When it came time for the first course, Willis was away so Hubbert gave it himself. "What I discovered was that the theoretical argument was having no effect whatever on these men," Hubbert recalled. The engineers were absolutely sure that the fractures were horizontal. Every article, every ad on fracking showed fractures oriented that way. They had been "completely brainwashed", Hubbert thought. "They didn't have any real evidence, but they'd been so thoroughly indoctrinated on this thing that they knew damned well these fractures were horizontal." It mattered, because if they didn't understand the forces at work, they couldn't control it precisely. The technique would remain more art than science.

When Willis returned to Houston, Hubbert told him the presentation had been a flop. Willis didn't say much at the time. But a few days later, on a Monday morning, Willis appeared in the doorway to Hubbert's office, looking anxious. He wanted Hubbert to come to the lab to see something. Swamped with backlogged paperwork, Hubbert told Willis it would have to wait. Willis left, then came back half an hour later, getting more and more fidgety. He'd been working on something over the weekend, he said, and Hubbert should come and see it. Hubbert relented and trudged over to the lab.

In Shell's Bellaire lab, one of the nation's best-funded research facilities, sat the contraption Willis had assembled at home over the weekend. It was a goldfish bowl, filled with liquid Knox gelatin and some plaster in it. Willis had used the gelatin to simulate rock – appropriate, given Hubbert's work on laws of scaling – and had stuck an Alka-Seltzer bottle in the middle of it to mimic a well. He'd put the liquid gelatin in the fridge and let it set, then pulled out the bottle. Then he'd used a baster to pump a slurry of plaster of Paris down the hole, filling it until the plaster began to push its way into the gelatin, forming fractures. As their theory predicted, the fractures were vertical.

Although Willis's setup was kludged together, Hubbert immediately realised it was what they needed to win over the field engineers: a clear demonstration. They'd have an opportunity to make their case at an internal Shell conference in early 1956, in several weeks' time. They got to work on building a larger version of the model. To replace Willis's goldfish bowl, Hubbert scoped out bigger aquariums on sale at local shops.

At the Shell conference, Hubbert and Willis explained their experiment and showed the plaster casts, first from one angle, with the fractures flaring out from either side of the well. Then they rotated the cast, so the audience could see that the fractures were thin and sharp, like a knife's blade. And of course, they were undoubtedly vertical.

Within a week of this demonstration, field engineers began sending in data they'd collected after fracturing wells. Some of them had put rubber plugs down wells to form an impression of the wall. Others sent cameras down the hole. This field data showed the fractures were indeed vertical. The theory was right – and finally the engineers believed it. Willis's contraption "had a magical effect", as Hubbert put it. "It made Christians out of these people."

AS THEIR THEORY PREDICTED, THE FRACTURES WERE VERTICAL.

MASON INMAN is an award-winning US journalist.

CREDIT
Excerpted from *The Oracle of Oil: A Maverick Geologist's Quest for a Sustainable Future* by Mason Inman with permission of the publisher, W. W. Norton & Company.

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WHALE SHARK WARRIOR

Brad Norman recruits everyone from astronomers to schoolchildren in his quest to unveil the secrets of whale sharks — and hopefully protect them. ELIZABETH FINKEL reports.

→

BRAD NORMAN keeps an eye out for whale sharks in Ningaloo Marine park, Australia.

01

AT NINGALOO REEF off northwest Australia, Brad Norman and I are on the hunt for the biggest fish in the sea. On the deck of a tour boat, we wait for the signal to jump into the water, along with eight wet-suited tourists.

THE GUIDES UNROLL their operation with military precision. A circling Cessna spots the behemoths from the air and messages the skipper of the boat, who alerts the crew. It's time. Clutching snorkel to face we step off the marlin board into 20 metres of churning sea.

Sacha, the guide bobbing in the sea to our right, holds out an arm and shows us where to line up. "Put your heads under", she yells. As if on cue, a whale shark materializes out of the blue. Like some immense royal personage parading past a guard of honour, he proceeds on his way, barely acknowledging us. He's accompanied by a royal retinue: in tight formation, there's two long thin sucker fish beneath his chest, a school of small bright blue fish at his flank, thousands of tiny crustacean hangers-on, and now me. Norman grabs my arm and swims me ahead of the tourist pack to take a close-up shot of the spots behind the pectoral fin.

This is not just another tourist snap. I have become part of a vast citizen science corps that is vital to Norman's mission to fill in the blank chapters of the whale shark's life story. The photo will be added to a library of such images that are used to track individuals based on their spotty pattern. Like a fingerprint, no two are alike. The identification is made with the help of a NASA algorithm, originally designed to identify star patterns revealed by the Hubble space telescope .

It's just one of the unconventional methods Norman has pioneered over the last 22 years to learn more about the animal. But his interest in the species goes beyond intellectual curiosity. For reasons still poorly understood, whale sharks are becoming more scarce. Every new whale shark that's tracked, every new behavior that's discovered brings Norman closer to understanding how to protect them.

Now Norman is feeling a new sense of urgency. Last July a global census found that in the last seventy-five years, the whale shark population has dropped by more than half. Soon after, the International Union for Conservation of Nature, in consultation with Norman, updated the whale shark's status from "threatened" to "endangered" on the IUCN Red List of imperiled species.

The greatest threat to whale sharks is human beings. Found in tropical oceans around the world, they are on the menu in many Asian countries as "tofu fish", and whale shark fin makes for an impressive table decoration at Chinese wedding banquets. Boat strikes also claim their share of fatalities.

So far whale sharks are protected in only 10 percent of the countries they inhabit. Norman is hopeful the new IUCN listing will change that. But "we need to move sooner rather than later," he says. "The critical time is now."

WHALE SHARKS MAY BE the biggest fish in the sea, reaching 18 meters in length, but they are rarely seen. Unlike true whales, they do not need to surface to breathe and likely spend large amounts of time on the ocean floor like their relatives, the bottom dwelling wobbegongs. But to feed they must sur-face. They dine on the ocean's floating feast of plankton, which is what brings them to Ningaloo every March.

On the first full moon of the month the coral spawn in unison – and somehow *Rhincodon typus* keeps this date in its diary. Other species spawn in turn, making for a multicourse menu that keeps the filter feeders sated until July. Where they go for their next feed has long been a mys-tery.

With so little known about whale sharks, researchers have no idea what other factors could be lowering their numbers. For instance they have no idea where they breed and give birth. Could their breeding grounds be compromised?

Norman represents one of their best bets for survival. He's been raising the global alarm about their status since 1999, when a report he wrote led to the IUCN reclassifying them from "indeterminate" to " vulnerable to extinction" and in 2001 he successfully nominated the whale shark for full protection in Australian waters. Those efforts have earned him a string of awards in-cluding a 2006 Rolex Award and the West Australian Premier's Outreach Award in 2009; in 2010 he was named a National Geographic Ocean hero.

You'd expect Norman's star status to be underpinned by an academic position and secure funding. But that's not the case. He doesn't have a PhD or a paid university position (he is an affiliate at Murdoch University), and he struggles to secure funding. "He lives 'hand to mouth' to give his time to the animals", ex-plains Lyn Beazley, former chief scientist of Western Australia and one of Norman's stalwart champions.

What Norman lacks in resources he makes up for in resourcefulness. Absent the funds to sup-port a research boat and scientific team over the past 22 years, he's recruited the help of tour boats, tourists and volunteers. And he has steadily developed 'out of the box' collaborations with astronomers, penguin researchers and vaccine developers to unveil more and more of the whale shark's story.

PERHAPS THERE'S AN UPSIDE of not being bound up in university bureaucracy. Norman is immersed in his community, and readily forges partnerships. The personality helps; there's little ego to get in the way. Within minutes of meeting Norman, you're mates. That small-town camaraderie was forged in the rural outskirts of Perth. His father was a butcher, and both parents ran a stock feed store. Growing up, he loved horses and thought of becoming a vet.

A swim with a whale shark changed all that.

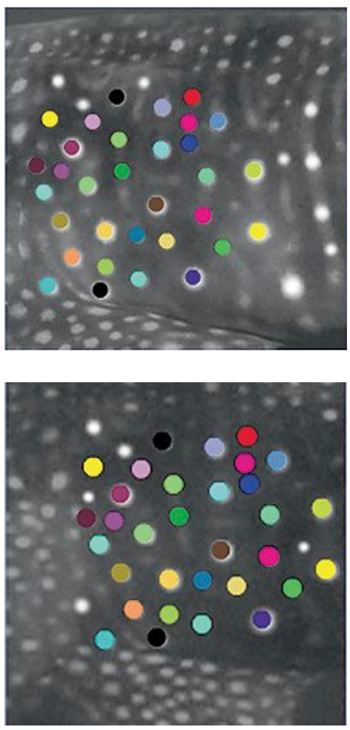
It was 1995. Norman had completed a degree in marine science at Murdoch University and was doing volunteer research for the Department of Parks and Wildlife (DPAW) at Ningaloo. Diving in to witness the whale shark's parade, he recalls, " I froze awestruck, watching this beautiful creature swim past." Beyond the awe, Norman realized these charismatic animals could be the flagship for protecting other struggling marine species. "I didn't want to hit people over the head with a wet fish, but whale sharks could make people more aware of the problem. That's where my passion went."

Whaleshark tourism was still in its infancy, but it was clear to Norman and the DPAW that the growing popularity of whale shark tourism would need to be managed lest it harmed the animals. (In 1995, a little over 1000 tourists swam with them over the five month season. By 2011, that figure was 17,000). Norman put his name forward to begin a study, and doors be-gan to open. Murdoch University enrolled him for a Master's degree, the tour boat operators offered him free rides, DPAW gave him office space, the local pub provided food, and lodg-ings were courtesy of the town caravan park. And thus, Norman's signature style was forged.

Too impatient to formalize his studies as a PhD, he powered ahead with gathering data.

He formed the not-for-profit group ECOCEAN, largely staffed by volunteers to help carry out the research and produce reports such as the Best Practise Whaleshark Ecotourism manual. Somehow he keeps scraping together resources to keep going. "I don't have a million bucks, so I have to be inventive and creative," he says. "I engage the public, the next generation of scien-tists — we get kids interested and give them the feeling of ownership."

02



A NASA program for identifying constellations matched up the spotty patterns on these two photos of whale sharks, showing they were the same individual.

WHAT NORMAN LACKS IN RESOURCES HE MAKES UP FOR IN RESOURCE-FULNESS.

One creative example is a school citizen science program called "Race Around the World". Schools raise $5000 for the satellite-tagging of a whale shark and the students help with tracking. So far 16 schools in the state of Western Australia have been involved; the goal for 2017 is to take the program Australia wide.

03
Whale sharks are the biggest fish in the sea, yet scientists know little about them. Norman has dedicated his career to filling that knowledge gap, which is key to conserving the species.

Students have already tracked 12 whale sharks and their data will help draw the still uncharted map of whale shark migration. For instance, just last April, Norman published a paper in *Pacific Conservation Biology* that revealed for the first time that apart from Ningaloo the whale shark had other haunts along the West Australian Coast. After they leave in July, they visit Shark Bay, some 500 kilometres south of Ningaloo, presumably to feast on another spawning species.

As his steady stream of publications in high-ranking journals attest, Norman's personal formula of agility, collegiality and determination is paying off.

struggling researcher's delight, Holmberg offered to help design a bigger and better data base.

The efforts of thousands of tourists might be captured this way. But the bottleneck was identifying the spots. Norman had established through his painstaking work that they were indeed unique fingerprints, but identifying them by eye was not only crazy laborious but error-prone.

It turned out one of Holmberg's college buddies had a solution to the problem. Zaven Arzou-manian was an astronomer with NASA's Goddard Space Flight Centre in Maryland. He regu-larly used a computer algorithm to identify new star patterns revealed by the Hubble space telescope.

04

Researcher and conservationist Brad Norman attaches a satellite tag to the dorsal fin.

NORMAN'S MASTER'S DEGREE research, begun in 1995, aimed to monitor the impact of the Ningaloo tourist industry on whale sharks. The first step was to find a way to identify individuals. Perhaps the whale shark's spotty pattern would provide a signature, in the same way that variations in zebra stripes and leopard spots had provided researchers with an ID for these animals. Norman began photographing the spots just behind the gills, near the pectoral fin where they seemed to show the highest variation. He did the identification by eye, a process Norman calls "crazy laborious".

What took the project to the next level was a chance email in 2003 from a software programmer by the name of Jason Holmberg. Based in Portland, Oregon, he had become smitten with whale sharks after a swim in the Galapagos. He liked what he'd read about Norman's work online, and to the

Perhaps the algorithm would also recognize the star patterns of a whale shark?

It sounds like the beginning of a joke: a marine scientist, a software programmer and a NASA astronomer walk into a bar….But the oddball team produced the goods. Arzoumanian modified the star pattern software to read whale shark spots. Holmberg and Norman began testing the software on thousands of photos and found that the program rapidly narrowed down the number of possible matches. A publication in 2005 in the *Journal of Applied Ecology* showed it identified individuals with 90% accuracy. Even so, explains Norman, the final analysis is always done by eye, by cross-matching to the whale shark's body scars or fin and tail notches to confirm the identification.

The method has been used to identify over 7000 individual whale sharks in 54 countries. "It's bigger than Ben Hur now", says Norman.

IT WAS THAT “OUT OF THE BOX” solution to the problem of identifying individual whale sharks that won Norman a $100,000 Rolex award in 2006. The funds enabled Norman to spread the methodology to researchers in Mozambique, Galapagos, Thailand, Mexico, Seychelles, UAE, Philippines, Taiwan, Indonesia, and the Maldives, who now contribute to the photo ID library. Holmberg continues to improve and maintain the site.

The Rolex award has also led him to cross-paths with other left-field types. When Norman swapped his wetsuit for a black tie to attend the Rolex Award ceremony in India in 2006, he met Rory Wilson, a passionate wildlife researcher and gifted engineer. Wilson’s award recog-nized his development of the equivalent of a “black box recorder” for animals.

If you’re an animal, your life story is pretty much told by your movements – the tale would be entirely different for a sloth and a penguin. With that in mind, in 1980 Wilson came up with the concept of a movement diary. Alone on an island off the coast of South Africa, he’d spent a year staring at African penguins, trying to figure out why the population was declining. He could observe them waddling around the island; he could weigh them and count their offspring. But these “Jekyll and Hyde” animals had an athletic watery life that was hidden to him. The frustration catapulted his inner engineer into action. He began spending long hours dreaming up a device that would reveal the penguin’s other life.

Once back home, he began building a tag equipped with sophisticated movement detectors – tri-axial accelerometers and magnetometers. Attached to their lower backs, forty times a second they measured whether the animal was going up, down or sideways. A second sensor attached to the beak, measured the angle so it was possible to calculate how much, and how often, prey was taken. When he retrieved these diaries from Magellanic penguins, a species closely related to African penguins, he found they ate an unfathomable amount – more than half their body weight in a day. Most of that mass was burnt off by the time the bird made it back to the nest.

That a penguin could eat this much food in a day was startling. “The diversity of what animals do is awe-inspiring,” he says. “The daily diary shows us how constrained our thinking is.” The finding probably explained why the African penguin population was dropping: its im-mense requirement for food was compromised by the increased competition from fishermen.

When the two black-tie bearing naturalists met, the conversation soon turned to: What might a motion diary reveal about the hidden life of whale sharks?

Several years later, the answers are coming. The pair designed a tag that clipped onto the shark’s dorsal fin but not too tightly – it would slither off in the course of a few days.

The data from the first tag was “a game changer”, says Wilson. “It’s an extraordinary experi-ence when you get a tag back – you’re opening the book on the animal for the first time.”

The tag had been attached for less than an hour, but it revealed a behaviour more often seen in birds. The whale shark glided downwards and then, like a bird flapping its wings, beat its tail to power back to the surface. Then it repeated the motion. It’s the same sort of energy-saving de-vice you’d see in a blue tit crossing a meadow, says Wilson.

ONE CHAPTER OF THE whale shark life story is still glaringly absent: its love life.

Most of the individuals that come to Ningaloo are youngsters, mostly males. Norman’s work has established that male sharks reach maturity by the age of nine, evidenced by the appearance of a pair of claspers near their back fins, their equivalent of a penis. But of the 1100 whale sharks that have visited Ningaloo in the past twenty years, very few were mature males or fe-males. So where does the adult action take place?

Since 2012 Norman has clamped satellite tags onto the dorsal fin of some whale sharks. These send a beep to the satellite, but can only do so when, in classical shark fashion, the dorsal fin breaches the surface. Those messages have revealed the outlines of the migration story. So far the furthest extent of travel is Indonesia, but many remain in local waters. Some have been tagged congregating at the surface in deep waters off the coast of West Australia. Could it be a mating ground? Norman is pinning his hopes on tagging the most mature males and females, if he can find some.

There are three ways of tracking the animals: by satellite, which tracks long distance travels; the motion diary, which records daily activity; and a network of acoustic receivers dispersed along the reef that records pings from whale sharks tagged with a transmitter. So far, the one that causes the most trouble for Norman is the satellite tag. To do their job they need to stay attached for the extent of the migration – at least a year. But clamping a tag onto a one meter high, 10 cm thick whale shark fin is a major challenge. Few tags stay attached long enough to deliver useful information. It turns out this is a problem that could use rocket science.

ONE CHAPTER OF THE WHALE SHARK LIFE STORY IS STILL GLARINGLY ABSENT: ITS LOVE LIFE.

Another chance meeting, at a Rolex award ceremony in Delhi in 2012, brought the right person into Norman's orbit at the right time: Mark Kendall, a former rocket scientist. Kendall had developed an "out of the box" way to use ballistics to deliver particulate vaccines just 50 microns below human skin, where the immune cells are concentrated. The principle is that the faster skin is hit, the stiffer it is, and the less its deflects tiny injected particles. Particulate vaccines are ideal for less developed countries, since they require no refrigeration.

One invention of Kendall's used a rocket gun to inject microscopic gold particles bearing a vaccine. Another, the *Nanopatch*, is a high density array of silicon micro projections tipped with dry particles of vaccine. About the size of a postage stamp, it uses a spring-based applicator to achieve velocity.

"NORMAN'S A BIT OF A CELEBRITY IN TOWN," A TOUR GUIDE TELLS ME.

You might not think a medical devices engineer and a marine scientist would strike a common cord. But as Kendall recalls, "We could immediately see the synergies; I'd been working on skin for the last eighteen years. My mind began racing". By the time they left Delhi, Norman and Kendall were working on a ballistically-inspired way to tag a whale shark.

Kendall was there in the water with us last July, getting first-hand experience of what was required to swim along with the whale shark and clamp the tag onto the dorsal fin.

His team of scientists and engineers at the University of Queensland are lining up to be in-volved in the project. "Many of us in science have a lot to learn from Norman," he says. "He is so integrated into his community and so collaborative, and he thinks outside the box."

THE RESIDENTS OF EXMOUTH are appreciative of Norman's work. "Norman's a bit of a celebrity in town", Sacha, the guide at Ningaloo, tells me. The town of some 2200 people on the shores of Ningaloo reef was founded at the height of the Cold War in 1967 as a communications base for nuclear-powered US submarines. Decommissioned as a military base in 1992, civilian telecommunications con-tinues to provide employment for some of the townsfolk, as do deep sea gas rigs. But the lion's share of jobs now comes from the tourist trade, and whale sharks are the star attraction.

In the town, they are plastered on everything from airport walls to lycra leggings. Yet for all their star billing and Norman's own celebrity status, he still finds himself in a desperate struggle to find funds for the work that is vital to their survival.

He finally submitted a PhD thesis earlier this year. It may at last open the doors to traditional funding streams. "We'd only need one government grant to make a big difference," he says. "I keep working in the hope we can crack it."

Beazley is hopeful too. "He's not your standard academic; he's travelled the world to teach people how to stop whale sharks from going extinct," she says. "Who else would be that dedi-cated? Someone should support him, he's a gem."

05

The power of collaboration: Norman and penguin researcher Rory Wilson (left) developed a "black box recorder" for whale sharks.

Meanwhile, Norman continues to break new ground. Most recently he's been going out on a small borrowed boat to observe the sharks feeding at dusk. The daytime parade serves some sort of reconnaissance function; their cavernous mouths are closed to avoid drag. But with the cover of nightfall, vast balls of animal plankton rise to the surface, and open-mouthed whale sharks rocket after them. "It's an amazing sight," a breathless Norman told me by phone in late July after returning from sea that evening.

Despite his challenges, the passion that has kept him going for 22 years shows no sign of faltering. "I'm not just a scientist, I'm a conservationist and public educator," he says. "We're kicking goals for whale sharks and making a difference. That's the legacy."

ELIZABETH FINKEL is the editor-in-chief of *Cosmos* magazine.

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PEOPLE, CULTURE
& REVIEWS

SPECTRUM

ZEITGEIST

The forgotten man of science

Alexander von Humboldt (1769–1859), revered scientist and beloved public figure during his lifetime, was first to show the linkages within ecosystems. So why doesn't anyone remember him? JIM ROUNTREE reports. →

01

ZEITGEIST

The forgotten man of science

ON 14 SEPTEMBER 1869, worldwide celebrations marked 100 years since the birth of a much-loved, highly revered scientist. There were speeches and festivities in Buenos Aires, Mexico City, Moscow and Melbourne. In almost every major US city, thousands attended concerts and parades. Twenty-five thousand people gathered in New York's Central Park for the unveiling of a commemorative statue and a torchlight parade. In Berlin, the man's hometown, offices were closed for the day and 80,000 people came out in spite of torrential rain.

It's hard to know what's more astounding – that a scientist could inspire such popular and passionate celebration, or that he should be very nearly forgotten today. The scientist was Alexander von Humboldt. If you've never heard of him, you can be forgiven – in the 150 years since his international commemoration, he has all but disappeared from the general consciousness.

Being German – Prussian in fact – hasn't helped, not in the English-speaking world anyway. But more than this, perhaps, is that Humboldt has no single theory or equation bearing his name. Rather, he is responsible for a broad scientific concept that is now so widely accepted that it comes as a surprise to us that anyone had to think of it. You might say that Humboldt is the father of environmental science. It was he who first developed a scientific understanding of ecosystems and how everything on the planet – living and non-living – is linked in myriad relationships.

One comparatively small innovation of Humboldt's goes a long way to capturing the nature of his thinking, and his influence. Today, no weather report is complete without a map showing temperature zones across the country. This simple, powerful idea of aggregating temperatures (or rainfall, or humidity or any other measurement) and displaying it graphically perfectly demonstrates Humboldt's holism. In contrast to numerical lists of data, a map with isotherms shows the regions of temperature, and that immediately gives us insights into their causes and effects – for example the relationships to altitude and land cover, to winds and ocean currents, and to the life forms that inhabit these areas. Immediately we begin to comprehend our planet as a single whole comprised of interlocking systems. This is the core of Humboldt's vision.

It's a similar story with his *Naturgemälde*, roughly translated as "nature paintings". Best known is the diagram of Chimborazo, an Andean volcano he climbed. Alongside illustrations of the changing zones of flora and fauna on each side of the mountain are data on temperature, pressure, and humidity. Again, the emphasis is on nature's interconnectedness, the different forms of life stratified according to altitude and other physical factors.

While his greatest legacy is his sweeping idea about the interconnectedness of the world, it would be wrong to see Humboldt as only a "big picture" man. Much of this work was based on measurements – lots of them. In this sense, Humboldt was pure scientist, using the best technology of the day to measure everything he could – temperature, humidity, the magnetic field, the colour of the sky. And alongside this were observations of rock and soil, the taste of the water, fungi, insects, plants, animals and people. All of this he brought together to show the links of dependency that criss-cross the natural world, including human dependencies on that world.

But more even than all this, Humboldt, infused with the spirit of German Romanticism, made a conscious effort to keep *all* of his senses open – to see, smell and feel … to *experience personally* every aspect of the world. For him there was no conflict between the objectivity of rigorous scientific measurement and the subjectivity of fully acknowledging – even indulging in – his emotional responses. And these were intense – unsurprising, given that he could find himself deep in a remote, dense, wet jungle one month and on the side of a volcano the next.

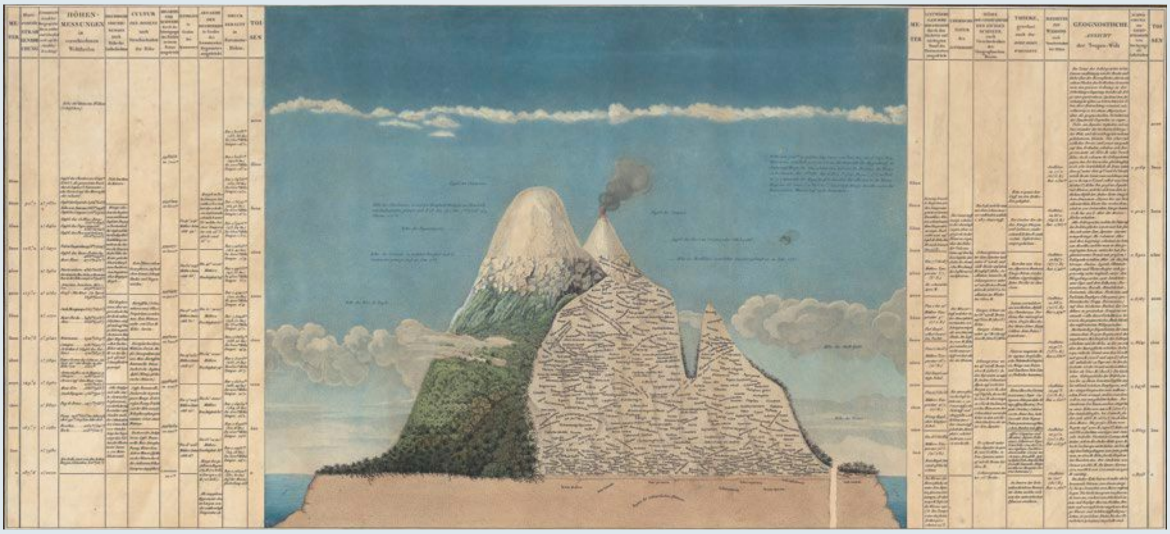
YOU MIGHT SAY THAT HUMBOLDT IS THE FATHER OF ENVIRONMENTAL SCIENCE.

This likely explains a good part of Humboldt's popularity – that he wrote of these experiences, allowing readers in Europe and the young United States to become, in their imaginations, adventurers themselves. Reading his most popular work, *Personal Narrative of Travels to the Equinoctial Regions of the New Continent during the years 1799-1804*, they could suffer the privations but also see the vistas, feeling something of the thrill of being the first to explore a new continent. Certainly this was the effect the book had on a young Charles Darwin. He was hugely influenced by Humboldt, and in many respects came to see the world through Humboldt's eyes when, with the *Personal Narrative* at his side, he embarked upon his own adventures on the Beagle years later.

Humboldt made two major expeditions in his life. The first was to modern-day Venezuela, Columbia and Peru, and then Cuba and Mexico, from 1799 to 1804. The second was to Russia in 1829. It was the former that was most influential, however, for the impact it had on Humboldt and for the influence he had on the world.

South America at the start of the 19th century was

02



The diagram of the Andean volcano, known as the Chimborazo Map, is the best-known of Humboldt's *Naturgemälde*, providing detailed information about the plants he found there.

made up of colonies still firmly in the grip of Spain. Humboldt observed this with the same unique blend of objectivism and heart that he applied to the natural world. He documented statistics of production and income and recorded social conditions. And just as his insights into ecosystems now form part of the general consensus, the views he formed about Latin American society and economics seem thoroughly modern. Colonisation was brutal and disastrous, he concluded, the treatment of indigenous peoples – wrongly characterised as savages – cruel and unjustifiable, and slavery was a particular evil. His *Political Essay on the Kingdom of New Spain*, which laid out these views, along with the evidence, was widely read.

Humboldt's protestations had a material effect on political change, helping build pressure that eventually led to the liberation of the South and Central American colonies. But they came with a price: his anti-colonial views are almost certainly the reason that the British never allowed him to travel to India, where he long wished to mount an expedition. He wanted to gather evidence that he was confident would confirm, in a quite different part of the world, the broad ecological conclusions he had made from his observations in South America. The Russian expedition sufficed, but was a consolation prize.

Viewed in hindsight, Humboldt seems very much the modern man – in many ways he could slip easily into the intellectual world of the 21st century and be quite comfortable. At the same time, he was absolutely pivotal in his own time and place. Here was a man who counted Goethe and Thomas Jefferson as personal friends, as well as Simón Bolivar, who went on to liberate Latin America from Spain. Humboldt dominated in the world of science for decades and provided incredible influence and inspiration. As a concrete example, he was the primary inspiration that eventually led to the creation of national parks around the world.

He was also a great public communicator. As Andrea Wulf writes in *The Invention of Nature: The Adventures of Alexander von Humboldt, the Lost Hero of Science*, in Berlin in 1827 he held free public lectures that were hugely popular. Attendees included academics and students, royalty, members of the public from all classes, and women – in fact, they comprised half the audience. It's likely that no such mix of people had ever gathered before, certainly not on equal terms, and all were equally enthralled and informed. It is a great testament to the democratic principles Humboldt espoused.

For Humboldt, these lectures provided the opportunity to assemble his thoughts for their final and complete expression in his *magnum opus*, the five-volume *Cosmos*, which he worked on until his death. The word *cosmos* Humboldt resurrected from Greek, where it means beauty and order. For him, it stood for everything in heaven and on earth.

Today we would do well to resurrect Humboldt's legacy. He still has a lot to tell us. Here was a man who in 1830 listed deforestation, irrigation and the "great masses of steam and gas" produced by industry as posing serious problems for the planet. How sadly true has his insight proven to be.

JIM ROUNTREE is editor of Cosmos Lessons.

IMAGES
01 Ullstein bild/ Getty Images
02 Zentralbibliothek Zürich

SNAPSHOT

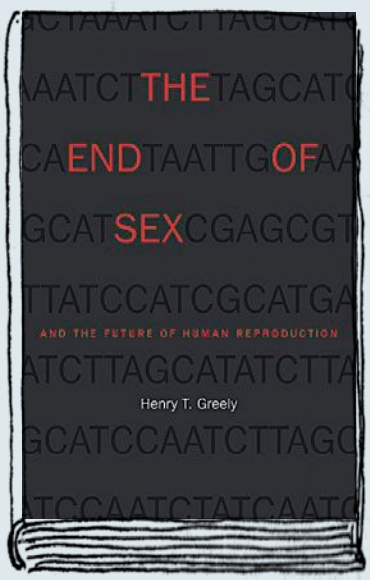
Spider tango

LIKE ITS AVIAN COUNTERPART, the male Australian peacock spider dances to attract a female. He waggles his strikingly patterned abdomen while his third set of white-accented legs clap along. After watching a video of this dance by Australian biologist Otto Jurgens, physicist Doekele Stavenga at the University of Groningen became enthralled by the spider's colourful markings, which distinguish one species from another. In insects, red colours are made from pigments but blues are made from colourless scales that sieve blue light. But as Stavenga reported in the *Journal of the Royal Society* in August, the structure of *Maratus splendens* (pictured) has a twist: rather than the typical stack of two thin films, it employs a double set.

IMAGE
Otto Jurgens

REVIEWS

Are we ready for babies on spec?



NON-FICTION
The End of Sex and the Future of Human Reproduction
by HENRY T. GREELY

Harvard University Press (2016)
RRP US$35.00

HANK GREELEY, a law professor who has long been a witty and warm presence in American bioethics, has written a book that tells us that sex, as we know it, will no longer be necessary. Got your attention? Good. That was his point, and why he called his book "The End of Sex."

What he means is not really the end of sex, but what he thinks the reasons that "wealthy people" or "people with the means" will no longer have reproductive sex, because they will be making their babies on spec to be sure that the baby in question is the right sort – healthy, with desirable traits, a high IQ and nice eyes.

If all of this sounds horrifying, don't be alarmed. For despite Greeley's argument, very little of the science on which it depends really exists, which gives the book feel of fantasy – rather like a book about unicorn regulation.

Greeley is a masterful writer, realistic about his hunches, a calm and careful guide through the science, even though he reminds the reader – frequently – that his last science class was decades ago.

And because he is such a good guide, this is a compelling book, even if you don't agree with his argument.

Greeley' fascination for genetics, genomics and stem cell biology is quite contagious and persuasive. As a watcher of science, he became convinced that people would want to know as much as possible about the embryo that would become their child. For many people with a family history of genetic disease, and for many people who are infertile, embryos are made in the lab, and tested before being implanted in a womb. But retrieving eggs is arduous and possibly dangerous.

For test tube babies to become routine, Greeley suggests the answer lies in our skin cells. Scientists are now able to scrape a few off the side of your cheek and turn them into stem cells – so-called iPS cells. Being stem cells, they can form any cell type; scientists have also been able to coax them to make rudimentary sperm and egg cells.

Greeley is happily optimistic that, instead of making love to the person who you intend to have a child with, people will use iPS to create plenty of embryos, instrumentalising the process entirely. Such a plan, he adds, will be available to wealthy people first but, as avoiding disabilities is a cost-saving policy, it would quickly become widespread.

If you have seen the movie *Gattaca*, I know what you are thinking. What would keep us from eventually living in a society where the people with the most access to social goods also have the "best" children, not only free of disease, but more beautiful and stronger?

Would people born to the poor, to the spontaneous, or the old fashioned end up regarded as failures? Would we despise disability? Or worst of all, would some perfected embryos become a commodity? An object of state control?

Once you take responsibility for human creation, each decision is fraught.

Greeley's book is not quite science fiction. It is too smart for that and it is grounded in some scientific possibilities that may – or may not – work. Whether they come to pass is another issue entirely. Whether iPS cells can make normal gametes and normal embryos is not at all certain. These uncertainties are daunting if what you want is a healthy child.

WOULD PEOPLE BORN TO THE POOR, TO THE SPONTANEOUS, OR THE OLD FASHIONED END UP REGARDED AS FAILURES?

Many years ago, I was a clinical bioethicist, the sort of person who aims to sort through competing arguments at hard crossroads in medicine. One day, on the bioethics committee we were discussing whether to stop care on a very sick baby who, if he lived, would likely be disabled. The baby's father looked up and said: "I don't care if he is smart or a great baseball player. I just want a kid I can take to the mall, and you know, just be a normal dad, because he is my kid, and I will love him no matter what."

It is this "no matter what" which is the essence of being a parent. And that is why the future Greeley longs for may be a long time coming.

— LAURIE ZOLOTH

NON-FICTION
Digital vs Human: how we'll live, love, and think in the future
by RICHARD WATSON

Scribe Publications (2016)
RRP $35.00

ACCORDING TO *Digital vs Human*, we need to start talking about the way robotics, AI, automation and the web are going to affect our future – but we aren't. Instead, we're wowed by the next app or website that mints a billionaire and, in the words of an online commenter, only really solves the problem "what is my mother no longer doing for me?".

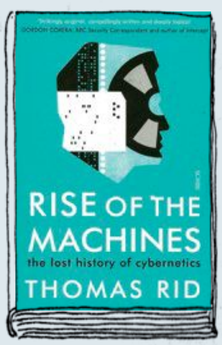
Author Watson thinks the technology itself is distracting us from talking about it – the big picture is taking shape out of our sight while we obsess over status updates and celebrity selfies. Like Watson's last book, *Future Files*, *Digital vs Human* is partly the story of ageing and our relationship to tech as we grow older. The book has a slight "harrumph, these kids and their phones" air about it, but he admits fears about technology are as old as papyrus scrolls. He cannily quotes Douglas Adams' pearl of wisdom: "Anything that gets invented after you're 30 is against the natural order of things."

But Waston draws on some fascinating research that seems to reveal how secretly unsure we all are, even selfie-obsessed kids – a poll found 27% of 18-24-year-old Brits felt "left behind" by digital communications. He documents how sectors such as healthcare, transport and medicine are on the cusp of revolution. While those sections sum up interesting case studies of things you'll see over the next decade or so, the book's real value is in the philosophical positions Watson takes. But his assertions and beliefs will spark different responses depending on your own position on technology. Your perspective is coloured by your individual prejudices, age, even where you're born, and thus the technological infrastructure you're used to.

For example, there's a little Ludditism. In talking about Ray Kurzweil's concept of the singularity (when machine intelligence outstrips ours) and the notion that machines will design and build machines in turn, he says, "let's hope these machines are nice to us" – seeming to give in to bias formed by everything from *Frankenstein* to *The Terminator*.

Watson raises the fact that the data we produce with all these updates and posts is making some companies rich off us, something little talked about to a degree that's almost catastrophic. It's a well-argued salvo in a social dialogue that needs to be constant, because the future is already here.

— DREW TURNEY



NON-FICTION
Rise of the Machines: the lost history of cybernetics
by THOMAS RID

Scribe Publications (2016)
RRP $35.00

AS WITH *Digital vs Human*, the recent book by futurist Richard Watson, war studies professor Thomas Rid's Rise of the Machines takes a look at our relationship to technology.

But where Watson's book is a practical look at the near future extrapolated from the bleeding edge of software and device science, *Rise of the Machines* takes a more philosophical approach to investigate how we got here. Even though most of the early chapters chronicle the history of the term "cybernetic" and all it entails, it's less history than a cultural barometer for how the cyber age has shaped the world – and will for the foreseeable future.

Such as it is, the book seeks to untangle the term "cyber" by scrutinising its history. As Rid says in the introduction, "The word refuses to be either noun or prefix. Its meaning is equally evasive, hazy and uncertain. Whatever it is, it is always stirring, it is always about the future, and it always has been."

The prism he looks through is the birth and growth of the cybernetics movement, and much of the first half of the book concerns itself with history. We learn about the effort to use computing machines to better aim large artillery in the Second World War, and how the movement then flowered into the work and theories of postwar-era computer scientist Norbert Wiener and his contemporaries.

A lot of this history (Turing, von Neumann) is stuff you'll know if you've read much about the history of computers, but Rid draws a path directly from the heady postwar days to more recent thought such as merging machines with humans.

There's not much in Rise of the Machines that concerns itself with practical applications or prediction. It's more about wondering what our relationship to machines means – or should mean. In one of several enlightening passages, Rid writes: "What if a mechanic with an artificial arm is trying to repair an engine? Is the arm part of the organism that is fiddling with the car engine? Or is the prosthesis part of the machinery that the man is trying to control?"

Throughout there is a seam of nervous tension that only breaches the surface a few times. Technology and machinery, *Rise of the Machines* reminds us, has long promised to either deliver or destroy us. As a question posed early on asks: "How much risk are advanced societies taking by delegating ever more control into the virtual hands of ever more networked and seemingly ever more intelligent machines?"

— DREW TURNEY

REVIEWS

NON-FICTION
Professor Astro Cats's Atomic Adventure
by DR DOMINIC WALLIMAN and BEN NEWMAN

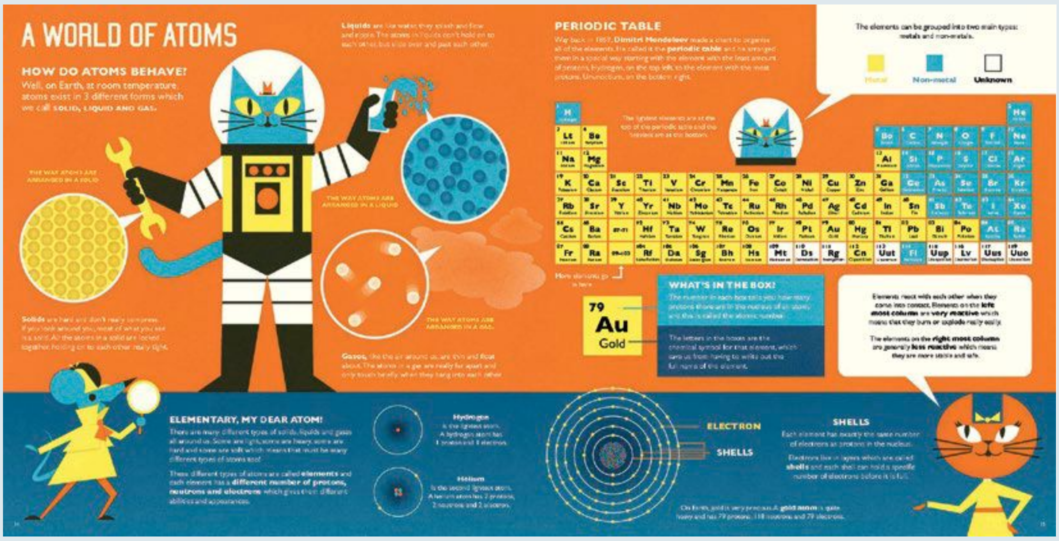
Flying Eye Books (2016)
RRP $29.99

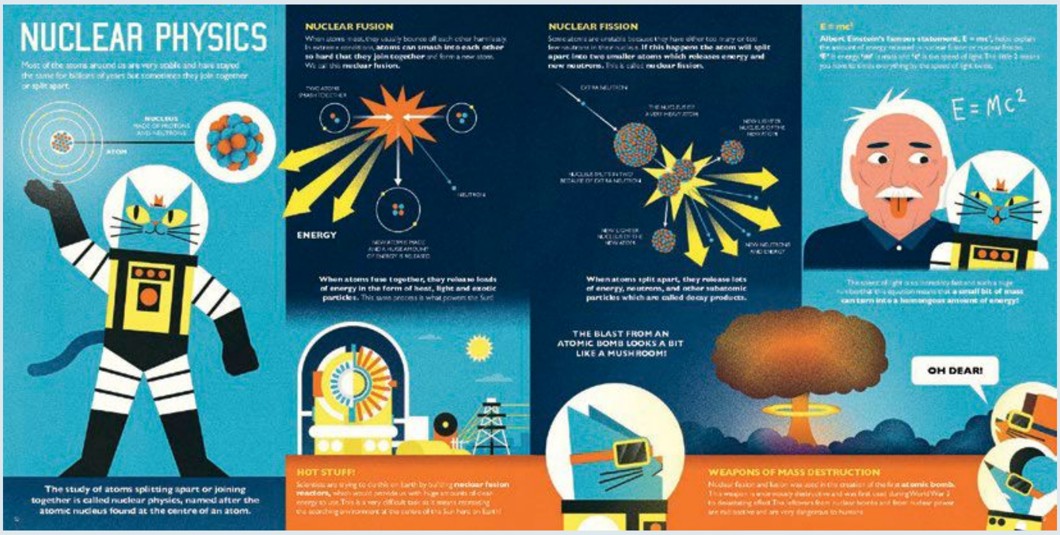
THIS IS THE SECOND collaboration between science writer Dominic Wallman, who has a PhD in quantum physics, and illustrator Ben Newman. Previously their wonderful inventions, Professor Astro Cat and his mouse Offsider, guided kids of all ages through the frontiers of space.

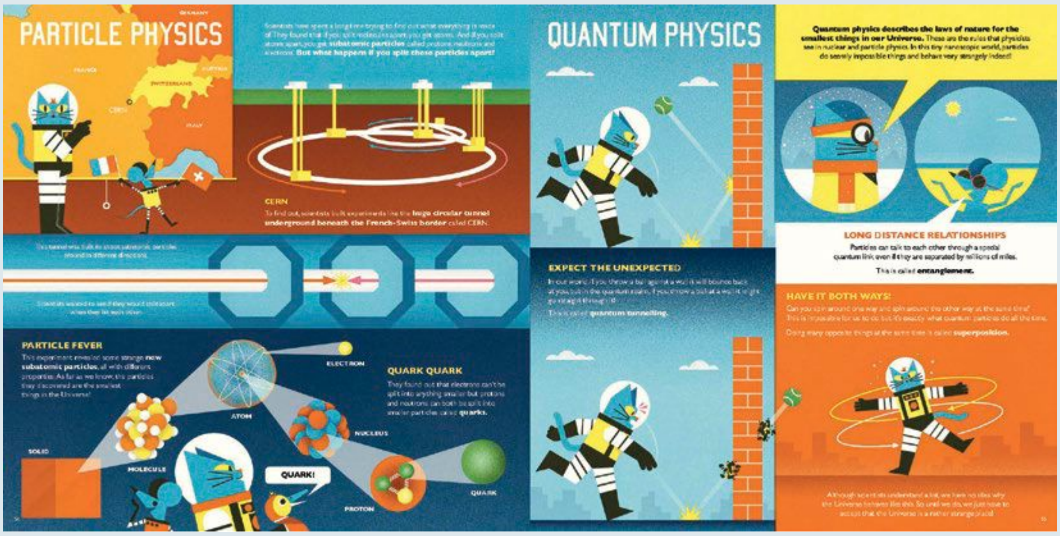
Now they are back to tackle the world of atomic physics in all its mysterious complexity. The result is a feast for eye and brain, marrying Newman's charming graphics with Wallman's knack of making the most baffling atomic concepts accessible.

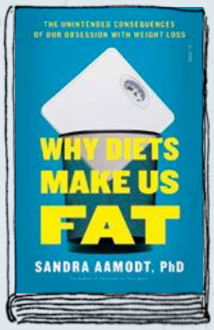
It is hard to think of a better introduction to serious science in these days when the importance of early engagement of young people with STEM has never been greater.

— BILL CONDIE









NON-FICTION
Why Diets Make Us Fat: the unintended consequences of our obsession with weight loss – and what to do instead
By SANDRA AAMODT

Scribe Publications (2016)
RRP $29.99

IF THE SIZE AND INFLUENCE of the diet industry and the battles many people wage – often over decades – to control their weight seem nonsensical to you, *Why Diets Make Us Fat* will be perfect fodder to bolster your case next time the topic comes up.

Aamodt, a neuroscientist, explains the science behind the way your body controls your weight, showing why it can be so hard to lose those extra pounds. A host of sobering statistics reveal just how taken in we are by empty (and expensive) promises. In her native US, Aamodt says, 108 million people – about a third of the population – went on diets last year, and half of them were within a healthy weight range when they started. In Europe, as far back as 2002 (according to an industry report), 231 million people attempted some form of diet, with only 1% achieving permanent weight loss.

The story of our battle with our weight isn't just about losing it, but keeping it off, and one of the linchpins of *Why Diets Make Us Fat* is the body's weight-control mechanism, an ideal weight range your brain will fight tooth and nail to keep you within. It's determined by genetics, and it works perfectly if you let it.

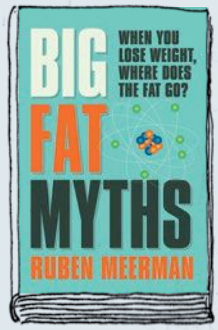
In a habitat like we evolved in (i.e. one without billboards exhorting us to consume what we don't need or the social strictures of eating certain meals at certain times), we'd eat when we were hungry, stop when we were full and stay within our pre determined weight range without too much effort.

The trouble, as Aamodt spends a lot of the book outlining, is that moving our weight outside that range is both extremely hard and unhealthy. Fall below it and your brain will assume you're starving. The conscious manifestation is a feeling of sluggishness and constant cold, and the brain works harder to extract what nutrients it can, taking resources away from immunity or other systems. Even after years of dieting it will try to raise your weight back to your accepted range, which explains why sustained weight loss is so difficult.

As Aamodt points out, the effort/reward chemistry of the brain plays a part too, with hormones encouraging us to eat more when we're dieting, making it that much harder.

Scientific research the book cites puts a pin in many of the dearest-held beliefs about dieting. The results aren't that different whether we're on low-carb, low-fat or intermittent starvation diets, and the rate of weight loss doesn't change the end result much either.

— DREW TURNEY



NON-FICTION
Big Fat Myths
By RUBEN MEERMAN

Penguin Random House Australia (2016)
RRP$34.99

IN THE CONSTANT BATTLE between salespeople spruiking costly diet products and diet books, the first casualty often seems the truth. There cannot be many weightwatchers who have not at least once scratched their heads in bemusement about how their bodies really do work and how they burn those unwanted kilograms.

Enter Ruben Meerman with this admirably concise guide to the science of losing weight. He brings the clear-sighted perspective of a physicist to the question (which he calls the Big Fat Question, or BFQ), "When someone loses weight, where does all the fat go?"

The short answer is that it is converted to carbon dioxide and water, but in arriving there Meerman leaves no myth unbusted.

It's highly nutritious fare.

— BILL CONDIE

TOP 5

Bestsellers

1

When Breath Becomes Air
by PAUL KALANITHI

Bodley Head (2016)
RRP $32.99

2

Being Mortal: Illness, Medicine
and What Matters in the End
by ATUL GAWANDE

Profile Books (2015)
RRP $22.99

3

The Immortal Life of
Henrietta Lacks
by REBECCA SKLOOT

Picador Australia (2010)
RRP $34.99

4

Quiet: The power of introverts
in a world that can't stop talking
by SUSAN CAIN

Penguin (2013)
RRP $22.99

5

Thinking, Fast and Slow:
by DANIEL KAHNEMAN

Penguin (2012)
RRP $24.99

— FROM THE NEW YORK TIMES
SCIENCE BESTSELLER LIST

REVIEWS

Up close with spiders

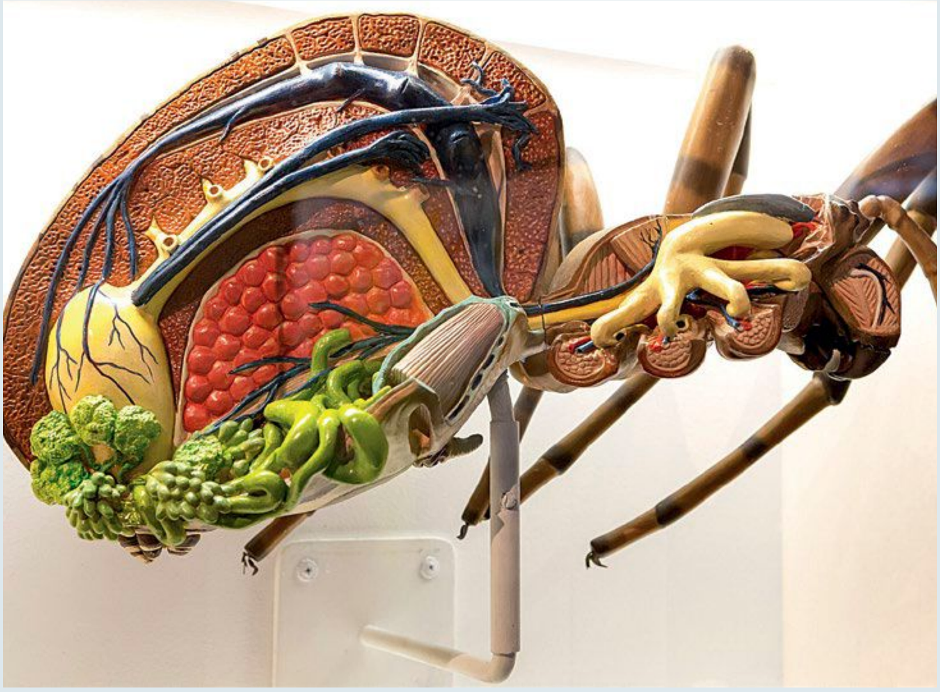


EXHIBIT
Spiders
AUSTRALIAN MUSEUM, SYDNEY

Opening end of October, 2016

IF YOU'RE SQUEAMISH, this exhibit may not be for you. But if you're fascinated by nature, evolution and everything that creeps and crawls, you'll love getting up-close and personal with Spiders.

Bring the kids for a nail-biting experience that immerses you in a world of cunning hunters and visionary architects.

With potent venoms and powerful jaws, spiders are among the deadliest hunters in the world. Researchers believe the Australian Karaops spider, for example, may be the fastest terrestrial ambush predator on Earth.

The fibres that spiders weave into intricate webs are so strong scientists are trying to recreate them at nano-scale to engineer advanced materials. And then there are the hungry female spiders that eat their non-suspecting partners after they mate.

At this exhibition, learn about spider behaviour and anatomy through larger-than-life models and use microscopes to check out preserved specimens. See what they see and find out what they feel through their amazing senses, which allow them to search for mates and food in the world around them with incredible precision. And bring your dancing shoes along to act out the exotic wiggle of the peacock spider's courtship jive.

You'll learn just how many spiders are around – there are more than you think – and find out which species are found where.

And if that leaves you itching for more, meet living specimens of some of Australia's most famous eight-legged critters – housed in secured habitats, of course.

Spiders is a joint exhibition between Questacon – The National Science and Technology Centre and the Australian Museum.

— VIVIANE RICHTER

DOCUMENTARY

Voyage of Time

IMAX Entertainment (2016)
The documentary will debut in US IMAX theatres on October 7.

THIS IS THE KIND of epic visual feast to which only an IMAX cinema can really do justice.

Strap yourself in for the history of the cosmos – an immersive journey that spans the aeons from the Big Bang through to the beginnings of life, down to its final, (speculative) dramatic collapse.

Acclaimed filmmaker Terrence Malick, famous for The Thin Red Line and The Tree of Life, is well-known for creating aesthetic masterpieces and Voyage of Time, Malick's first – and ambitious – documentary, looks to be no exception.

Witness the birth of stars and galaxies, and travel alongside the ebbs and flows of life on our planet.

Malick collaborated with leading US scientists to get the science right in creating astrophysical imagery, capture the evolution of Earth's complex organisms from unicellular life and recreate movements of extinct animals.

Brad Pitt narrates the 40-minute IMAX cinema version of the film and Cate Blanchett's soothing voice accompanies the feature-length edition, which debuted at the 73rd Venice International Film Festival.

While this documentary describes the cataclysmic beginnings of the universe, the birth of this film also saw turbulence. In 2013, Malick was dragged to court by the film's investor Seven Seas Partnership over claims that Malick's company, Sycamore Pictures, funnelled millions from the documentary's funds to other films.

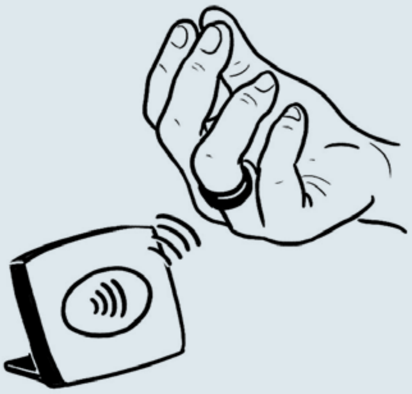
But Voyage's future was secured in 2015, when IMAX Corporation and Broad Green Pictures joined Sophisticated Films and Wild Bunch to pick up the tab, securing an exclusive IMAX release.

"Terrence Malick is one of the most innovative filmmakers in the world," IMAX Corporation CEO Greg Foster said in a press release. Investing in Voyage of Time, he added, was "capturing lightning in a bottle".

With snippets of the long-anticipated film revealing artistic imagery only too characteristic of Malick, this film will be well worth the wait.

— VIVIANE RICHTER

GADGET



WEARABLE

NFC Ring

INFINEON

HEAD TO THE BEACH without your wallet with this wearable that lets you pay – like a Jedi – with the wave of your hand.

The NFC Ring, recently launched by Infineon Technologies, uses Near Field Communication (NFC) technology which is already featured in most smartphones. The ring contains a security chip that communicates with the payment terminal via a passive antenna, triggering and processing payment within a few milliseconds in a range of four centimetres.

The swipe-payment technology is the same general concept as payment rings developed by VISA and trialled on athletes at the Rio Olympic Games. But while VISA have not yet rolled out their product on the market, Infineon's NFC Ring is now available worldwide for pre-order.

And if you just sighed at the thought of yet another device you have to remember to charge, don't stress – this gadget requires no batteries. You can get your hands on the more economical nickel-free titanium options for $20, or splurge on the very sleek $40 advanced ceramic designs.

— VIVIANE RICHTER

→ bit.ly/cos71gadget

PAUL DAVIES is a theoretical physicist, cosmologist, astrobiologist and best-selling author.

Abacus

Embracing e

Could mathematics help you find true love?

FEW PEOPLE LOVE mathematics. A common refrain among students is, "Why do I have to learn this stuff? When will I need it?" But having a working knowledge of the basic concepts is essential in daily life as an adult. We use them when counting cash, calculating mortgage payments and filling out tax returns.

In fact, it was financial matters such as loans, interest payments and gambling that spurred the development of a lot of early mathematics. Negative numbers, for example, were needed to represent debt, and the mathematical rules for their use were worked out in India and the Islamic world by the 7th century.

One money problem that was carefully analysed in the 17th century concerned compound interest – a familiar enough concept today. Just like modern banks, the money lenders of the day competed for customers using interest rates as incentives. But when making comparisons the customer always has to be careful of the small print. Interest rates are normally expressed on an annual basis. For example, a simple 5% annual interest means that $100 investment becomes $105 at the end of one year. However, if interest is credited, say, every six months, the customer gets a higher overall annual return.

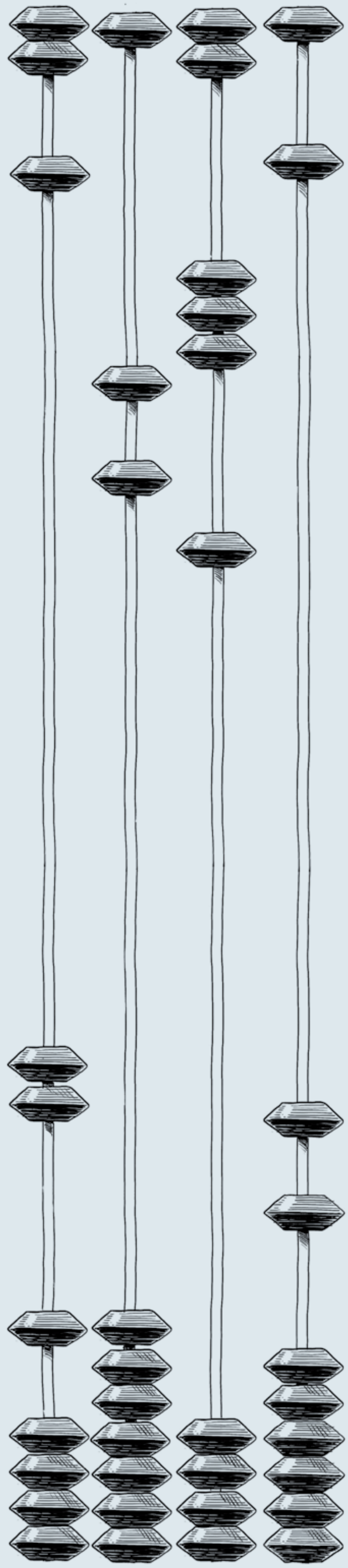
To keep the arithmetic simple, imagine a bank that paid 100% annual interest (that would be nice!). If credited annually, that rate of interest would turn $100 into $200 at the end of the year. But if credited every six months, then $50 gets credited to the account after six months, so at the end of the year the original capital has earned $100, but the $50 credited after six months will itself earn $25 interest over the second half of the year. So by offering biannual compound interest, the bank would pay the customer $125 interest at the end of one year rather than $100. A customer who started with $100 would now have $225 in the account.

If the interest is paid quarterly, the deal is even better, amounting to a little over $244 at the end of the year. The more often the interest is credited, the higher the final total. But it is a process of diminishing returns: the total goes up by a smaller and smaller amount the more frequently you credit the interest. Crediting every day would yield a bit over $271. That is to say, the original capital will have been boosted 2.71 times.

All of which raises the question: what would be the upper limit to this compounding process? Mathematicians were pondering this even back in the 17th century. In 1683, the mathematician Jacob Bernoulli found the answer: 2.7182818... (the ellipsis indicates that this number is an unending decimal). It is an *irrational number* (see Abacus, Cosmos issue 69, page 76) and, like π, proved to be a fundamental mathematical constant that turns up in fields as diverse as accounting, physics, engineering, statistics and probability theory. It is such an important number it is given a letter all its own: e.

Peruse any textbook on science, engineering or economics, and you will see the symbol "e" scattered throughout. It is most often used in connection with "exponential growth" – a term that has entered the popular lexicon, though it is often misused. The correct meaning refers to a specific type of rapid, runaway growth in which a quantity doubles in a fixed time, and then doubles again, and again, *ad infinitum*. The population of bacteria in a dish, for example, will

The 'Exponential Growth' formula wasn't a gimmick after all! ILLUSTRATIONS: JEFFREY PHILLIPS



increase exponentially if their growth is unrestrained.

One familiar example of exponential growth is Moore's Law, named after Gordon Moore, co-founder of Intel. After noticing in 1965 that the size of transistors was rapidly shrinking, which meant more of them could fit onto a computer chip, he predicted that processing power would double roughly every two years (and the price would drop by half). Remarkably, this exponential growth has remained more or less consistent for several decades, though nobody expects it to go on forever.

And e makes a surprise appearance in less obvious places, too. My favourite example is e's application to the secretary problem. Imagine there are 100 applicants for a secretarial job, to be randomly interviewed. At the end of each interview, the interviewer must give the applicant an irrevocable decision as to whether they've got the job. It would be risky to see them all, dismissing the first 99, because the hundredth interviewee would have to be given the job regardless of quality. The conundrum is this: to maximise the probability of getting the best candidate, how many should be interviewed before selecting the first remaining candidate who trumps the ones already seen? It turns out the answer is 100/e, or about 37. This result is worth remembering by people who like to play the dating game methodically.

So mathematical knowledge isn't just useful at tax time. Perhaps if more people knew maths could help them find love, more would be willing to embrace it.

WHY IS IT SO?

WHY DO STARS SPARKLE?

It's all to do with the way light travels through the atmosphere. JAKE PORT explains.

01

GAZING UP AT THE HEAVENS at night, it's easy to get lost in the beauty and immensity of the universe: the moon's silvery glow, planets moving through their orbits, distant stars twinkling with light emitted millions of years ago.

This dancing of light we see when we look at stars has fascinated humans for centuries – even the smallest humans. "Twinkle twinkle little star, how I wonder what you are" is one of the first songs we learn as children. As we grow older, we learn the names of the stars and constellations. But what about that twinkle? Why do stars "dance" in the night sky?

To explain why, we must first turn our gaze to ground level. Picture the wavy motion of air just above burning hot sand. We see this effect because the hot air has a different density than the cooler air above it, and it moves up. As it does, the heat dissipates and alters the density of the air, making it refract light, bending and redirecting it in a slightly different way than the cooler air it meets. To our eyes, it almost appears as if the air is liquid.

The way light travels can be manipulated and redirected by forces altering something called the refractive index. Essentially, this index refers to how much a beam of light can bend in a new direction: a high refractive index means the light will be bent a lot; a low index a little. To get back to our star subject (pun intended): between us and the billions of suns above and around us is a thick film of atmosphere. While this is responsible for keeping us alive, it also distorts light.

The atmosphere is a multilayered "cake", with stacked levels of decreasing density the higher up you go. In the same way the heat of the sand causes interference in the air above, light doesn't have a smooth journey as it makes its way from space to our eyes. Where the different layers meet, light is slightly refracted in a new direction, a process that repeats as it penetrates each successive layer. This results in a zig-zag effect, creating the illusion that the star is slightly shifting. The scientific name is "stellar scintillation", and it's the reason space-based telescopes produce far superior images to ground-based observatories.

But why, you may wonder, don't *all* stars twinkle? There are two main reasons. One is that the light from stars closer to the horizon has to travel through more atmosphere to reach you and so is even more zig-zagged than light from stars higher up. The other is that what appears to be a star is sometimes, in fact, a planet.

A star twinkles not only because its light has to pass through the atmosphere, but also because its light is tiny. The distance of these stars from Earth is so huge that they appear as just a dot. Planets, on the other hand, are closer, so their light appears more as a disc than a dot. The atmospheric distortion is partly cancelled out by light from the planet zigging and zagging in opposite directions.

So the next time you gaze skyward at night, wondering about dancing stars, or when your child or grandchild asks you why that little star in the nursery rhyme twinkles, you'll have an answer.

JAKE PORT, a Melbourne-based writer, contributes to the explainer series on cosmosmagazine.com

IMAGE
01 ChaNaWiT / Getty Images

ILLUSTRATIONS
Jeffrey Phillips

Got a burning question that needs explanation? We want to hear from you. Send your requests to competitions@cosmosmagazine.com
Our favourites will win a *Cosmos* prize pack and also have their question answered in an upcoming edition.

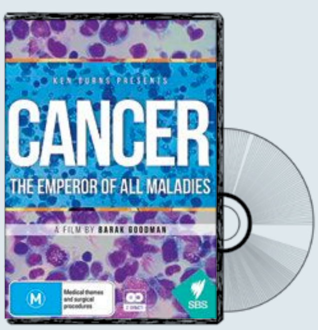
WHERE IN THE COSMOS?

Wess Edgar is a Geologist at the Cosmo Deeps Gold Mine which is located two hours south of Darwin.

Given the coincidence of names on the June–July magazine cover Wess couldn't resist taking a photo at the mine reading the edition.

COMPETITION

Which type of cancer causes the most deaths in Australia?



Email competitions@cosmosmagazine.com the answer with your name and address by 7 November. Four correct entries will win a DVD copy of *Cancer: The Emperor of All Maladies*, courtesy of Madman Entertainment.

Cancer: The Emperor of All Maladies, based on the Pulitzer Prize-winning book by Siddhartha Mukherjee, tells the complete story of cancer, from its first description in an ancient Egyptian scroll to the gleaming laboratories of modern research institutions. At six hours, the film interweaves a sweeping historical narrative; with intimate stories about contemporary patients; and an investigation into the latest scientific breakthroughs that may have brought us, at long last, to the brink of lasting cures.

MIND GAMES

Quiz

Q1. What was the liquid fuel used to power the Octobot?

Q2. Which particle may be evidence of a new force of nature?

Q3. How did researchers help paraplegics regain feeling in their legs?

Q4. What is the shape of bacteria that attach to colon tumours?

Q5. Bacteria and other microbes in the mouth glom together to form what substance?

Q6. The bacteria responsible for dental disease are able to shield the tumour from the immune system by using what protein?

Q7. To run a marathon in two hours, what would the ideal elevation be for the route?

Q8. The three small black whales found washed ashore in Hokkaido, Japan looked similar to what other whale species?

Q9. How did scientists find Proxima Centauri's exoplanet?

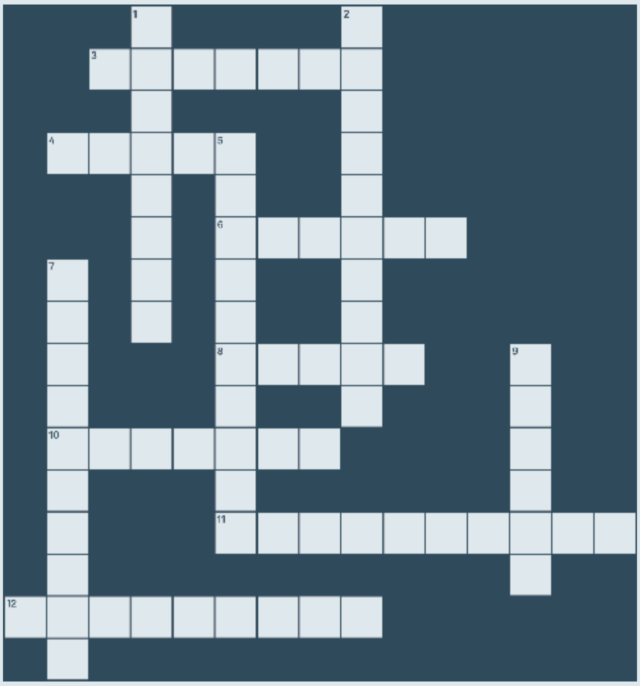
Q10. What is the name of the exoplanet that could have liquid water on its surface?

Q11. Who is the father of space based astronomy?

Q12. Starshade can reduce light diffraction using what effect?

Answers will be published in issue 72.

Cosmos crossword



Answers will be published in issue 72.

ACROSS

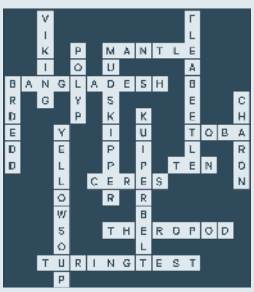
3. 'The great dying' mass extinction event, where 96% of all species were lost, happened at the end of this time period.
4. Acronym for the infrared imaging device on Juno used to capture the north and south poles of Jupiter in remarkable detail.
6. Protein used by food scientists to create edible wrappers.
8. Name of the asteroid that the OSIRIS-REx spacecraft is set to reach in 2023.
10. Sea creature that hermit crabs use as protection.
11. Molecule that forms when food is cooked at high temperatures.
12. Research that tested the effectiveness of common nosebleed drugs found that this remedy was similarly effective (4,5).

DOWN

1. Meaning 'four-footed'.
2. Principle of fluid dynamics that helps the Dyson Air multiplier suck in surrounding air.
5. Name used to describe the community of microorganisms that live inside our bodies.
7. Name of the drug that clears the toxic proteins associated with Alzheimer's disease.
9. Scientists are 'sniffing out' this acid that indicates an old book is beginning to break down.

SOLUTIONS: COSMOS 70

CROSSWORD



QUIZ

1. Reservoir of magma approximately 10 kilometres below surface
2. The Pacific plate and the Australasian plate
3. Quasi-satellites
4. Around a century
5. Through sandflies
6. 17
7. In a quarry in southern Sweden
8. Mars and Jupiter
9. From birth
10. 100 times the distance of the moon
11. A meteorite that doesn't fall on Earth today because its parent asteroid is now completely destroyed.
12. Large

WINNERS

COMPETITION: COSMOS 70

The Human Genome Project was declared complete in 2003.

Congratulations to our winners for answering correctly:

Robyn Devenish, Mandurah, WA; Juliette Merckens Auee, Mordialloc, VIC; Greg Hancock, Parramatta, NSW and Ross Avery, Elwood, VIC; will each receive a DVD copy of *DNA Nation*, courtesy of Madman Entertainment.

COMPETITIONS

WHERE IN THE COSMOS

Send a photo of yourself reading a copy of *Cosmos* Magazine in an interesting place anywhere in the universe to competitions@cosmosmagazine.com.

Tell us your name, the names of others in your picture, your address, what you're doing and why you're there. If published you will receive a *Cosmos* prize pack.

PORTRAIT

Nerida Wilson, marine molecular biologist

NERIDA WILSON was diving off Victoria's Mornington Pier when she spied her first nudibranch, "an incredible bright orange creature with blue and pink dots," she recalls. It was her introduction to some of the most flamboyant animals on the planet – examples of Darwin's "endless forms most beautiful". She's dedicated herself to understanding how such diversity evolved in what is basically a sea slug.

For her PhD at the University of Queensland, Wilson explored the nudibranch family tree using the shape of their sperm and DNA sequences to trace relationships between species. Later her interests expanded to Antarctic nudibranchs. She traced their evolutionary relationships through the defensive chemicals they make. Those chemicals, other researchers discovered, could aid development of new leukemia drugs.

Wilson has held postdoctoral positions around the world, from Auburn University in Alabama to the Western Australian Museum, her current post. Along the way, she has discovered more than 50 new species, the most recent while diving off western Australia's Pilbara coast.

Nudibranchs, it seems, consume most of her waking hours. "Obsessions are incurable," she says. "I think that's clear."

— ELIZABETH FINKEL

IMAGE
f22 photography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