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COSMOS 70
COVER STORY & FEATURES

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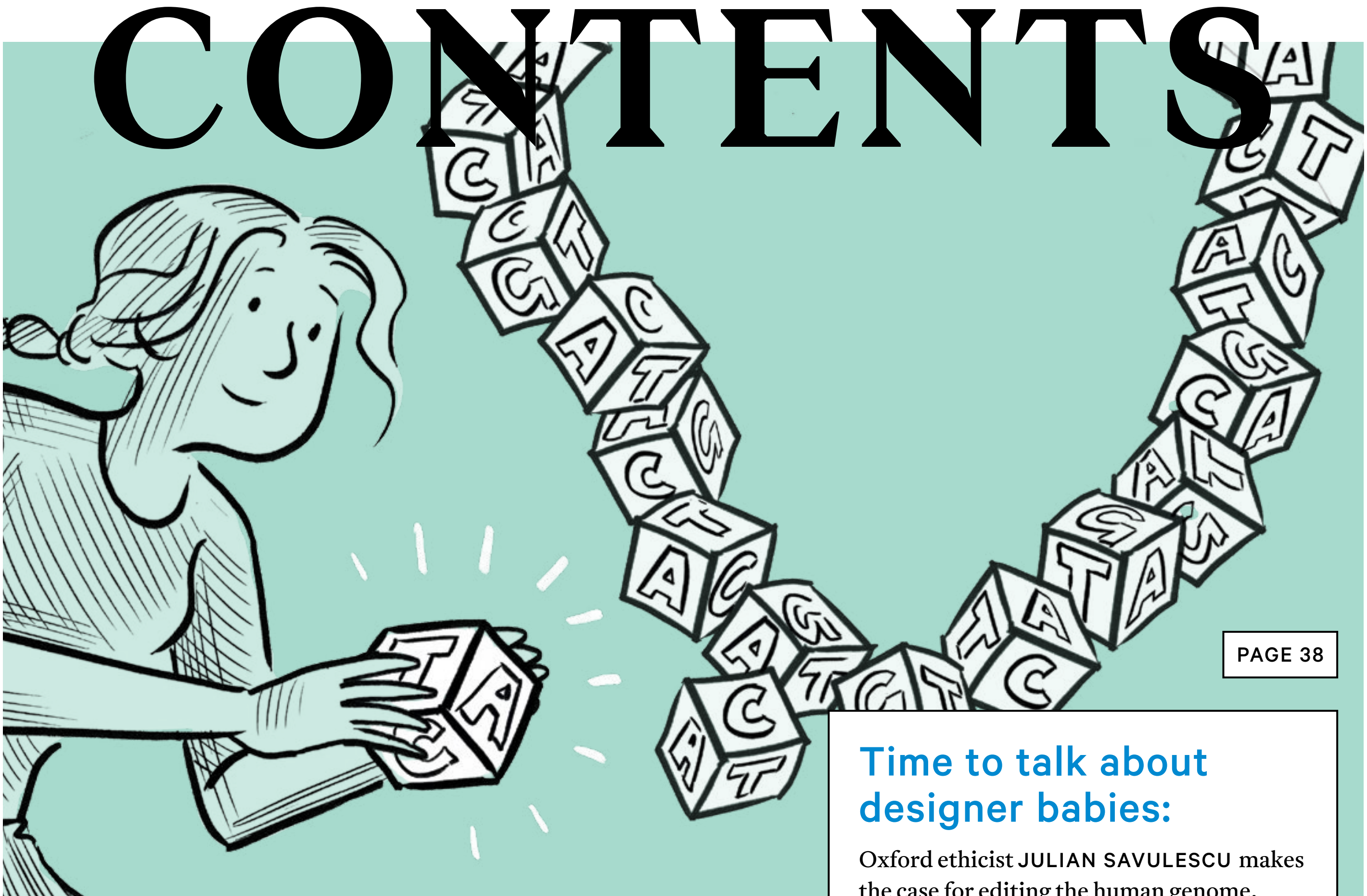

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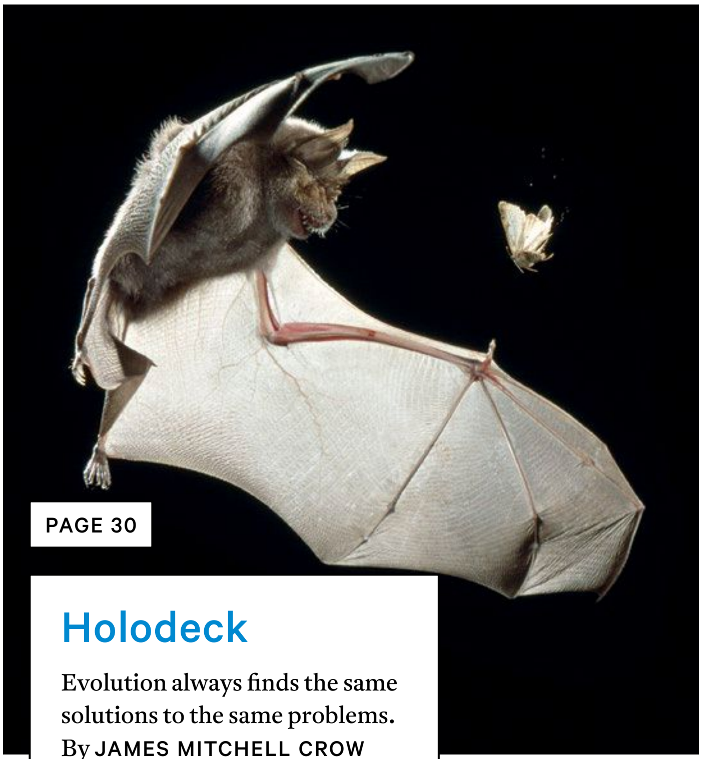
DISPATCHES, ESSAYS & REVIEWS



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Holodeck

Evolution always finds the same solutions to the same problems.
By JAMES MITCHELL CROW

FEEDBACK

WRITE TO US

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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OVERTAKEN BY THE BIG BANG

Katie Mack (*Cosmos*, Issue 69, page 21) refers to light that has taken 13.4 billion years to reach us, and that we are therefore looking at a galaxy as it was only 400 million years after the Big Bang. Surely, 400 million years after the Big Bang, we and that galaxy were not 13.4 billion light years apart and that 13.4 billion year old light should have passed us ages ago! Can you explain, please?

My second query relates to red shift. If we think that the colour of a heavenly body is red-shifted, that presupposes that we know what colour we expect it to be. How would we know?

— SIMON ALLEN
Cooma, NSW

EDITOR'S REPLY:

Ah, but meanwhile, the distance between "us" grew much longer. Imagine a hungry ant on the surface of a small balloon, and you dab a nice piece of jam 10 centimetres away. The ant races towards it at top speed of 1 cm/second, thinking lunch is 10 seconds away. But then you blow air into the balloon, creating more space between the ant and the jam. If you expand the balloon fast enough, it could take the ant a billion years to cross that initial 10 centimetres!

As for red shift, each element on the periodic table has a kind of "light fingerprint" – a selection of colours that it can absorb and emit. These fingerprints are still recognisable even if stretched.

LEFT WONDERING ABOUT THE ANSWER

In recent "Philosopher's Corner" by Laurie Zoloth (*Cosmos*, issue 69, page 22), I assume Ms Zoloth supports animal testing but it's hard to see why from her article. I can only assume she's ducked the issue.

Is primate research ethical? I'm none the wiser after reading it.

— ROB BOOTH
Via Email

A CELL MEMBRANE IS NOT A CELL WALL

I enjoyed *Cosmos* issue 69 very much, particularly the articles on Cancer Research and Darwin's Garden.

However, in the article on regenerative biology (Young Frankenstein, *Cosmos* 69, page 56), I was dismayed to see the term "cell wall" used to describe movement of ions into frog cells.

The cell wall is a distinctly different structure to the cell membrane and is only found in plants, fungi, some protists and bacteria. Its function is to provide structure and support whereas the cell membrane is found in all organisms.

— BARBARA WELLER
Toowoomba, Queensland

EDITOR'S REPLY:

Well-spotted!
Thanks for the correction.

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EDITOR'S NOTE

ELIZABETH FINKEL
Editor-in-chief

It's time to discuss GM babies

TAMPER WITH THE DNA of future generations? I had always thought this was a moral line in the sand that would never be crossed — that it had been inscribed with weighty moral force by the pioneers of genetic engineering in the 1970s.

I was mistaken.

The era of genetic engineering began in 1972, when Paul Berg at Stanford University learnt to cut and paste DNA from one virus to another. Dubbed the father of genetic engineering, he realised he'd opened Pandora's box. People were worried: would scientists create monsters?

Berg called for a moratorium and organised the 1975 Asilomar Conference on Recombinant DNA. Amidst the windswept Monterey pines and crashing waves of California's coast, 140 scientists, lawyers, journalists and ethicists discussed the potential dangers of GM microbes and came up with guidelines to safely contain them.

I had thought that was the moment when the line in the sand was drawn: thou shalt not tamper with the DNA of a human sperm, egg or a newly formed embryo. But on probing, I find no evidence. "There wasn't a moral line in the sand," Asilomar co-organiser David Baltimore, now an emeritus professor at California Institute of Technology, told me. "There was the simple recognition we were not techically in a position to consider such a thing".

Nevertheless, since then many countries have considered germ-line gene modification beyond the pale, and enshrined this belief in legislation.

For decades, the regulatory harness held firm. We've had genetically-modified bacteria that produce our drugs, pest-resistant cotton, goats producing spider silk in their milk, gene therapy trials for sick people. But no tampering with the human gene pool.

Until April of last year. Making use of the new CRISPR technique – so accurate it has been named genetic editing rather than engineering – Chinese researchers "edited" the DNA of unviable human embryos to correct a gene that causes severe anaemia.

Sure enough, it sounded the alarm bells. Jennifer Doudna, the Berkeley scientist who developed CRISPR in 2013, said she'd stopped sleeping at night. NIH head Francis Collins condemned the trespass saying it was "viewed almost universally as a line that should not be crossed".

But it's certainly not a universal reaction.

Like Oxford ethicist Julian Savulescu, author of our cover story, Baltimore agrees there is a strong moral case for editing the human germ line. In a bookend to Asilomar, he and Berg helped organise an international meeting of scientists in Washington last December to discuss the ethical implications of the tool. "It's not ready for prime time now, but it's only years off," he says. "We should be thinking about it."

ISSUE 70

COVER
According to some scientists and ethicists, we can expect a bonnie baby like this around 2026. She will have the genetic odds stacked in her favour to lead a long, healthy life. What's wrong with that?
CREDIT: ERIN VEY / GETTY IMAGES

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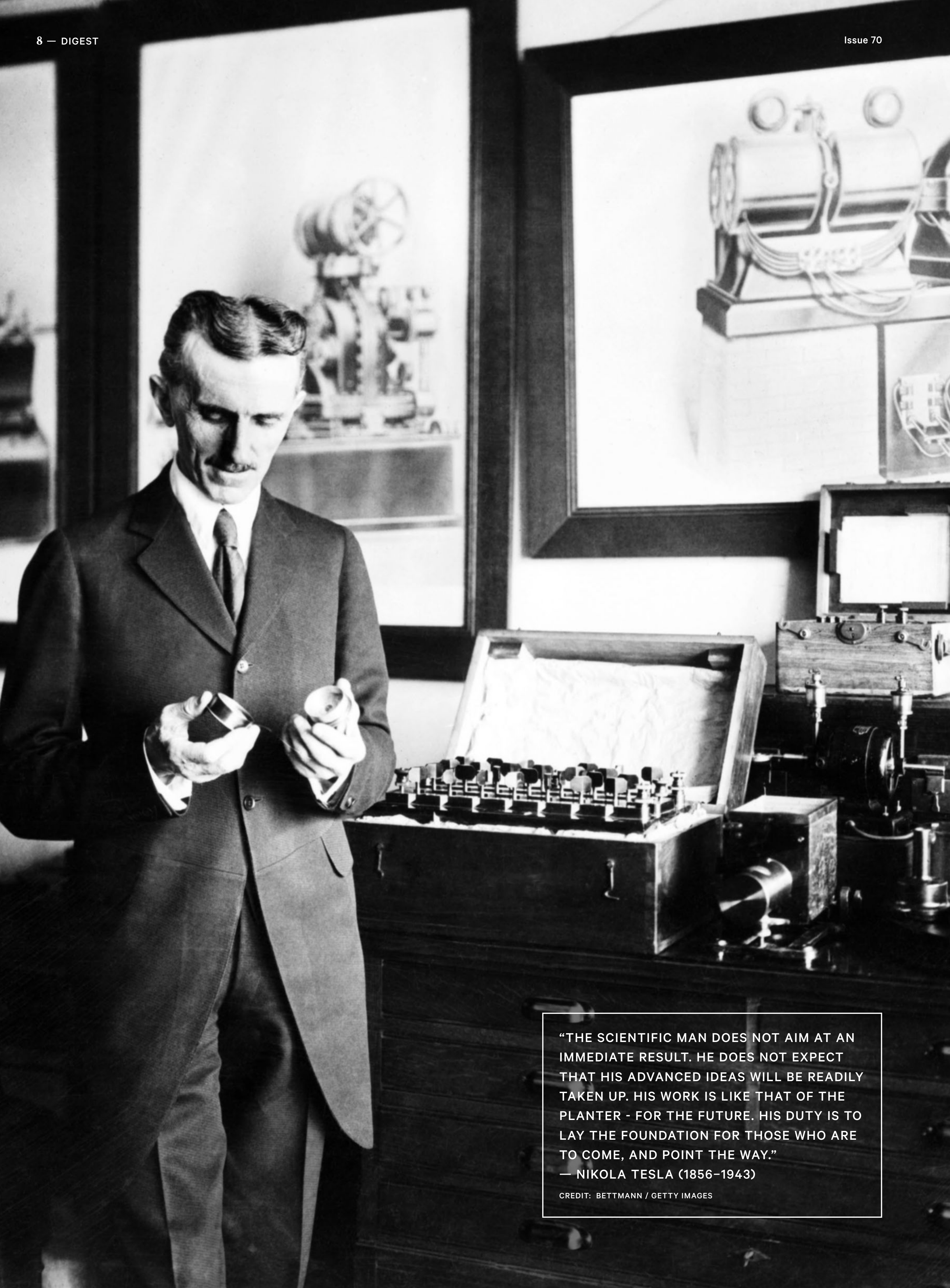


"THE SCIENTIFIC MAN DOES NOT AIM AT AN IMMEDIATE RESULT. HE DOES NOT EXPECT THAT HIS ADVANCED IDEAS WILL BE READILY TAKEN UP. HIS WORK IS LIKE THAT OF THE PLANTER - FOR THE FUTURE. HIS DUTY IS TO LAY THE FOUNDATION FOR THOSE WHO ARE TO COME, AND POINT THE WAY."
— NIKOLA TESLA (1856–1943)

CREDIT: BETTMANN / GETTY IMAGES

A CLOSER LOOK AT THE BIG STORIES

DIGEST

SPACE

Juno locks into Jupiter's orbit

Overcoming considerable odds, NASA's spacecraft arrived safely and manoeuvred into the gas giant's orbit. RICHARD A. LOVETT reports.

After a tricky journey whose success was far from guaranteed, NASA's Juno spacecraft is now orbiting Jupiter. On the evening of 4 July PDT, it braved one of the most extreme environments in the solar system to skim within 5,000 kilometres of the giant planet's cloud tops, firing its main engines to brake just enough to put it in the desired orbit. →

An artist's rendering of Juno approaching Jupiter.

CREDIT: NASA / JPL-CALTECH

→ "After a 1.7-billion-mile journey, we hit our burn within one second on a target that was just tens of kilometres large," says the mission's project manager Rick Nybakken of NASA's Jet Propulsion Laboratory in Pasadena, California. "That's how well the spacecraft performed tonight."

"We conquered Jupiter," added Scott Bolton, the mission's principal investigator.

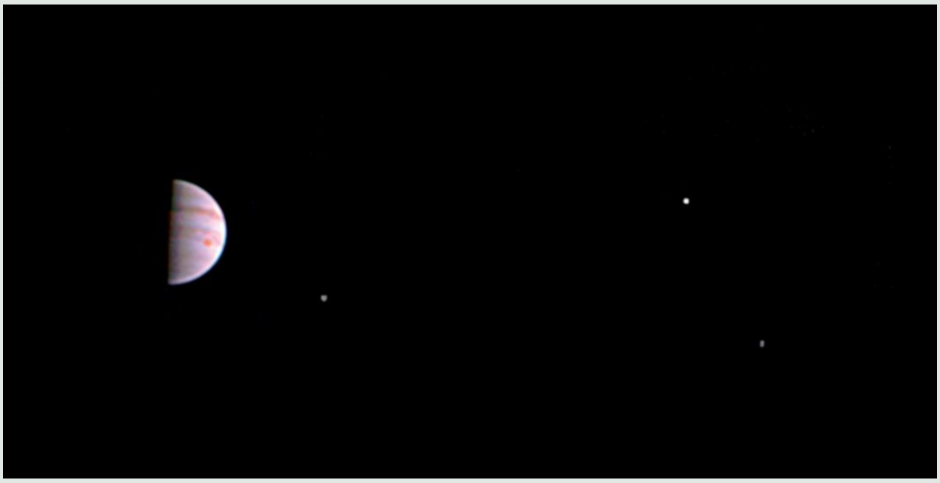
Although the spacecraft's engines had been fired two times previously for mid-course corrections, this was the burn that had the scientists and engineers biting their nails.

That's because it had to be conducted within Jupiter's intense radiation belts, which could interfere with Juno's electronics, causing its engines to misfire and the spacecraft to veer off course.

NASA even had a backup plan – if the engine unexpectedly shut down, the probe's computer would reboot as quickly as possible in an effort to restart the engine to keep the probe from whizzing past Jupiter into interplanetary space.

Another risk was that the spacecraft might hit a fleck of dust as it zoomed between Jupiter and the inner reaches of its rings. "Even a small piece can do serious damage," Bolton said, adding that the engine nozzle was particularly vulnerable because it had a protective coating that might get chipped, interfering with the engine's ability to burn properly.

NASA's Juno spacecraft arrived on time and on target.
CREDIT: NASA / JPL-CALTECH / EYES



In this image, taken by the "JunoCam" 5 days after the spacecraft entered orbit July 10th, Jupiter's great red spot and three of the planet's four biggest moons are visible. CREDIT: NASA / JPL-CALTECH / SWRI / MSSS

But none of this happened.

The burn started on time and lasted within one second of its target time. "It was a song of perfection," Nybakken said.

An hour later, the spacecraft passed its last test by rotating from its deceleration orientation back into one in which its solar panels were again turned towards the sun – critical for a solar-powered craft.

"As soon as we turn away from the sun, a time clock starts," Bolton said. "The whole game is to get turned back to the sun before you run out of battery."

The spacecraft is now in a 53-day orbit. Its next close pass of Jupiter will occur in late August. During that pass, Juno will scout for unexpected issues, then fire its engine again to descend into a 14-day orbit, from which it will repeatedly swing by Jupiter over the next year and a half.

That late-August passage will be the first time Juno returns data about the giant planet's near environs. On its first pass, the flight crew wanted to make sure that the only computer systems active were those that were absolutely necessary for the critical braking manoeuvre. "So all of the science [was] turned off," Bolton said.

Once it begins, some of the mission's research will focus on understanding Jupiter's atmosphere. But the primary goal will be to see what Jupiter can reveal about the dawn of the solar system, and what Bolton calls the "recipe" for both the formation of our own solar system and ones we've discovered around other stars.

"Jupiter has a unique position in that recipe because it was the first planet to form," he says.

Part of that recipe will be determined by using Juno's instruments to find out how much water is contained in Jupiter's upper atmosphere – an important marker of how far from the sun Jupiter was when it formed.

THE PRIMARY GOAL WILL BE TO SEE WHAT JUPITER CAN REVEAL ABOUT THE DAWN OF THE SOLAR SYSTEM.

Another will come from Jupiter's gravity field – does it have a rocky core? If so, Bolton says, that means it formed after rocky materials began to form in the disc of gas and dust surrounding the infant sun.

All of that, he adds, helps us understand our own origins.

"Jupiter sucks up the majority of the leftovers," Bolton says. "We are the leftovers of the leftovers."

In other words, Juno's successful arrival at Jupiter might ultimately help us understand ourselves.

"By studying Jupiter," Bolton says, "what you're really learning is the history of the elements that eventually made us."

→ See a video about the Juno mission here: bit.ly/cos70juno

PHYSICS

Full speed ahead

The universe is expanding faster than scientists thought possible. CATHAL O'CONNELL explains why.

Imagine you're driving down a hill and the car's brakes fail, sending you careening downward at an ever-increasing speed. That scenario is frightening enough, but now imagine that the car begins to accelerate even faster, seemingly defying the laws of gravity. In a similar way, scientists have discovered our universe is accelerating much faster than they thought possible.

A team of American and Australian astronomers found that distant galaxies are flying away from us about 8% more rapidly than they should be, given the starting speed of acceleration shortly after the Big Bang.

"A funny universe just got funnier," said Brad Tucker, an Australian National University astronomer and co-author of the work, which can be found on *Arxiv* and will appear in *The Astrophysical Journal*. This faster-than-expected rate of expansion could mean the universe is gearing up to tear itself apart in what some are calling the "Big Rip".

Astronomers have known since the 1930s that the universe is expanding. But in the 1990s scientists made a strange discovery: the universe wasn't just drifting apart in the aftermath of the Big Bang, it was accelerating. Brian Schmidt, Adam Riess and Saul Perlmutter, who won the 2011 Nobel prize for that finding, named the driving force "dark energy". Scientists still don't know what it is, but they do know it represents the chief ingredient of the universe, comprising 70% of its matter-energy mix.

Now a team of astronomers, led by Riess at Johns Hopkins University, have found that not only is the universe expanding, it's accelerating faster than expected. Using the Hubble Space Telescope, they clocked the speed of 18 retreating galaxies over a two-year period. They focused on specific beacons within each galaxy – 2400 Cepheids stars and 300 Type Ia supernovae. Since both types have a standard luminosity, it's a bit like gauging the distance to a town from the brightness of its streetlights. The astronomers also measured the speed of the stars' retreat using Doppler shift – the same principle police radar scanners use to pinpoint a passing car's speed.

Riess and colleagues have calculated the most accurate figure so far for the expansion rate of the universe, known as the Hubble constant. The new calculation shows the universe is expanding at about 73 kilometres per second per megaparsec (3.26 million light-years) with an uncertainty of 2.4%. This means that a galaxy one million light years from us is rushing away at about 22.4 kilometres per second, while another galaxy two million light years distant is flying away twice as fast, at 44.8 kilometres per second.

The problem is, this speed of expansion disagrees with that predicted from measurements using the faint glow of radiation left over from the Big Bang, called the cosmic microwave background. Previous measurements had hinted that our universe was expanding faster than predicted, but the measurements were too inaccurate to be sure. The new set of precision measurements adds more weight to the view that there is something missing from our best theory of the universe.

"Maybe the universe is tricking us, or our understanding of the Universe isn't complete," says Alex Filippenko, an astronomer at University of California, Berkeley and co-author of the paper.

One possibility is that dark energy, already known to be accelerating the universe, may be growing stronger – in other words, that the acceleration of the universe is itself speeding up.

MAYBE THE UNIVERSE IS TRICKING US, OR OUR UNDERSTANDING OF THE UNIVERSE ISN'T COMPLETE.

"The new results have an impact on the dark energy issue, although it's too soon to say what," says cosmologist Paul Davies at Arizona State University.

Alternatively, some physicists propose a yet-to-be-discovered particle may have been present during the early expansion of the universe and altered its acceleration.

One candidate for this particle is dark radiation, which is like the dark matter version of the photon.

But there is another possibility: that these distance measurements may not be as reliable as we think. So don't throw out your physics textbook just yet.

Taken by Hubble Space Telescope, this image shows UGC 9391, a galaxy containing stars that help astromers determine how quickly the universe is expanding.

CREDIT: NASA / ESA / L. FRATTARE (STSCI)

LIFE SCIENCES

"Hobbit" ancestor discovered

A handful of 700,000-year-old bones lays to rest the debate over whether the diminutive hominin was a distinct species. DYANI LEWIS and BILL CONDIE report.

After more than a decade of debate over whether the "hobbit" — the remains of a tiny hominin discovered in Indonesia in 2004 — was a distinct species, scientists have unearthed a new collection of bones that suggests it was.

When the hobbit was first discovered, researchers estimated the remains to be about 12,000 years old, which would mean the creatures overlapped in time with our own species. That timing prompted some scientists to conclude that the remains were from a diseased member of *Homo sapiens* rather than from a separate species. A subsequent analysis published in March this year that used more precise dating methods suggested the hobbit actually lived 60,000 to 100,000 years ago.

But the new find, a jawbone and six teeth found at Mata Menge, just 70 kilometres from the Liang Bua cave where the previous bones were discovered, pushes the timeline for these meter-tall creatures back much further. The new discovery, summed up in a pair of studies published in *Nature*, suggests they lived more than half a million years earlier than previously thought. That bolsters the theory that they were a distinct species, *Homo floresiensis*.

But researchers would need bones from the hominin's body to be absolutely sure the fossils are from the hobbit's ancestors, says archaeologist Gert van den Bergh from the University of Wollongong.

Meanwhile, a separate discovery published in the *Journal of Archaeological Science* has narrowed the time gap between the disappearance of *Homo floresiensis* and the arrival of modern humans.

Researchers at the University of Wollongong and Indonesia's National Research Centre for Archaeology found evidence that early humans likely were using fire at Liang Bua between 24,000 and 41,000 years ago. Since there's no evidence of *Homo floresiensis* ever using fire, the cooks were most likely modern humans, say study leader Mike Morley of the University of Wollongong.

If so, those ancient fireplaces would be the earliest evidence of modern humans in Southeast Asia.

A mold of a *Homo floresiensis* skull made from fragments found in Liang Bua Cave in Flores, Indonesia.

CREDIT: JAVIER TRUEBA / MSF / GETTY IMAGES

SPACE

Mystery meteorite found in Swedish quarry

The space rock offers a glimpse at the early solar system. BELINDA SMITH reports.

A Swedish limestone quarry turned up a rocky revelation: a new type of meteorite that may help astronomers reconstruct the history of the solar system.

Birger Schmitz from Lund University in Sweden and colleagues described the 470-million-year-old piece of space rock in *Nature Communications* in June.

The Thorsberg quarry in southern Sweden had given up space rocks before – it is a rich source of L chondrite meteorites, thought to be debris from a collision between a large asteroid and another object. But evidence of the other half of that collision had never been found. Then, in 2014, workers noticed a strange dark grey smudge in the limestone layers, about eight centimetres long and 6.5 wide. After years of weathering, it didn't look like a typical meteorite. But when analysing the different types (or isotopes) of oxygen and chromium in the rock, Schmitz and his team discovered it was unlike any other.

The strange bit of space detritus turned out to be an entirely new type of meteorite, which the research team named Oesterplana 065.

Phil Bland, astronomer and meteorite hunter at Curtin University in Western Australia, who wasn't involved with the study says "We've found tens of thousands of meteorites on Earth," "To find a completely new type – well, it's fantastic."

Schmitz's team found that the meteorite's age was within a million years of the age of chondrites from the quarry. It's likely, they suggest, that the asteroid that spawned the fragment collided with the L chondrite's parent asteroid, but it shattered into tiny pieces which would explain why the meteorite is – so far – one of a kind.

The team writes that Oesterplana 065 "may be the first documented example of an 'extinct' meteorite" – one whose parent asteroid has been completely destroyed.

Finding more bits of extinct meteorites and tracing which types fell on Earth – and when – will help astronomers to piece together clues about our solar system's youth, the researchers write.

"There is potential to reconstruct important aspects of the solar system history by looking down in Earth's sediments, in addition to looking up at the skies."

EARTH SCIENCES

Huge magma chamber cause of New Zealand temblors

A massive reservoir of hot rock is building up below the North Island — but an eruption isn't likely any time soon. BELINDA SMITH reports.

The culprit behind a recent swarm of earthquakes in New Zealand's Bay of Plenty has been found: a growing pool of magma less than 10 kilometres below ground.

Geophysicists from the New Zealand research institute GNS Science, led by Ian Hamling, tracked how the ground lifted and sank in the Taupo Volcanic Zone, a 30-kilometre area running northeast from the centre of the North Island to the Bay of Plenty coast. They saw the northern section de-formed in a way consistent with a ballooning reservoir of magma beneath.

"There is every possibility the magma body under the Bay of Plenty coast had been there for centuries, and possibly even longer," Hamling says.

Volcanism and New Zealand go hand in hand – especially in the North Island where Rotorua, a town famous for its hot springs, and Lake Taupo sit atop the Taupo Volcanic Zone.

The zone was formed as the Pacific plate, on which New Zealand sits, slowly slides beneath the Australasian plate at the rate of 38 to 49 millimetres per year.

Across its northern segment, earthquakes have shaken coastal towns such as Matata, with several thousand reported between 2003 and 2011.

So Hamling and colleagues used a combination of survey data dating back to the 1950s, as well as recent GPS and satellite images, to measure how much the earth around the area has lifted or compressed.

While a 2015 study, also led by Hamling, showed central and southern sections of the zone have tended to sink a little, the most recent work saw some 400 square kilometres around Matata lifted by 40 centimetres since 1950 – with a burst between 2003 and 2011. Half of this area was offshore.

The pattern and amount of lift couldn't have been produced by tectonic processes (or movements in the crust), so they modelled how a magma reservoir might affect the overlying earth.

The best fit was a blob of magma around 9.5 kilometres below ground, which inflated by around 0.2 cubic kilometres since 1950.

Such reservoirs of hot rock are common, Hamling says, and uncovering one does not mean a volcanic eruption is around the corner.

"While there is absolutely no evidence pointing to volcanic unrest in the Bay of Plenty, this finding underlines the fact that we live in a geologically active country where it pays to be prepared."

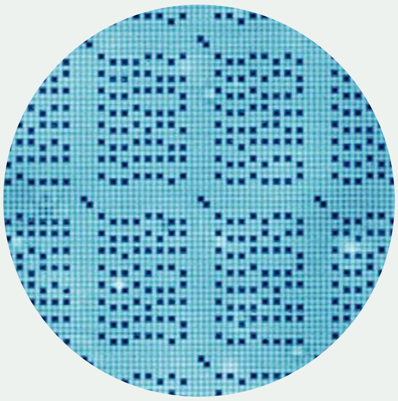
The work was published in *Scientific Advances*.

An active stratovolcano in the Bay of Plenty off New Zealand's North Island.

CREDIT: MICHAEL NOLAN / ROBERTHARDING / GETTY IMAGES

BY THE NUMBERS

ATOMIC HARD DRIVE



CREDIT: TU DELFT

90

The amount of information, in terabytes, a new hard drive the size of an Australian $1 postage stamp can store. The proof-of-concept, unveiled in *Nature Nanotechnology* in July by Dutch researchers, works by encoding data onto a grid of chlorine atoms on a copper surface in a way that allows them to be read as binary code.

0.1

Side length, in millimetres, of a cube of this atomic hard drive, which can store the entire contents of the US Library of Congress.

-210

The temperature, in degrees Celsius, the storage device must remain at to retain information. The mini-drive won't be ready for commercial use until researchers overcome this drawback.

TECHNOLOGY

Introducing robo-ray: part animal, part machine

The tiny artificial stingray is the first step towards bigger, more complex tissue-engineered robots, scientists say. BELINDA SMITH reports.

It's a cybernetic organism: living tissue over a metal endoskeleton.

No, it's not the T-800 from the 1991 film *Terminator 2*, but a robotic stingray made of rat heart cells stretched over a gold frame that can glide through water just like the real thing.

Sung-Jin Park from Harvard University, and colleagues in the US and South Korea, unveiled their new method for building bio-inspired robots with engineered tissue in the journal *Science*.

The tiny robo-ray, made of rat heart cells layered over a gold frame, is guided by light.

CREDIT: KARAGHEN HUDSON / MICHAEL ROSNACH

Batoid fish, a family that includes stingrays, are ideal inspiration for robotics. As they manoeuvre through water, their wing-like fins ripple with a front-to-rear undulating motion.

This means they're exceptionally energy-efficient swimmers and their flattened bodies stabilise them against rolling.

Inspired by batoids, Park and colleagues decided to reverse engineer a stingray's muscle and skeletal structures – albeit on a smaller scale.

They started with a 3D body made of stretchy polymer, then overlaid it with a stiff gold skeleton and another stretchy polymer layer. Living cells from heart tissue, which contract naturally, were added last.

The cells were genetically engineered to contract when exposed to certain coloured light. They were printed onto the top of the robo-ray in a serpentine pattern, like squiggles, on the fin.

The end result was a "living robot" just 16 millimetres long and weighing 10 grams but housing 200,000 rat heart cells. Cells at the front of the robo-ray, when stimulated, contracted the fins down. When they relaxed, the gold skeleton popped them up again.

This movement stimulated the neighbouring cell to contract, and so on down the line.

When popped in a 37°C salt solution – similar to a rat heart environment – with glucose for energy and a light to guide it, the tiny hybrid propelled itself through the liquid, albeit very slowly.

With an average speed of 1.5 millimetres per second, the robo-ray could be steered by adjusting the light's brightness on either fin. More intense light causes the cells to twitch faster.

Park and colleagues found the robot could maintain 80% of its initial speed for six consecutive days.

Their prototypes, the researchers write, are a step towards "autonomous and adaptive creatures able to process multiple sensory inputs and produce complex behaviours".

→ A video showing the robo-ray in action can be viewed here: bit.ly/cos70roboray

LIFE SCIENCES

In Syria, an old disease arises anew

The war-torn country faces a new threat – this time from a disfiguring pathogen. VIVIAN RICHTER reports.

Violent conflict has racked Syria for years, leaving thousands dead and more fleeing in search of safety. Now, the country faces a new threat.

Cutaneous leishmaniasis (CL), an historic affliction of the Old World, causes ulcers and leaves disfiguring scars on the face and body. The infectious agent is a group of species of the single-celled parasite *Leishmania*, spread by sandflies common in the Middle East.

According to a June study in the journal *PLOS Neglected Tropical Diseases*, CL in Syria jumped from 23,000 cases per year before the civil war to 41,000 cases in the first half of 2013 alone. But tracking the disease in conflict zones is difficult. The authors suspect the numbers may be closer to 100,000. "We may be witnessing an epidemic of historic and unprecedented proportions," they write.

With half the country's public hospitals destroyed, suffering is compounded by lack of access to healthcare. "We're not getting on top of the infection," says Grant Hill-Cawthorne, an epidemiologist at the University of Sydney.

Improving refugee living conditions and better diagnosis and treatment could help curb the spread of the disease. The drug currently used to treat CL, sodium stibogluconate, has severe side effects. In 2014, the US FDA approved a broad-spectrum antimicrobial, miltefosine, for CL. The problem, Hill-Cawthorne says, is "there are lots of different species of leishmaniasis, [and] all of them cause slightly different symptoms and respond differently to drugs".

CLIMATE WATCH

EARTH SCIENCES

Wildfires to increase in the subarctic

Fire will become far more frequent in Alaska's boreal forests and tundra – releasing more carbon into the atmosphere. APRIL REESE reports on the new research.

It may be hard to imagine the land of ice and snow on fire. But new research suggests that as the northern high latitudes continue warming, much of Alaska's boreal forest and tundra will burn on a regular basis – releasing into the atmosphere the vast amounts of carbon dioxide they store.

Unlike forest and grassland ecosystems in milder climates, tundra and boreal forests – dominated by cold-loving spruce, pine and other conifers – rarely burn. But they're hypersensitive to changes in temperature and moisture, and as the climate warms and dries vegetation, those ecosystems will ignite much more easily, the researchers found. According to the study, published in May in the journal *Ecography*, fire risk for some areas could be up to four times higher by 2100.

"We saw a significant jump," says University of Idaho's Adam Young, who led the study.

And with more fires come more carbon emissions: forests and grasslands that once absorbed carbon from the air, helping to reduce climate change, will release carbon instead.

Boreal forest and tundra have the most carbon to lose. These ecosystems, which comprise 33% of Earth's land area, store 50% of the world's soil carbon.

"The fate of these massive carbon stocks is directly tied to wildfire," Young and his co-authors write in the *Ecography* study. The burns will likely amplify the loss of stores within permafrost underlying the tundra, which are already escaping as these frozen soils melt with the rise in temperature.

Smoke rises from the Eagle Trail forest fire in interior Alaska, near the town of Tok.

CREDIT: PATRICK ENDRES / DESIGN PICS / GETTY IMAGES

To understand the future of fire in Alaska's two most dominant ecosystems, the team first looked to the past. Drawing from federal fire records, Young and his colleagues examined where wildfires occurred in Alaskan boreal forest and tundra over the past 60 years. Combining that information with climate data, they created statistical models to tease out the link between climate and fire activity during that period. Then they used those patterns, along with climate projections, to predict fire activity through to 2100.

The team found that most fires since 1950 occurred in areas with warm, dry summers. More surprisingly, Young says, they were able to identify a burn threshold – a temperature below which areas rarely burned. "You see this really distinct falloff in fire when you go below 13.4°C," Young says.

Given that higher latitudes are warming twice as fast as the rest of the world, Alaska is especially vulnerable to a spike in fire frequency. More than 90% of the study area, which included all of Alaska except southeastern Alaska and the Aleutian Islands, could burn more often by mid-century, the researchers found. Wildfires like those that swept Alaska's Noatak Preserve in 2010, scorching more than 100,000 acres of tundra, will likely become far more common. Some areas are already seeing unusual fire activity.

In the Davidson Mountains in northeastern Alaska, where average summer temperatures have reached 14.2°C, fires increased considerably between 2000 and 2010, according to a separate recent study published in the *Canadian Journal of Forest Research*.

The projected rise in wildfires in Alaska is part of a global trend. Other studies suggest that wildfires will increase in other parts of the United States as well as Australia, South America, central Asia, southern Europe and southern Africa.

Young and his team hope the work can help land managers and firefighters prepare for Alaska's fiery future. But over time, burning can cause a shift in vegetation: scorched boreal forests may give way to broadleaf species, such as aspen, which don't burn with the same frequency. "The forest that comes back, because it's a novel climate, may not be the forest that was there before," says Jeremy Littell, from the US Interior Department's Alaska Climate Science Centre, who was not involved in the study. And if the new forest burns less often, the carbon threat may not be as great.

Scientists can speculate about how these ecosystems may respond to future climate change and fires, but no one will know for sure until that day comes. Says Littell: "Ecosystems are notorious for giving scientists and land mangers surprises we weren't counting on."

TECHNOPHILE

Buildings that can build themselves

Smart bricks that can self-assemble into structures could be the key to future disaster relief. By CATHAL O'CONNELL.

Picture this scenario: two hours after a bridge is destroyed in an earthquake, its replacement arrives in a crate. Thousands of handball-sized spheres roll out, spilling over one another in their haste to reach the river's edge. The first spheres pop into cube shapes and lock together to make a platform. Other blocks arrive, assembling into a staircase, while yet more form columns to buttress it from below. The self-building bridge stretches across the water.

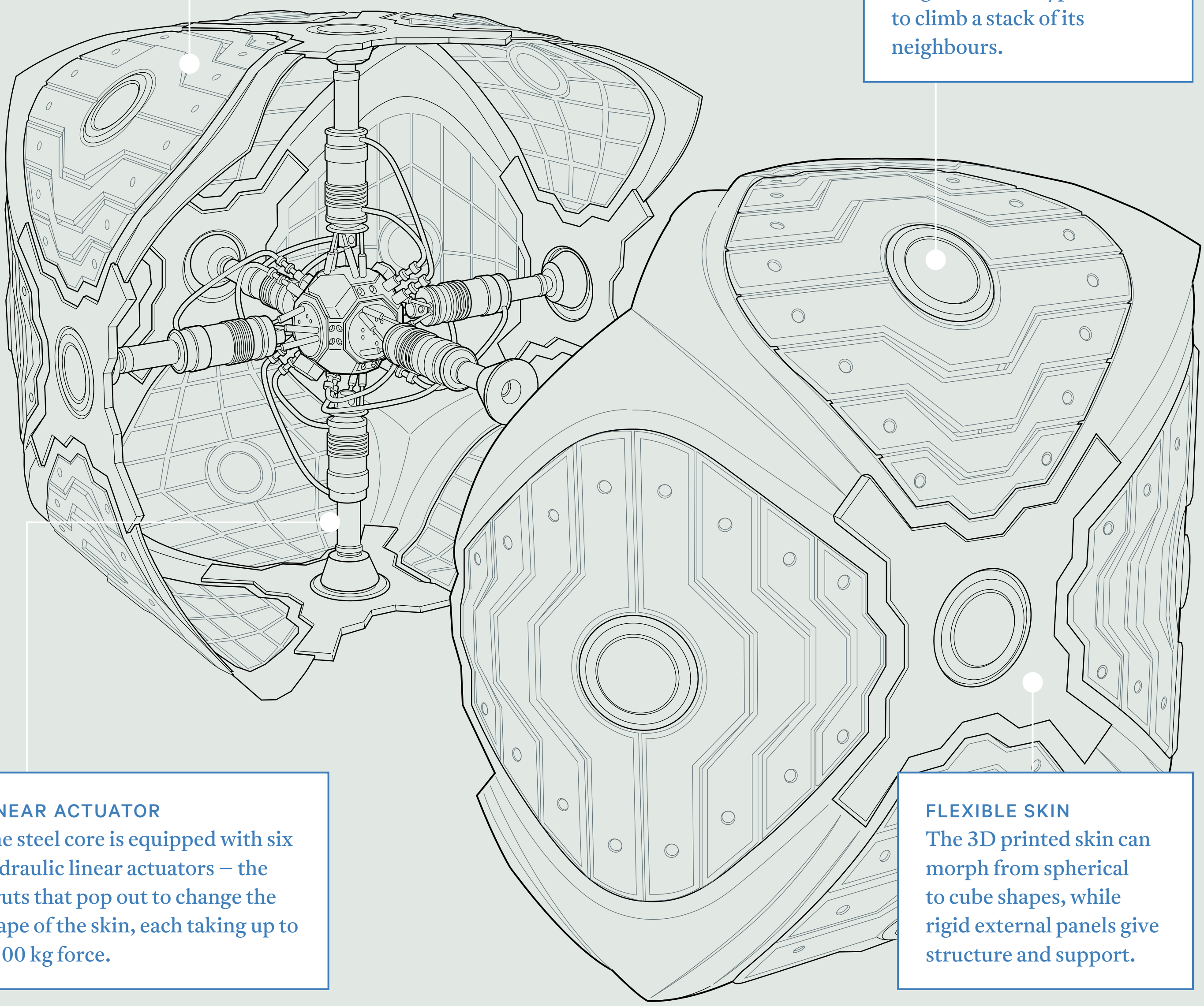
Skyscrapers and passenger jets are engineering marvels made up of billions of individual parts, yet they are dwarfed in complexity by the smallest living organism, which may have trillions of parts. The secret of nature's construction prowess is self-assembly – the ability of each individual component to organise itself into position for the good of the whole. Inspired by nature, a new generation of engineers are creating swarms of robots, able to assemble themselves into myriad different forms.

Harvard University has its Kilobot, a 1000-strong swarm of 3 cm-tall robots that shuffle along on vibrating legs. Give these bots a pattern and they can coordinate like a cheerleading squad to display the desired shape – but only in two dimensions; and they just form pretty patterns rather than useful structures. Massachusetts Institute of Technology has developed M-Blocks, little cubes that can leap up on one another to make basic 3D structures. Inside each block is a motor that revs up a flywheel to 20,000 rpm, generating a store of energy. Braking the flywheel releases that pent-up energy and the brick hops forward like a wayward cricket – it works, though it's not well controlled.

Now a team at the Architectural Association's Design Research Laboratory in London has created the most sophisticated self-assembling system yet: the HyperCell. These shape-shifting cells start out as a 10 cm x 10 cm cube but can morph their elastic skin into a sphere using six internal pistons. By shifting an internal weight, the ball can roll in any direction, like the spherical-bodied BB-8 droid from *Star Wars: The Force Awakens*.

What's more, these cells are smart. Each cell contains a tiny computer chip. It can sense its environment and avoid obstacles. The cells can even communicate with each other – vital when working together. The cells use magnets to join up. Rotating its internal magnets allows a HyperCell to climb on top of its colleagues until it finds the right position, then lock into place.

There is no top-down management system telling the cells what to do. Instead,



SOLAR PANEL
Power comes from a flexible polymer solar cell embedded in the shell, while an internal battery stores charge.

ELECTROMAGNET
Internal electromagnets can rotate within the core to face another hypercell and lock on. Further rotations of the magnet allow a hypercell to climb a stack of its neighbours.

LINEAR ACTUATOR
The steel core is equipped with six hydraulic linear actuators – the struts that pop out to change the shape of the skin, each taking up to a 100 kg force.

FLEXIBLE SKIN
The 3D printed skin can morph from spherical to cube shapes, while rigid external panels give structure and support.

they operate according to the hive mind principle. Give a group of HyperCells a task, and each individual cell decides how it can best help achieve the global aim – like a team of bees or a colony of termites.

The inventors have grand plans for their smart bricks: to redefine what a building is. "[Indoor] space today is usually used for various activities, but while the activities change, the space itself is the same," says Pavlina Vardoulaki, architect, designer and member of the HyperCell team. She envisions a new form of "living architecture" – buildings that evolve to suit the wishes of their occupants.

The first applications, though, are likely to be in disaster relief. HyperCells could help erect temporary shelters, scaffolding to hold up teetering buildings, or even bridges to bring people to safety.

So far, the team has built about 40 prototypes, and the HyperCells can only support about 100 kg. The challenge will be manufacturing stronger HyperCells, with a price tag low enough to be practical, given that hundreds or even thousands of cells are needed for a basic structure. But in the cells' favour, they're reusable – and could, at the end of a mission, disassemble on demand and even pack themselves neatly back into their crate.

→ See HyperCells in action here: bit.ly/cos70hypercells

ILLUSTRATION: ANTHONY CALVERT

BROUGHT TO YOU BY THE AUSTRALIAN COUNCIL OF DEANS OF AGRICULTURE

FROM THE FRONT LINE

African farming trials create food for thought

Small changes in maize-growing techniques are helping farmers in Mozambique boost production. VIVIANE RICHTER reports.

Chopping up coloured strips of material with travel scissors was not how Caspar Roxburgh expected to introduce agricultural science to developing Africa. But as he began a field trial that would boost maize production for rural farmers in Mozambique, he knew his work had to get a little creative.

Roxburgh became inspired to study international development after travelling to South America and witnessing economic hardship. "I thought, coming from a position of privilege, I should do something to return the favour," he recalls. But he wasn't interested in a purely theoretical degree – he wanted the practical skills to complement it.

While pursuing a double degree in agricultural science and international development at Melbourne's La Trobe University, he became interested in maize farming practices in Africa. As a PhD candidate at the University of Queensland, he went to the Manica Province in rural Mozambique to survey maize farmers – work which would evolve into his PhD thesis.

"I find this system where they have lots of rainfall, the soils aren't too bad, they have lots of land –and yet the productivity was among the lowest in sub-Saharan Africa," Roxburgh says. "I really wanted to know more about this."

Roxburgh spoke to 52 farmers from three different communities. It turned out there wasn't much consensus among farmers about the best way to grow the maize – management around plant densities, sowing dates, fertiliser use and the times of weeding varied significantly.

When Roxburgh plugged this information into predictive computer models, he discovered changing these variables could theoretically increase maize yields by up to 120% without extra costs or labour.

So with the help of local farmers, Roxburgh ran field trials in two regions.

In the field trials, farmers plant maize in rows marked with material wrapped around sticks to indicate different conditions. CREDIT: CHARLES STURT UNIVERSITY

As illiteracy often made communication difficult, Roxburgh had to find creative solutions. One example included assigning the farmers to teams, each responsible for planting a different condition in rows marked with bits of coloured material wrapped around sticks. "It also made for great photos!" he recalls.

Through these trials, Roxburgh discovered that changing the weeding schedule alone increased the maize yield by 50% – with no additional labour.

Roxburgh's work received a warm reception from the local farmers. But implementing these strategies permanently or to other parts of the region is a challenge, he says, even though the need is there. Food production in the first half of the 21st century will need to increase by up to 70%, using nearly the same amount of land, the United Nations' Food and Agriculture Organisation has calculated.

"There's no single solution to how that's going to be achieved," says Roxburgh. "We need more studies at the local level and it takes years to tease out options that are viable for every specific community."

He also believes more community workers are required to implement that work with farmers.

Back in Australia, a 2014 Australian Council of Deans of Agriculture study revealed six jobs are available to every agricultural science graduate every year.

THEY HAVE LOTS OF LAND – AND YET THE PRODUCTIVITY WAS AMONG THE LOWEST IN SUB-SAHARAN AFRICA.

Roxburgh, once a humanities student himself, says these jobs are not all graphs and stats. "I'm not actually a particularly good scientist," he admits. "But I can write and communicate – those are the skills that people are looking for in rural agricultural development."

Roxburgh, who is now writing his thesis and wants to expand his agricultural horizons in Southeast Asia, says he has had enormous interest from research organisations worldwide.

"We need more people who don't come from a traditional STEM background, but who see the potential of STEM skills to make a difference," he says. ©

Even simply changing the weeding schedule increased the maize yield by 50%.

CREDIT: CHARLES STURT UNIVERSITY

Clever approach to tackling weeds

Growing canola that fights invaders could be the solution. VIVIANE RICHTER reports.

A crop that does its own weeding may sound like a dream to any farmer.

But two varieties of canola can do just that, a team of Australian researchers has discovered. These varieties stop weeds from growing by releasing chemicals into the soil, a finding which could revolutionise the development of crops.

For farmers, weeds are not just irritating – they're a costly problem. Australian grain growers alone lose an estimated $3.3 billion and 2.76 million tonnes of harvest to weeds every year.

And while weeds are still largely controlled with synthetic herbicides, many species, including the most problematic annual ryegrass, are evolving resistance.

"There are 15 modes of action in herbicides for ryegrass control – we have resistance to 11 of those," says Jim Pratley, agricultural scientist at Charles Sturt University. With farmers starting to run out of options, he says, "there is groundswell to look around for other approaches".

Pratley came across an alternative by accident nearly 30 years ago. He discovered a weed called silver grass actively reduced the growth of wheat and lupin crops by secreting 25 different herbicidal chemicals from its roots, giving itself a better chance to thrive. Pratley describes this natural competition between plants, or "allelopathy", as "chemical warfare" where the victor is most tolerant of the other's cocktail.

"We thought, if weeds have these chemicals, crops may have them too," Pratley recalls. Problem is, he says, "we've bred out any allelopathic capability in crops because we haven't been challenging them with weeds during their development as varieties".

So his team sought to reverse that exercise, and turned to canola. In lab experiments, the team screened 70 different canola varieties for how they

Certain canola varieties can slow ryegrass growth. CREDIT: CAROLYN HEBBARD / GETTY IMAGES

affected the growth of ryegrass plants around them. Two varieties, Av-opal and Pak85388-502, reduced the growth of the weed's roots by at least 70%.

The scientists confirmed their lab results in a field trial. Not only did these two canola varieties significantly slow down ryegrass growth, they also stopped a number of other weeds in the trial's second year. "That was a bonus," says Pratley.

The researchers returned to the lab and identified three chemicals common to the roots of both allelopathic canola varieties – sinapyl alcohol, p-hydroxybenzoic acid and 3,5,6,7,8-pentahydroxy flavones – which they believe are at least partly responsible for inhibiting weed growth.

Pratley hopes these allelopathic chemicals are the beginning of a list of biomarkers which scientists could screen and select for in early breeding programs. Selecting crops for weed-destruction during crop development could reduce the need for synthetic herbicides, he says.

With further field trials of Av-opal and Pak85388-502 underway, the team will continue the search for more allelopathic canola varieties. Even though ryegrass will likely evolve resistance to allelopathic chemicals eventually, Pratley says, rotating crops that secrete different sets of chemicals will help farmers ensure weeds remain challenged. "The allelopathy agenda is not going to be the panacea," Pratley says. "But it is going to be a tool that will reduce our dependence on synthetic herbicides and prolong the efficacy of our existing herbicides." ©

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FROM THE FRONT LINE

Feather map reveals secrets of waterbirds

Researchers are enlisting the help of citizens to track bird movements. VIVIANE RICHTER reports.

Pristine plumage may secure waterbirds an audience, but it's the atomic detail in their feathers that could one day help protect their homes.

A team of Australian scientists is using nuclear techniques to analyse waterbird feathers and create a "feather map" that tracks bird movements. The research, they hope, will help water managers ensure the birds stay healthy and their habitats are protected.

Wetlands in Australia are under pressure from drought, river regulation, climate change and changes to land use. It is estimated that only half of what existed prior to European settlement remains.

The straw-necked ibis, along with other birds that breed in colonies and nest only in wetlands, have been struggling under the stress and populations are in decline.

Waterbirds congregate in large numbers at known breeding wetlands when they become flooded, but where they fly off to in the meantime has been a mystery. Australian waterbird feathers being sent to Kate Brandis at the University of New South Wales (UNSW) are set to change that.

"Feathers are made of keratin which, once it's formed, doesn't change again," Brandis explains. "So feathers create a record of what the birds have been eating and drinking, which is specific to where they are in the landscape."

WE CAN MAKE SURE THE POPULATION IS KEPT HEALTHY, SO THAT WHEN BREEDING OPPORTUNITIES DO ARISE, THEY'RE IN A FIT STATE TO BREED.

As part of a citizen science project, members of the public are being asked to collect feathers from different wetlands around Australia and mail them to Brandis, who will analyse them with colleagues at the Australian Nuclear Science and Technology Organisation (ANSTO) and UNSW.

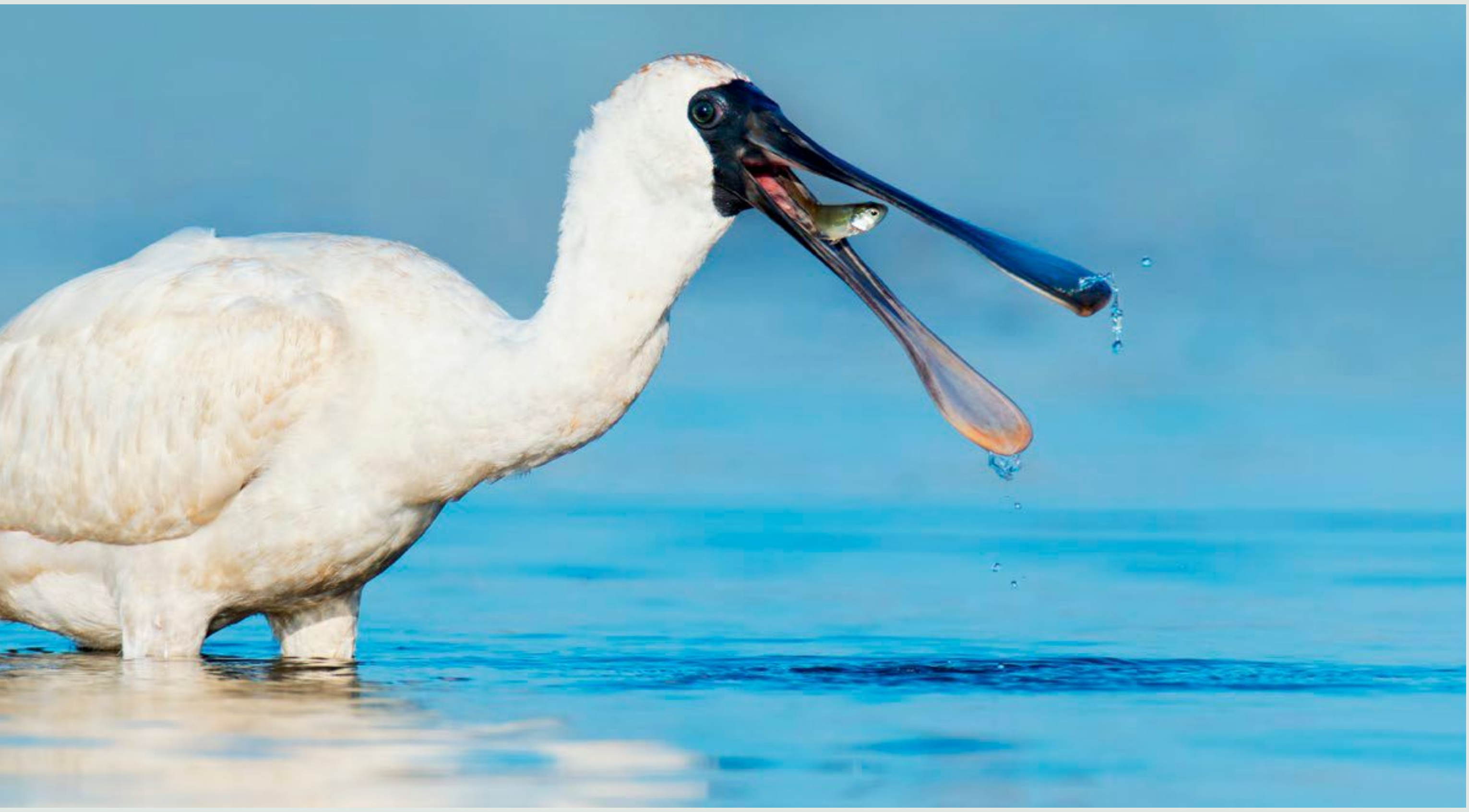
First, Brandis' team will probe the feathers' elements by bombarding a sample with high-energy X-rays. These rays are absorbed and emitted, or "fluoresced", as wavelengths that are characteristic of different elements. Each feather will be scanned to reveal the ratios of up to 28 different elements, which vary in different soils.

"The elements are tied to the geology and the soil of a region and we know they vary greatly across the country," Brandis explains.

Waterbirds incorporate elements from the soil into their feathers through the plants and insects they eat. Brandis found in a pilot study that calcium, potassium and sulfur levels in bird feathers vary the most between a subset of wetlands.

But identifying elements alone is not enough to give away the birds' location. For more data, Brandis' team will analyse each feather's stable isotopes of oxygen, hydrogen, nitrogen and carbon.

Isotopes are different forms of the same element – they contain the same



number of protons but a different number of neutrons at the centre of the atom. Carbon, for instance, comes in two stable forms, carbon-12 and carbon-13.

Birds ingest different oxygen and hydrogen isotopes through the water they drink, and carbon and nitrogen isotopes through proteins in their food. Brandis' team will study each feather sample in a mass spectrometer, where a detector counts how many atoms of the different isotopes are present.

The Feather Map aims to learn more about waterbirds' habitat and diet by analysing information stored in their feathers. CREDIT: UNSW/NICK CUBBIN

The ratios of these isotopes are characteristic of different wetlands in Australia.

In a 2010 pilot study, Brandis showed this by comparing the elements and isotopes in chick feathers from three different wetland sites that had become breeding hotspots for colonial waterbirds after the Murray-Darling Basin flooded.

And analysing feathers is not just useful for tracking the elusive waterbirds. They "can also give us a bit more information on the health of the wetland and the diet of Australian birds," Brandis says.

Brandis will combine this element and isotope data to create her Feather Map, where feathers collected from chicks and birds that don't travel long distances will provide a reference "signature" for the wetland each feather was collected from. The feathers of birds that do travel long distances, such as the straw-necked ibis which moves between wetland habitats, can then be matched to these signatures based on their own elements and isotopes.

Feathers create a record of what the birds have been eating and drinking, which is specific to where they are in the landscape.

CREDIT: JAN WEGENER / BIA / MINDEN PICTURES / GETTY IMAGES

Brandis hopes her map will help inform policymakers' and water managers' decisions about water flow to ensure waterbird habitats are conserved.

"We can make sure that the population is kept healthy, so that when breeding opportunities do arise, they're in a fit state to breed," says Brandis.

Although Brandis has already received thousands of feathers, the researchers need many more.

→ To learn how you can get involved, visit www.ansto.gov.au/feathermap

BROUGHT TO YOU BY UNIVERSITY OF NEW ENGLAND

FROM THE FRONT LINE

Physicists help deliver precision to paddocks

Farming is on the cusp of a new scientific revolution. VIVIANE RICHTER reports.

A farm in Australia is the testing ground for sophisticated sensors and tracking systems that boost crop and livestock productivity with precision. These gadgets – controlled from a smartphone – could revolutionise farm management around the world.

At the University of New England's 2,900-hectare Sustainable Manageable Accessible Rural Technologies Farm, or "SMART Farm", high-tech sensors track soil moisture at hundreds of locations, plane-mounted infrared cameras measure the health of crops and radio transmitters in livestock ear tags track and monitor sheep.

All sensors and trackers connect wirelessly to researchers' tablets and smartphones.

These "smart farm" practices are at the vanguard of "precision agriculture" – a type of farming that involves measuring differences in crop productivity within a region and using that information to make improvements. And the SMART Farm – a demonstration site for new technologies that improve productivity and environmental sustainability – is yielding handsome results.

Analysing data from moisture probes in cotton plots, for instance, has allowed researchers to customise irrigation and double cotton production per megalitre of water. And colour-infrared crop-sensing devices, which allow resources to be focused only where they're needed, have led to a 40% reduction in fertiliser input.

THIS FARM IS DESIGNED TO CAPTURE THE IMAGINATION OF THE WORLD AND THE FARMERS OF THE FUTURE.

In the past six months, UNE researchers also have come up with a new tool for farmers. They've produced the world's first livestock yield maps, which show precisely which grazing areas lead to the biggest weight gains in sheep. These maps could help farmers improve grazing efficiency in open paddocks, which is now only about 30%.

UNE physicist David Lamb, who leads the SMART Farm project says the farm's aim is not only to improve current agricultural practices, but also to "capture the imagination of the outside world and the farmers of the future".

There is high demand in the agriculture industry for experts in everything from sensors and robotics to maths and chemistry, as well as the traditional agriculture and environmental science disciplines.

Multi-disciplinary schools like UNE's School of Science and Technology are the key to providing the crucial mix of pure

University of New England physicist David Lamb says precision agriculture is transforming the industry. CREDIT: SIMON SCOTT and applied sciences that farmers and agricultural researchers need in the 21st century, Lamb says.

Lamb's own path to precision agriculture began with a stroke of good luck. Arriving at the rural Australian university for a lectureship in the mid-1990s, as the agricultural sector was on the cusp of a technology revolution, he was "in the right place at the right time", he says. "Precision agriculture" had just been born, thanks to the global positioning system (GPS) that the US military had recently released for civilian use.

And Lamb, who had stomped around farms as a kid, was hooked.

"Everything just switched on around the same time," he recalls. Lamb's team was modifying GPS devices and attaching them to grain harvesters next to weight monitors and calculating variations in crop yields.

Lamb soon realised that with all the technological advances in the industry, the need for physics-trained researchers in agriculture was critical.

The SMART Farm is a way to show people what a career in agriculture in the 21st century can look like.

The project has attracted attention within and outside of Australia, garnering significant funding from industry partners in Australia and inspiring other researchers around the world to follow its lead.

The team's collaborators at the University of New Mexico, for instance, are using similar livestock tracking technology for rangeland management in the American Southwest.

"Farming of the future is about sustainable intensification – we have the tools now where we can monitor, manage and manipulate the way we do things to get the best out of the soil as well as our limited water and nutrients," Lamb says.

But more physicists are needed. Forget supercolliders – agriculture can be just as fun and challenging.

"I'm doing more physics than I've ever done," Lamb says. "I'm outdoors in the paddock – and I'm having heaps of fun doing it."

→ www.une.edu.au/smartfarm

Greening the cud

Better cattle feed is a win-win for poor farmers and the environment. By DYANI LEWIS.

What do cows eat? If you're about to say "grass", then ruminant nutritionist Fran Cowley from the University of New England will quickly set you straight.

"They *chew* grass," she concedes, but the nutrients that a cow needs to grow come almost entirely from the billions of microbes that take up residence in its gut.

Cowley's job is to tweak this roiling ecosystem so that it churns out more nutrients for the cow, and less of the potent greenhouse gas methane.

"It's a win-win situation," she says.

But there's a third important beneficiary in the equation. The farmers Cowley works with – subsistence farmers in Indonesia, Cambodia and Myanmar – are some of the poorest, many earning less that $2 a day.

Fatter, healthier cows can make the difference between just scraping by and having enough money to send your children to school and pay for unexpected medical bills.

Traditionally, smallholder farmers – those who cultivate rice and other crops on small parcels of land – might own just one or two cows. These "cash cows" don't earn the farmers a steady income, but they are useful assets that can be sold for quick cash when times are tough.

"It's like an online savings account," says Cowley.

Cowley works directly with farmers and local research organisations to find cheap, low-cost or no-cost feed that can turn a "savings" cow into a money-spinner.

Tree legumes, such as Leucaena, are one solution. Like soy and other legumes, Leucaena trees use nitrogen-fixing bacteria to harvest nitrogen from the soil. This allows them to plump their leaves full of protein, which makes for a high-quality cow feed that doesn't need to be purchased and replanted each year, and takes far less time to harvest than dry straw.

Leftover waste meal from cassava, palm oil, and coconut processing are also good feed options in some communities.

The aim is for cows to be healthy enough to produce one calf per cow per year, which can be fattened and sold. Additional resources are put towards buying skinny cattle and fattening them for market, too. The difference between the cows' usual diet and a more nutritious diet is huge. Fattening times can be slashed from 18 months to just six.

Not only does this deliver money to farmers' pockets, it drastically reduces the amount of methane the cows belch into the air. When cows are fed high quality, protein-rich diets, the ecosystem of microbes in their rumen – which Cowley describes as a "big fermentation vat" – shifts.

Instead of being dominated by polluting methane-producers, the ecosystem becomes dominated by cow-fattening nutrient-producers. These bacteria churn out volatile fatty acids, such as propionate, which is absorbed and converted to glucose in the cow's liver.

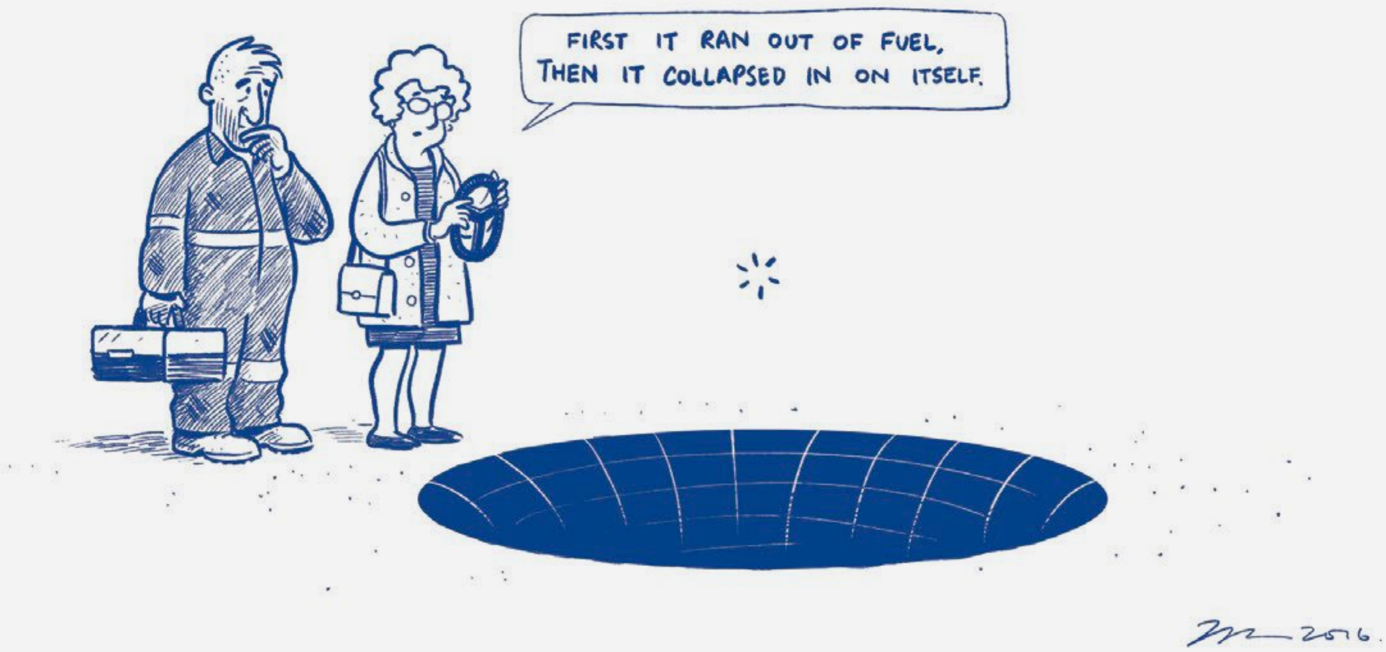
Now, when she travels to villages on the island of Lombok in Indonesia, Cowley sees change. More brick houses, more tractors and motorbikes, fewer bark huts than only a couple of years ago. And children who once spent hours each day gathering straw can attend school.

"To actually see the changes happening in communities is really rewarding," she says.

Fran Cowley, looking for a 'win-win' with cow nutrition . CREDIT: UNIVERSITY OF NEW ENGLAND

OPINIONS, IDEAS & PERSPECTIVES

VIEWPOINT



“A BLACK HOLE IS THE ULTIMATE METAPHOR FOR AN INVISIBLE DESTROYER”

KATIE MACK — ASTROPHYSICS

NORMAN SWAN
BODY TALK

KATIE MACK
ASTRO KATIE

ALAN FINKEL
INCURABLE ENGINEER

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

BODY TALK

Cut the fat?

The debate over obesity surgery.

SO YOU'VE DEVELOPED type 2 diabetes and are overweight? Some experts might want you to consider surgery.

It's a far cry from the standard prescription: blood-sugar lowering medications, diet and exercise. But that's the advice of a panel of 48 experts, published last May in a journal called *Diabetes Care*. What they recommend, sooner rather than later, is bariatric surgery to shrink the size of your stomach and bypass bits of your small intestine. (Bariatric comes from the Greek word for weight).

Surgery for diabetes may seem extreme. But for more than half of those affected, standard interventions fail to control their high blood sugar and the resultant damage to blood vessels can lead to blindness, kidney failure, heart disease and stroke. By contrast, surgery can reverse diabetes in up to 60% of patients.

The 48 experts are not rebels. They were " voting members" at the Diabetes Surgery Summit held in London last September. Their guidelines have been endorsed by 45 international professional societies.

Besides a reversible gastric band, two non- reversible procedures are used in bariatric surgery: vertical sleeve gastrectomy and Roux-en-Y gastric bypass. The first staples off a major chunk of the stomach so you eat less; the second reroutes food from the stapled stomach to the lower part of the bowel, bypassing the duodenum so you both eat and absorb less.

The 48 experts – three quarters of whom were not surgeons – recommend surgery should be offered to anyone whose Body Mass Index is above 30 if their blood sugar isn't well controlled. They also call on governments and health insurers to provide subsidies.

The number of potential candidates for surgery is huge. There are currently about a million people with type 2 diabetes in Australia, and an estimated 50–60% of them are obese. If they were to receive surgery at $11,000 per operation, that's a $2.75 billion price tag, not including dieticians, psychologists, failed operations and complications.

That's an eye popping number but it's not that different to the bills for knee and hip replacements, cardiac stenting, and bypass operations – procedures that often arise from obesity and diabetes. If we don't baulk at these procedures, why should we baulk at bariatric surgery?

Well, we know why. It's because we think "diabesity" – where diabetes is linked to obesity – is an entirely preventable condition, resulting from weak will and perhaps 'bad parenting'.

Yet there isn't a shred of evidence that indulgent parenting causes obesity.

Research from Joe Proietto and colleagues at the University of Melbourne has found that in obese youngsters, the hormones that regulate appetite seem to be at fault. They are rigidly set at high levels, and are not brought down by dieting. This goes a long way to explaining what we all know: weight-loss diets don't work in the long term.

People who develop diabesity later in life may also be victims of their hormones. Unpublished studies from Stephanie Amiel's group at King's College in London and other studies from the University of Cincinnati suggest that some young people, even before the kilos start piling on, are unusually resistant to the hormone insulin that lowers blood sugar. The pancreas responds by pumping out even more insulin; insulin in turn triggers fat storage.

The fascinating thing about bariatric surgery is that it seems to re-set both blood sugar levels and appetite control in a way that dieting doesn't. Within days of surgery, well before any significant weight loss, patients suddenly experience a return to lower blood sugar levels. And there's a sustained preference for a lower fat, less sugary diet.

Exactly how that happens is a bit of a mystery. The gastrointestinal (GI) tract secretes more than 40 hormones and is densely wired with nerve cells. These chemical and neural signals control our metabolism and appetite control. Changing its architecture changes those signals. Microbes that live in the bowel add chemical signals of their own and are also clearly affected by surgery.

A greater role for surgery does not replace interventions to help people take control of their lifestyle choices. It also doesn't mean you let up on unhealthy food marketing to children and the availability of cheap sugar-filled soft drinks.
The only weak will in the prevention of obesity is that of politicians unwilling to regulate the food industry and stare down its lobbyists.

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

ASTRO KATIE

The bright side of black holes

They are key to the evolution of galaxies.

OVER A BILLION YEARS AGO, two black holes in a distant galaxy spiralled together, rippling the very fabric of space. In December, those ripples reached the Laser Interferometer Gravitational-Wave Observatory (LIGO) in the US, marking the second gravitational wave detection in history. The first occurred just three months before.

Black holes are real, and they're speaking to us directly from across the cosmos.

In popular culture, a black hole is the ultimate metaphor for an invisible destroyer: a dark, inescapable force swallowing everything in its path. Not even light can escape its gravitational pull. Yet black holes are some of the most essential, ubiquitous and brightest objects in the universe.

Black holes were first proposed as a natural result of the death of a star. Now there are hints that black holes might also be an essential part of the formation and evolution of galaxies.

Our own galaxy is teeming with black holes – hundreds of millions according to one estimate. The simplest way to make a black hole is to take a star many times as massive as the Sun and wait several million years for it to run out of fuel. When that happens, it will collapse in on itself.

To a physicist, a black hole is fairly simple: a pure spacetime object defined only by its mass, spin (leftover from the spin of the progenitor star), and perhaps an electric charge. According to a yet-to-be-proven theorem, black holes cannot have any other properties. From an astronomer's point of view, however, black holes are anything but simple.

The first stellar-remnant black hole was discovered in 1964, when astronomers zeroed in on a source of strong X-rays and radio waves. It was named Cygnus X-1 after the constellation where it was spotted. Cygnus X-1 is producing light, rather than devouring it. That's because it's not alone: Cygnus X-1 is in a binary orbit with a hot blue star that it is slowly cannibalising. As the stellar material nears the black hole, it condenses into a disc of hot material, making the black hole visible in the same way a whirlpool is made visible by colliding material swept up in the vortex. Systems like this are called X-ray binaries and they're easy to spot with X-ray telescopes. But more massive black holes can outshine entire galaxies.

Supermassive black holes, weighing in at millions to billions of solar masses, can be some of the brightest objects in the universe. As far as we can tell, every decent-sized galaxy has a supermassive black hole in the centre of it. Such a monster might have formed through the merging of smaller black holes or through voracious consumption of nearby matter; most black holes probably grow through a mix of these two processes. When actively consuming gas and dust, supermassive black holes light up like the X-ray binaries, but on a much larger scale.

These powerful objects, called active galactic nuclei, serve as the central engines for violent outflows of matter and radiation. While matter falls into the black hole in a hot, swirling disc, the tangled magnetic fields produced by the interaction of the disc and the central black hole can also drive matter and radiation outward in powerful jets extending thousands of light years. This violent upheaval helps make black holes, which are hard to see, at least easier to trace. The four million solar mass black hole in the centre of our own galaxy is detected through its consumption of small amounts of interstellar gas and dust, and by watching stars zip around it in close orbits.

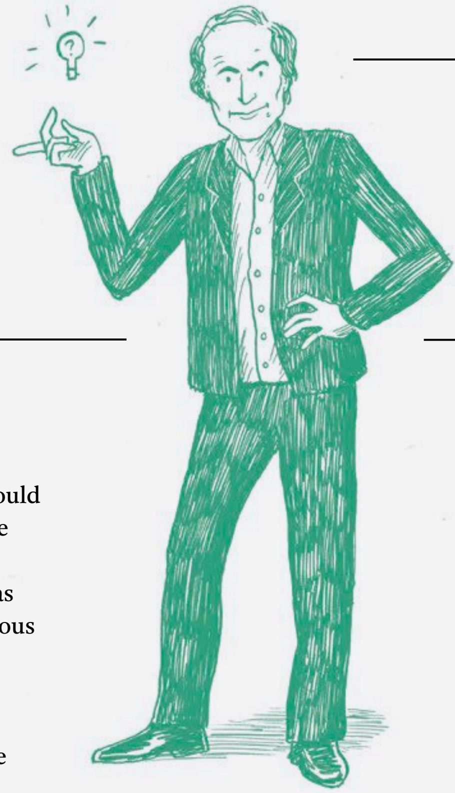
IT SEEMS CLEAR THAT THE GROWTH OF BLACK HOLES AND THE GROWTH OF GALAXIES ARE INEXTRICABLY LINKED.

Astronomers are still working to understand exactly how supermassive black holes in the centres of galaxies grow to such enormous sizes, but it seems clear that the growth of black holes and the growth of galaxies are inextricably linked. Even though a supermassive black hole constitutes a tiny fraction of a galaxy's total mass, the two appear to build up in lockstep with each other. How one manages to influence the other is still a mystery.

Black holes are far more than just a cool abstract concept about the stretching of time and the "spaghettification" of things that fall in. They are central to the evolution and structure of the cosmos. And we're just starting to explore how.

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

INCURABLE ENGINEER



Finding a sure cure for election dysfunction

Delays with the federal vote count prove that Australia needs a new polling system.

ON 2 JULY, 11 million Australians elbowed their way into tiny cardboard polling booths to vote. Then, along with the other 5 million or so who cast postal or early votes, they agonised for 10 days waiting to find out who would rule the country. When it comes to voting, we're doing it the way we did 100 years ago. What happened to progress?

All the organisations I belong to shifted to secure electronic voting years ago. I receive an email asking me to vote for a new treasurer or committee member via a unique link that can be used only once. The system works perfectly well.

"Why can't we do the same for our national elections?" I asked myself as I tried to lay down my metre-wide Senate voting form on the half-metre-wide polling booth shelf to scratch down my selection with a pencil.

It seems a no-brainer. But we are far from the only country stuck in the doldrums of paper voting. Only three nations have braved the new electronic world – Estonia, with nationwide internet voting, and Brazil and India with electronic voting machines installed in traditional polling booths.

So why the reluctance?

It turns out that using a touch screen to vote in national elections is far more problematic than voting to elect the committee of my golf club.

Given that members of parliament govern most aspects of our lives, we should not be prepared to accept any risk in the voting process.

And there are risks. A target as big as a national election would attract malicious hackers like moths to a flame. So any decision to shift to electronic voting should not be taken lightly.

There are also good reasons to make any electronic voting available only in polling stations – with obvious exceptions for voters who are out of the country or otherwise cannot attend in person.

If we allowed the electorate to vote from the comfort of their own homes, it could open them to the threat of coercion, where a controlling personality forces others to vote a particular way. Our polling booths, while flimsy, guard our privacy and protect us from this.

Polling booths are also good at protecting the confidentiality of voters by decoupling identity from the contents of the ballot paper. You register your identity at the first station and then go off to vote in privacy. But even with electronic voting, this time-honoured two-step process could be preserved.

Simplicity is essential. In the privacy of a cubicle, instructions from the electronic voting machine would guide the voter through the process. Airlines have learnt to do this for unattended check-in, so you would think it could be possible for voting.

Improved accuracy is another key advantage of an electronic system. If there is one thing that machines do better than humans, it is arithmetic.

The system also has to be verifiable. If the vote is close, the loser may demand a recount. The easiest way to ensure that's possible is to have a paper backup. Once a person has voted, the machine could print a copy, which the voter would put into a ballot box for safekeeping – just as they do today.

These checks and balances would help address the biggest concern about electronic voting: cyber-attack.

Restricting electronic voting to polling booths and ensuring that there is a paper back-up for a manual recount would substantially reduce this risk. But every aspect of the system would have to be validated and tested by security experts.

All things considered, the pros of shifting to an electronic system far outweigh the cons. Within minutes of the close of polling, the data from the voting machines at each polling booth would be electronically gathered, securely transferred to a central counting system and the results of the election would be known.

Voting for our national leaders is our most cherished right. It's difficult to meet the goals of speed and accuracy while guaranteeing the process will not be corrupt, difficult or subject to coercion or criminal interference. But when the clever country is left in limbo for 10 days, you have to think about a better way.

There is no reason not to try to bring voting into the 21st century.

Graeme Clark Oration 2016

Science and Technology: New Frontiers for Helping People with Mental Illness

Delivered by Thomas R. Insel, MD Verily Life Sciences, USA

6.15pm Tuesday 30 August 2016

Plenary 2, Melbourne Convention and Exhibition Centre
South Wharf, Melbourne

Mental illnesses are some of the most common and disabling disorders in medicine, yet we have a very limited understanding of their medical basis.

This lecture by Dr Thomas Insel, a world authority on mental illness, will describe recent scientific advances and explore ways research advances can help those suffering from a serious mental illness.

The Graeme Clark Oration is a free event, however registration is essential.

Visit the Graeme Clark Oration website to learn more and to register:
www.graemeclarkoration.org.au

An initiative of:

The Graeme Clark Oration

Convergence Science Network

The University of Melbourne

HOLODECK:
COMPILED BY JAMES MITCHELL CROW

ALL EYES ON THE PRIZE

HERE'S LOOKING AT YOU, SQUID

Look into the eye of an octopus and you'll find yourself staring back at one not so different from your own. Yet we are about as closely related to an octopus as we are to clams.

The octopus evolved its complex camera eye independently of vertebrates like us. Biologists estimate the eye has evolved independently more than 50 times in species such as flies, flatworms, molluscs and vertebrates.

The eye is such a precisely engineered organ that even Darwin initially found it hard to believe natural selection could have produced it.

Yet over and over, we see that evolving complex structures is not a fluke. Given the same problem to solve, evolution tends to arrive at the same solution. It's called convergent evolution.

CREDIT: JOEL SARTORE / NATIONAL GEOGRAPHIC PHOTO ARK / GETTY IMAGES

A HEDGEHOG WITH FEATHERS?

Except for bats, New Zealand has no native land mammals. But rustling around in the undergrowth of its thick forests, you'll find a very odd bird. Almost blind, round and squat, the kiwi is the only avian species with nostrils at the end of its beak, which it uses to hunt insects at night. It nests below ground in burrows, and its feathers are more like fur.

To fill the forest floor ecological niche, the kiwi evolved characteristics that make it more similar to a European hedgehog than any bird. The late evolutionary biologist Stephen Jay Gould dubbed it "an honorary mammal".

CREDIT: (LEFT) TUI DE ROY / MINDEN PICTURES / GETTY IMAGES; (RIGHT) LES STOCKER / GETTY IMAGES

A BUTTERFLY'S LONG-LOST TWIN

The image on the left is *not* a butterfly. It's a lacewing, a member of a family that died out over 125 million years ago. Despite arising from a completely different branch of the insect family tree, it is almost indistinguishable from the modern Owl Butterfly (right).

Recently unearthed, beautifully preserved specimens of these extinct kalligrammatid lacewings from northern China show just how similar they were to butterflies. This year, fossil dissections showed they also fed though a long tube-like proboscis. They had large wings made from scales and even evolved prominent wing eyespots, designed to startle predators.

CREDIT: (LEFT) CONRAD LABANDEIRA / JORGE SANTIAGO-BLAY; (RIGHT) PETE OXFORD / MINDEN PICTURES / GETTY IMAGES

GENE GENIES

Bats flying through the night emit high-pitched sounds and listen for echoes to zero in on flying insects. Dolphins use the same strategy to hunt fish in the murky depths.

Bats and dolphins independently evolved echolocation. But it turns out that they used the same genetic tool kit to do so.

In 2013, Stephen Rossiter at Queen Mary University of London found that bats and dolphins had altered the same 200 genes to achieve their superpower. Some of those genes, like prestin, affect hearing sensitivity.

A year later, Atsushi Ogura at the Nagahama Institute in Japan discovered another gene that two species have in common – this time, the octopus and Homo sapiens. The eight-legged cephalopod uses the same gene we do to tell cells to morph into an eye: the master control gene Pax6.

CREDIT: (LEFT) STEPHEN DALTON / MINDEN PICTURES / GETTY IMAGES; (RIGHT) CHRISTOPHER SWANN / GETTY IMAGES

BUILD YOUR OWN BABY?

It's a moral imperative, argues JULIAN SAVULESCU.

HOMO SAPIENS EVOLVED on the African savannahs, resigned to short, difficult lives. In just a few hundred years – a blink of evolutionary time – we've transformed our environment, as well as our odds of survival.

IN TODAY'S INDUSTRIALISED, globalised world, we live to extreme old age. But this extended life span comes with a trade-off: our DNA is now out of sync with our environment. We can live for eight, nine, even ten decades, while the use-by date on our DNA is closer to 40–50 years. That means people spend their later years living with the diseases of ageing: dementia, cancer, heart disease, arthritis and osteoporosis. If our DNA is letting us down, why shouldn't we alter it to suit our environment?

We've had the technology to manipulate genes since the 1970s – legions of plants and animals have been genetically modified. But the technique was deemed too crude to apply to human embryos. Now, an extremely precise new technique known as CRISPR Cas-9 has blasted through that barrier. It is so much more precise that it's known as genetic editing rather than genetic engineering. First introduced in 2012, it allows a cell's genome to be sliced and genes to be removed or added.

CRISPR Cas-9 has transformed the art of genetic modification. It has also shifted what was for decades an unmoveable ethical line in the sand. Since April 2015, Chinese scientists have twice carried out genetic editing on human embryos. While the researchers purposely used embryos incapable of maturing, they nevertheless opened the door to the possibilities. Once the technique is perfected, many wonder, will genetic editing of viable human embryos be inevitable?

In some countries, including Australia, the UK, and many European nations, ethical concerns have prompted restrictions or an outright ban on the use of CRISPR-Cas9. But others, such as China, have taken a more permissive approach to the technology.

The US has become a major battleground in the ethical debate over CRISPR-Cas9. In March 2015 a number of US researchers, including those employed by private companies who are testing gene editing as a treatment for diseases such as HIV, haemophilia, sickle-cell anaemia and cancer, called for a moratorium on the genetic editing of human embryos. A month later, Francis Collins, Director of the US National Institutes of Health, proclaimed the agency would not fund research that is viewed "almost universally as a line that should not be crossed".

At the end of that year, an international summit was held in Washington, co-hosted by the US National Academy of Sciences and US National Academy of Medicine, the UK Royal Society and the Chinese Academy of Sciences. The participants came to a different view. While they held that "it would be irresponsible to proceed with any clinical use of germline editing," they did not push for a moratorium on research. Instead, they concluded that "as scientific knowledge advances and societal views evolve, the clinical use of germline editing should be revisited on a regular basis."

The moral line in the sand, it seems, is now indistinct.

This debate may soon come to a neighbourhood near you. Ultimately it's not the scientists, but members of the public and their political representatives who determine what laws and regulations are needed. In Australia, the question is: should we allow the research to happen here? And does this new tool send us down a slippery slope to a world where all babies are engineered? Another consideration: genetically edited embryos would pass on their edited DNA to future generations. Do we have the right to consign all future generations to our current idea of what an ideal DNA code is?

Precision genetic editing has catapulted us to the threshold of a GATTACA-like world. Now we have to decide whether to take the next step.

By any measure, it will be a fraught decision. The perils of genetically engineering babies have been well-articulated. They range from the potential for creating a genetic elite to unpredictability of the long-term effects of altering the DNA of our species. That's why genetic editing of embryos has been seen as a moral no-go zone for four decades. But some ethicists are now changing their minds.

Oxford-based, Australian-born bioethicist Julian Savulescu is at the forefront of those who believe we should allow human embryo editing. An advocate of "procreative beneficence," which holds that parents should select the best child they could have based on the best available information, he believes the technique is an ethical imperative. Here, in his own words, Savulescu makes his case.

WHY PERMITTING HUMAN GENOME EDITING IS AN ETHICAL OBLIGATION —

The human animal is not some finely balanced masterpiece of divine creation. It is the result of natural selection under particular environmental pressures. Humans exhibit some 250 genetic disorders; only 20–25% of embryos are fit enough to develop into a baby; and 6% of newborns exhibit a major birth defect.

DNA manipulation allows us to correct genetic aberrations and enhance the human genome. It allows us to liberate ourselves from the biological constraints of evolution and move toward a state of self-designed evolution.

There are six ethical principles that obligate us to embrace human genome editing:

1. REDUCE HUMAN SUFFERING

Whether it's a single gene disorder like cystic fibrosis or a multi-gene disorder like schizophrenia, inherited diseases cause great suffering. Gene editing could theoretically repair these faulty genes. In April 2015, Junjiu Huang and colleagues at Sun Yat-sen University in Guangzhou, China, attempted to use CRISPR-Cas9 on embryos carrying the blood-clotting disorder beta thalassemia.

If the technique is safe, there is a moral imperative to use it, in the same way there's an ethical obligation to help alleviate the suffering of a person born with haemophilia. Those with the disease receive regular infusions of a clotting factor their entire lives. There is no morally relevant difference between treating a haemophiliac with drugs and restoring the function of that gene while the person is still an embryo.

We should treat gene editing as we would any other medical intervention.

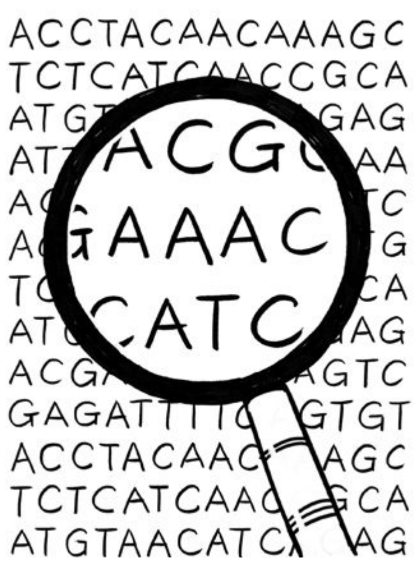
Some people argue that gene editing of human embryos is unnecessary since parents can already use in vitro fertilization (IVF) to select embryos that do not carry genetic disorders. But that argument fails for three reasons.

First, selecting embryos requires that parents are able to produce a sufficient number of embryos to select only the healthy ones. But 16% of couples produce only one embryo. A genetically-impaired embryo may be their only choice.

Second, when it comes to multi-gene disorders such as schizophrenia, there are never going to be enough embryos to select those with the healthiest combination of genes. For instance, in a disorder that involves the dysfunction of 15 genes, it's estimated it would take thousands of embryos to find those few that have a healthy combination of gene variants. Genetic editing with CRISPR-Cas9 has the potential to correct multiple genes in a single embryo. Moreover, genetic selection is not a cure for disease. It merely stops a person who would have had a disease from coming into existence and allows a different, disease-free person to be born.

Another argument is that gene editing of embryos is unnecessary because gene therapy can be carried out on people born with a disease. The genes of particular organs or tissues are treated – say the lungs of a person with cystic fibrosis.

GENE EDITING COULD THEORETICALLY REPAIR FAULTY GENES.

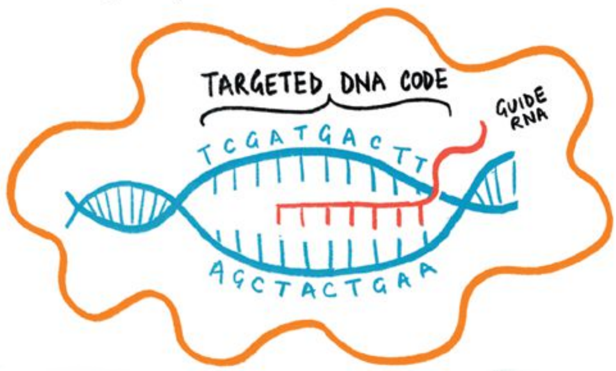


HOW GENOME EDITING WORKS

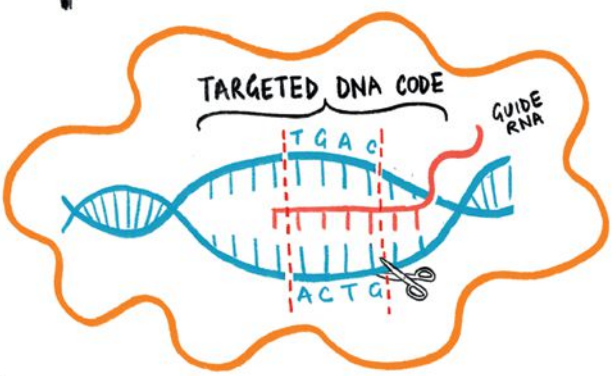
1 GUIDE MOLECULE AND ENZYME TOOL JOIN FORCES TO FIND TARGET DNA

2 TARGET DNA IS FOUND

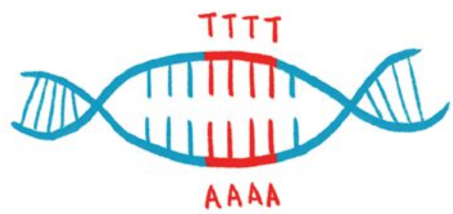
3 THE ENZYME OPENS THE DNA AND THE GUIDE RNA LINES UP WITH THE TARGET



4 THE ENZYME TOOL CUTS THE DNA



5 THE DNA CAN THEN BE EDITED



USES FOR GENE EDITING


FOOD & LIVESTOCK MODIFICATION


GENE THERAPY TREATMENT


DESIGNER BABIES

But so far, the successes of gene therapy have been extremely limited. No such treatment for cystic fibrosis exists, despite decades of attempts. Gene editing has the potential to cure every cell of a disease permanently.

2. A FAIRER WAY TO SPEND MEDICAL RESOURCES

In some cases we can effectively treat genetic diseases with existing methods. But those treatments are extremely costly. In a world of limited resources, excessive spending on one disease means there is less to spend on other diseases. Fairness requires we choose the most cost-effective option.

Take Gaucher's disease, for example, which affects babies born lacking an enzyme needed to break down fatty substances called sphingolipids. As a result, they build up in the liver, spleen, nervous system and bone marrow, interfering with the normal function of these organs. It is possible to treat the disease, which is especially common in Ashkenazi Jews, by giving a modified form of the missing enzyme via intravenous infusion every two weeks. But it is very expensive. In the UK the annual cost is around £18,000,000 ($31,339,659).

Such treatments are lifelong. Correcting the fault in the embryo through gene editing would cure this disease in a single hit and would be far less expensive. I estimate the cost would be in the range A$8,757–$17,515 in total per person, compared with A$876,834 for 50 years of treatment.

Carriers of a genetic disease like Gaucher's, which affects one in 500 Ashkenazi Jews (one in 14 are carriers) would likely know their status and opt to have IVF to test the genetic health of their embryos. But if all people are to have the opportunity to produce the healthiest embryos, then the entire population would need to have babies using IVF to enable genetic testing and editing.

So wouldn't this raise the costs to an unsustainable level?

Not in the long-term. I predict that within 20 years, as the effectiveness of IVF vastly surpasses natural reproduction and the cost of reading an entire genome plummets, the majority of births in developed countries will occur through IVF. Embryos will have their genome read, the best embryos will be selected, and increasingly they will be edited.

3. EDIT OUR DNA TO MATCHOUR LIFESPAN

The global population is greying. In 1950 one in 20 were over the age of 65; by 2050 that figure is projected to be one in six. People are also living to a very advanced old age. In developed countries the lifespan is over 80 years, and those in the less developed world are catching up. So far, graphs show no slow-down: lifespan increases by about 2.5 years each decade.

But with ageing comes Alzheimers' disease, heart disease, cancer, osteoporosis. The world's medical systems are buckling under the weight of this burden.

The diseases of ageing could possibly be delayed or arrested by gene-editing. Genes associated with cancer, dementia, heart disease and bone density are known. Mice have already been genetically engineered to be resistant to cancer and delay ageing.

4. GENETIC SHORT STRAWS

Nature is a biological lottery. Some are born healthy; others are dealt painful, abbreviated lives.

The prospect of genetic inequality are at the heart of public concern about genetic editing.

While we may legitimately worry about the creation of a genetic masterclass, we should also be concerned about those who draw the short genetic straw. The US Department of Education has estimated that nearly 50% of the US population lack the literacy to enjoy the rights and responsibilities of citizenship. This is largely social but also partly genetic.

THE PROSPECT OF GENETIC INEQUALITY IS AT THE HEART OF PUBLIC CONCERN ABOUT GENETIC EDITING.

AT PRESENT GENE EDITING SHOULD ONLY BE USED IN RESEARCH TO REFINE THE TECHNIQUE.

We already accept that as a society we need to intervene to help those short-changed by their biology. We do so with remedial education, diet and social support. Why not use gene editing to even the playing field?

If gene editing were targeted at natural genetic inequality it would reduce rather than increase inequality.

5. DISCOVER CURES

People worry that gene editing will be used to benefit the richest, not the neediest. But gene-editing of human embryos could benefit all of us — by giving us a greater understanding of human development and disease.

To that end, last February, the UK Human Fertilisation and Embryology Authority licensed a research team at London's Francis Crick Institute to carry out gene editing on embryos. The experiment aims to discover how a particular gene called OCT4 influences an embryo's development. The research may reveal why IVF so often fails — and ultimately improve IVF success rates. This would reduce, not increase inequality.

6. HUMAN ENHANCEMENT

In April 2016, a second Chinese group led by Yong Fan at Guangzhou Medical University attempted to engineer HIV resistance in human embryos. Their goal was to replicate a naturally-occurring human genetic variation in a gene called CCR5. People with two copies of this genetic variation are completely resistant to HIV infection. This experiment showcases how gene editing could be used to protect populations that are highly at risk of contracting HIV, such as those in Sub-Saharan Africa.

Extending our imagination a little further, if there is a mass bioweapon attack, or catastrophic climate change, natural evolution will be too slow to reconstitute a resistant human population. Like the dinosaurs, we would likely become extinct. The ability to genetically enhance embryos is the insurance policy for human survival.

We also need to consider our moral fitness. We live in a world populated by 70,000,000 psychopaths – 1% of the population. If a small percentage are technologically savvy or have access to wealth and power, they could inflict great harm on society. Genes that control antisocial behaviour are well-known. For instance the so-called "warrior" gene, first identified in a Dutch family whose violent members often wound up in prison, is a mutation in a gene called MAO-A, which controls the levels of neurotransmitters in the brain.

But we don't have to look to deviant behaviours for examples of the potential benefits of human gene editing. When it comes to ordinary populations, altruism and concern for others is in short supply. Reseacher Wojciech Kopczuk and colleagues report that Americans value the life of a non-American at just 0.5% of their compatriots. In the US and Europe, anti-immigration parties and policies are bringing our xenophobic tendencies into high relief. Our DNA is partly responsible: we evolved to be tribal rather than global citizens.

If these xenophobic genes could be identified, it may be possible to do away with the trait. As I have argued in my book "Unfit for the Future" (with co-author Ingmar Persson) we have a moral obligation to bring about radical enhancement of the ethical aspects of our own human nature.

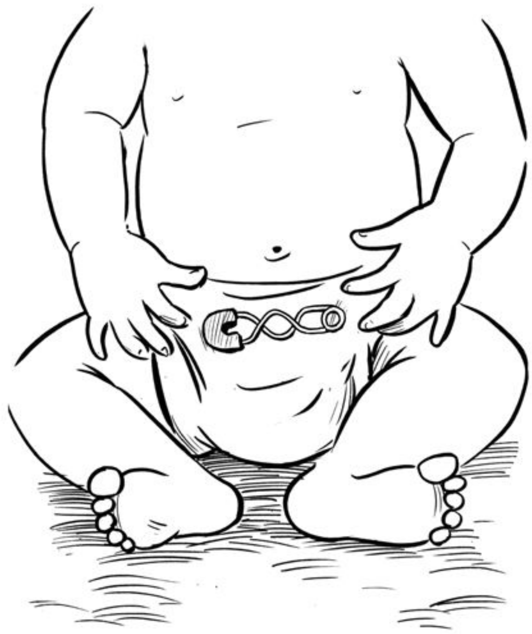
OTHER OBJECTIONS —

There are, of course, grave and well-founded concerns about safety. As the two Chinese experiments showed, gene editing is not ready for clinical use. The percentage of embryos that received any editing at all was only 15% — and of these, many incurred errors. Edits were placed in the wrong part of the DNA and the embryo did not receive uniform editing of the DNA in all its cells. That means not all tissues would receive the benefits — a major problem if the embryo is being edited for HIV resistance.

Given these issues, at present, gene editing should only be used in research to refine the technique. One law that mandates this is the UK's Human Fertilisation and Embryology Act. It only allows embryos to develop until 14 days.

If gene editing were to be used to cure a disease in an embryo, it should first be attempted in a disease that is lethal in early life and where there is no treatment, such as the severe form of OTC deficiency, a rare genetic disorder in which ammonia accumulates in the blood. The accuracy of gene editing could be tested in the embryo prior to implantation and tested again during early pregnancy.

Another objection from some ethicists is that



gene editing goes against freewill since it involves one person designing another. There is also the problem that the embryo cannot consent to such life changing interventions.

But if it's impossible to get consent, consent is irrelevant. The embryo can neither ask to be edited or to be left alone. As moral agents, we must make the most ethical choice.

As far as freedom, genetic illness drastically reduces it. Take cystic fibrosis. Those who suffer from the disease spend most of their lives in hospitals. If we had a drug that would cure cystic fibrosis on day one of life, we would administer it. Gene editing merely involves curing disease at day zero. It increases freedom.

THE EVILS OF EUGENICS

Isn't this just what the Nazis would have dreamt about?

Eugenics, per se, is not an evil thing. The objectionable part of Nazi eugenics was that it was coercive, designed to achieve a racist society, and was based on bad science. Modern, ethical eugenics involves free choice by parents, is aimed at achieving health and well-being for the child, and is based on good science.

The Nazis also used sterilisation to achieve their goals. But we haven't banned sterilisation – we use it in a regulated, ethical way.

EMBRYO EDITING IS PASSED ON TO THE NEXT GENERATION

A final major concern about editing the DNA of embryos is that these changes will be passed on to future generations. Many have argued that we cannot predict the long-term consequences. In some cases, we won't know the consequences for the individual who harbours the modification for their entire life. We also don't know the consequences for the human population. For example, what if a gene that appeared to cause some harm to an individual actually protected them from an epidemic? For instance, people who carry a single copy of the sickle cell anemia gene are more resistant to malaria.

It comes down to a case-by-case basis. In the case of curing a fatal genetic disease like cystic fibrosis, where the affected embryo carries two copies of the flawed gene, the consequences for that person are clearly positive. For cases where the merits are less clear, we need to wait for the rapidly developing science of genomics to reveal the consequences of genetic editing.

Of course there are risks with anything in life. We are constantly modifying our genome unintentionally, by smoking, drinking, plane travel, sun exposure, exposure to viruses, even delayed parenting.

If it is OK to damage the genome, why isn't it OK to repair it? And if it is OK to repair it, why isn't it OK to enhance it?

CONCLUSION —

Many will disagree with me about the great potential of genetic editing to prevent disease, and the ethics of using it on embryos to achieve this goal. Drawing a distinction between the editing of embryos for research purposes and for reproductive purposes will allow us to debate such issues without impeding research in the meantime.

All things considered, manipulation of human DNA is an ethical imperative.

JULIAN SAVULESCU is a an ethicist at the University of Oxford.

ILLUSTRATIONS
Jeffery Phillips

AGENTS OF EXTINCTION

Why have some monster volcanoes triggered global catastrophes while others have not? KATE RAVILIOUS reports.

→

DEADLY FIRE: Today's eruptions, such as this 2014 flow from the Bardarbunga Volcano in Iceland, are nothing compared to past 'flood basalt' events.

WELCOME TO the late Permian. It's 253 million years ago and life on Earth is thriving.

IT'S REFERRED TO AS THE 'GREAT DYING' AND IT IS THE BIGGEST MASS EXTINCTION OUR PLANET HAS EVER EXPERIENCED.

THE OCEANS ARE A SHOWPIECE of biodiversity, sporting trilobites, molluscs, coral and fish. On land, animals and plants have moved away from the swamps to stake out their lives on dry land. Blunt-horned reptiles the size of cows, known as pareiasaurs, crash through vast conifer and fern forests, chased by sleek, fast predators known as gorgonopsians – mammal-like reptiles that are relatives of the lineage that gave rise to mammals.

Fast-forward one million years and Earth is a barren wasteland. Entire ecosystems have disappeared. Rocks all over the world bear witness to the catastrophe with an abrupt change in the appearance of their layers – the so-called Permian-Triassic transition. Below the transition there is limestone, coal and an abundance of Permian species. Immediately above it's mostly lifeless shale – only 5% of species have made it through. In the oceans, the coral reefs and most species have vanished. Tiny clams and snails are the main survivors. On land, the forests have gone, and with them the insects and animals. It's referred to as the "Great Dying" and it is the biggest mass extinction our planet has ever experienced.

What caused it? Geologists have identified the smoking gun: the Siberian Traps in Northern Siberia. Traps, the Swedish word for stairs, refers to the stepped appearance of lava flows that oozed from a vast rift in the Earth's crust for nearly one million years. Flowing in fits and starts, like a chocolate fountain, it covered a region the size of Western Europe in lava one kilometre thick.

Earth was hell. Ash filled the skies and sulphurous acid rain poured down. Chlorine and bromine gases tore a hole in the ozone layer, letting UV light through to shred the DNA of land animals and plants. Volcanic CO_2 and methane emissions sent global temperatures soaring.

For land species, it was probably the assault from UV light that tipped them over the edge. But in the oceans, it was the heat. The seas turned into a hot bath with temperatures reaching 40 degrees. As water heats, it loses its ability to dissolve gases like oxygen. The heat also drove bacterial blooms that consumed oxygen. The loss of oxygen tuned the oceans into a dead zone; sea life suffocated, even the hardy trilobites. Overall, life was set back 300 million years. Undisturbed by animals, the ocean floors became covered in bacterial slime, just as they had been during the Precambrian era.

Our planet produces one of these monstrous "flood basalt" eruptions roughly every 30 million years. They occur, scientists believe, when portions of the ocean floor sink into Earth's mantle, leaving magma nowhere to go but up. Compared with the brief, explosive volcanic eruptions we are familiar with today, flood basalts are in a class of their own.

But not all of them are as deadly as the Siberian Traps. A similar eruption burst forth about 60 million years ago in the landmass now covered by the North Atlantic. It created the spectacular rock columns known as the Giant's Causeway in Northern Ireland, as well as the soaring cliffs of Baffin Island on Canada's northeast flank and western Greenland. Again, a vast area of the Earth was deluged in magma and the climate warmed. Yet on this occasion, things were different. Instead of the mass extinction of reptiles and forests, crocodiles moved poleward to bask on Alaskan beaches beneath swaying palms.

What makes one mega-eruption catastrophic to life on Earth, while another brings only minor setbacks? It's a question that has puzzled Paul Wignall, a geologist at the University of Leeds in the UK. A renowned mass extinction detective, Wignall travels the world in search of the clues left by these global catastrophes, gathering evidence to understand what caused them. Now he thinks he has spotted a curious link between the arrangement of Earth's continents and the potential of a volcanic eruption to cause mass extinction. Kate Ravilious recently spoke with Wignall, and he explains the evolution of his idea and what past extinctions may teach us about a warming Earth.

02
The Giant's Causeway in Northern Ireland bears witness to a flood basalt eruption in the North Atlantic 60 million years ago. But in this case, there was no mass extinction.

THERE WAS A STRING OF AT LEAST SIX VOLCANO-DRIVEN MASS EXTINCTIONS AND THEY ALL COINCIDED WITH THE EXISTENCE OF A SINGLE SUPER-CONTINENT.

KATE RAVILIOUS: *You've been studying mass extinctions for more than 30 years. What attracted you to this line of research?*
PAUL WIGNALL: I find mass extinctions fascinating. They're the worst disasters in the history of this planet and tell us how our world responds to severe crises. When I first became interested in mass extinctions in the early 1980s, the idea that the dinosaurs were killed by a meteorite – now widely accepted – was new, and one of the most exciting theories in science.

KR: *In your recent book, The Worst of Times, you suggest that mass extinctions are more likely when the continents are arranged in one big landmass – a supercontinent. How did you arrive at this theory?*
PW: Ever since I started work in this field, I've noticed that the correlation between volcanism and extinction events comes and goes, and I've wondered why. Around seven years ago, I was working on a 260-million-year-old mass extinction event and its link with an eruption in southwest China, known as the Emeishan Traps. By dating the fossils found just underneath the lava, we were able to show that the timing of the eruption matched the timing of the extinctions seen elsewhere around the world.

Having convinced ourselves that this eruption triggered the mass extinction, it struck me that there was a string of at least six volcano-driven mass extinctions in the distant past, including the Great Dying, and that they all coincided with the existence of a single supercontinent known as Pangea that began to break up about 175 million years ago. I began to wonder if the existence of the supercontinent made the impact of the volcanoes worse than they might otherwise have been.

KR: *Can you walk us through the logic of why this relationship likely exists?*
PW: Fragmented continents are better able to remove CO_2 from the atmosphere than a single supercontinent. It's all to do with rocks reacting with CO_2 and trapping it chemically as bicarbonate ions which are washed into streams and eventually shallow seas. Sea creatures take up the bicarbonate into their shells, and when they die, carbon is buried for the long-term as limestone (calcium carbonate). The conveyer belt that moves CO_2 from the atmosphere into rock minerals is rainwater which dissolves the gas and, being slightly acidic, breaks down the rock so that carbon-trapping chemical reactions take place.

The conveyer belt works well with small continents because nowhere is too far from the sea, so they have wetter climates and therefore can move more CO_2 into limestone. Small continents also have more shallow seas due to their trailing continental shelves, so they provide more habitat for limestone-building creatures. Stick all the continents together into a giant land mass and you end up with vast interior deserts, and fewer shallow seas. It is easier to end up with runaway global warming in a supercontinental world.

KR: *So of all the factors that go with megavolcanism, such as corrosion of the ozone layer and acid rain, you're suggesting it's actually the rising CO_2 levels that tip life over into a mass extinction?*
PW: Yes, I think this is the crucial factor. Global warming has many harmful consequences: the heat itself can be a real problem, especially in lower latitudes, and knock-on effects like oxygen loss in the oceans are also devastating to life. No doubt there are other factors involved too, and ozone destruction, even for short intervals, can be harmful particularly for terrestrial plant life.

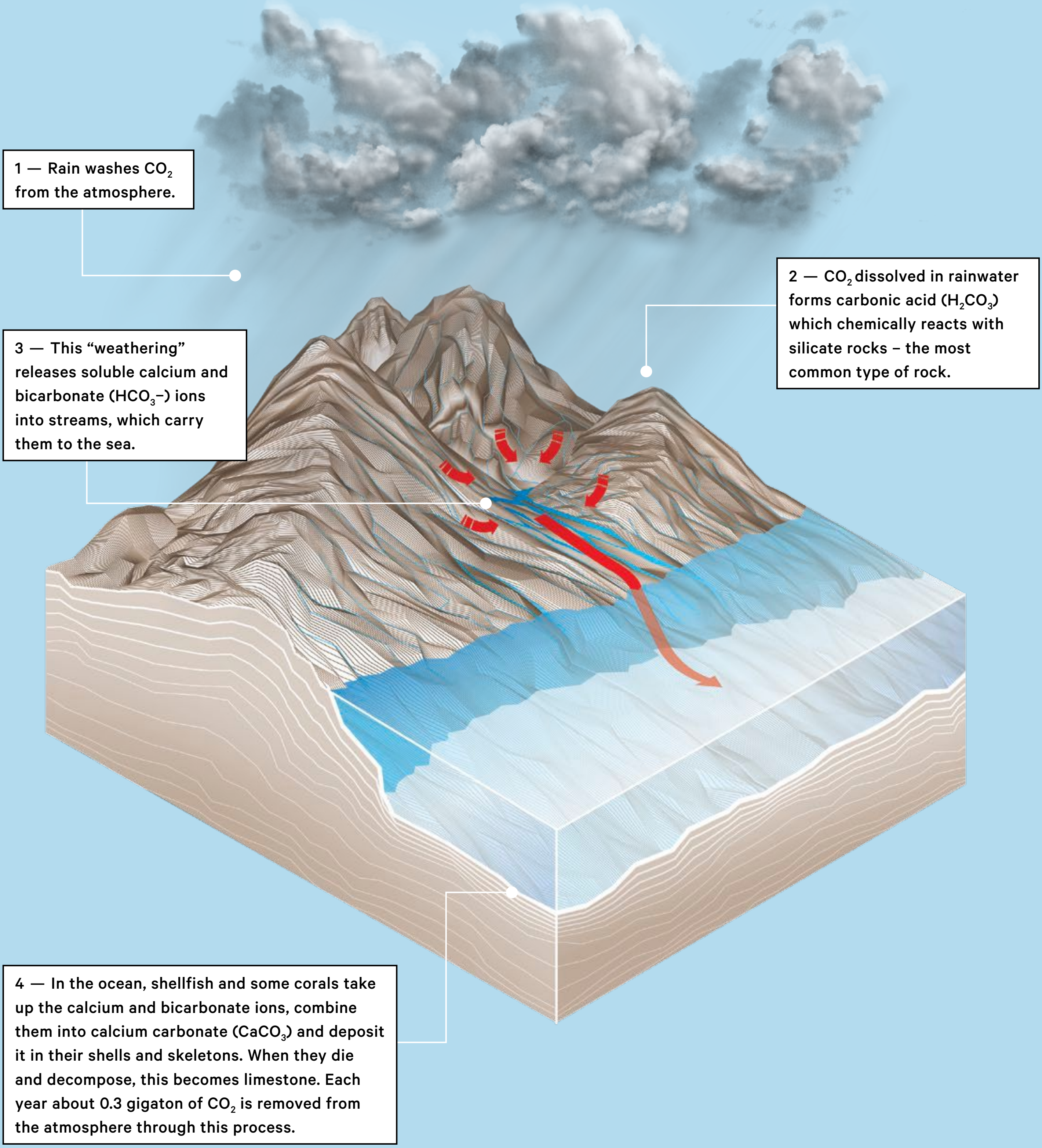
KR: *In hindsight, the relationship between supercontinents, volcanism and mass extinctions seems obvious. Why hadn't anyone spotted it before?*
PW: Up until now, most research has fallen into two camps: either volcanism did it, or something else – like a meteorite impact – did it. In fact, I think the relationship between volcanoes and extinctions is more nuanced. There was always a problem with the "volcanoes-did-it" hypothesis because there are plenty of giant eruptions not linked with extinctions. A supercontinent is the missing link in the chain.

KR: *What theories had other scientists put forth about why some volcanoes triggered mass extinctions and others did not?*
PW: Around a decade ago, Henrik Svensen of the University of Oslo came up with the idea that some volcanoes push magma through "juicier" [more carbon-rich] areas of the Earth's crust than others. As the magma goes through the crust it bakes the rocks around it, and if that rock happens to be coal or shale it releases additional CO_2. By contrast, when magma passes through ancient, dry crust, it doesn't produce this extra pulse of greenhouse gases.

It is a good and valid hypothesis. But there are several cases that fail to fit the theory, such as the 60-million-year-old North Atlantic eruption, which passed through coal deposits. But it isn't associated with a significant mass extinction event.

A CLOSER LOOK

CARBON DIOXIDE'S JOURNEY FROM THE AIR TO THE SEAFLOOR



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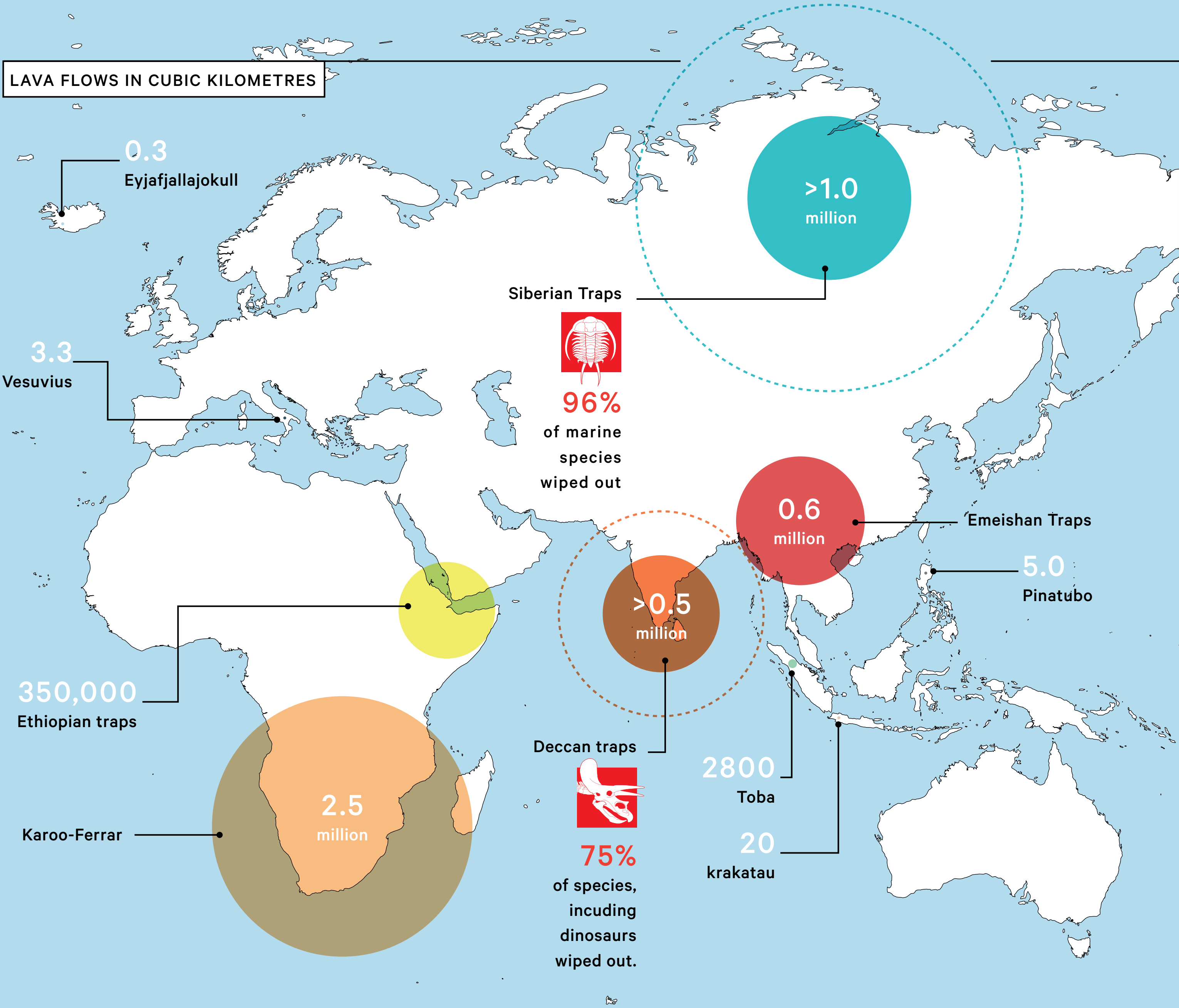
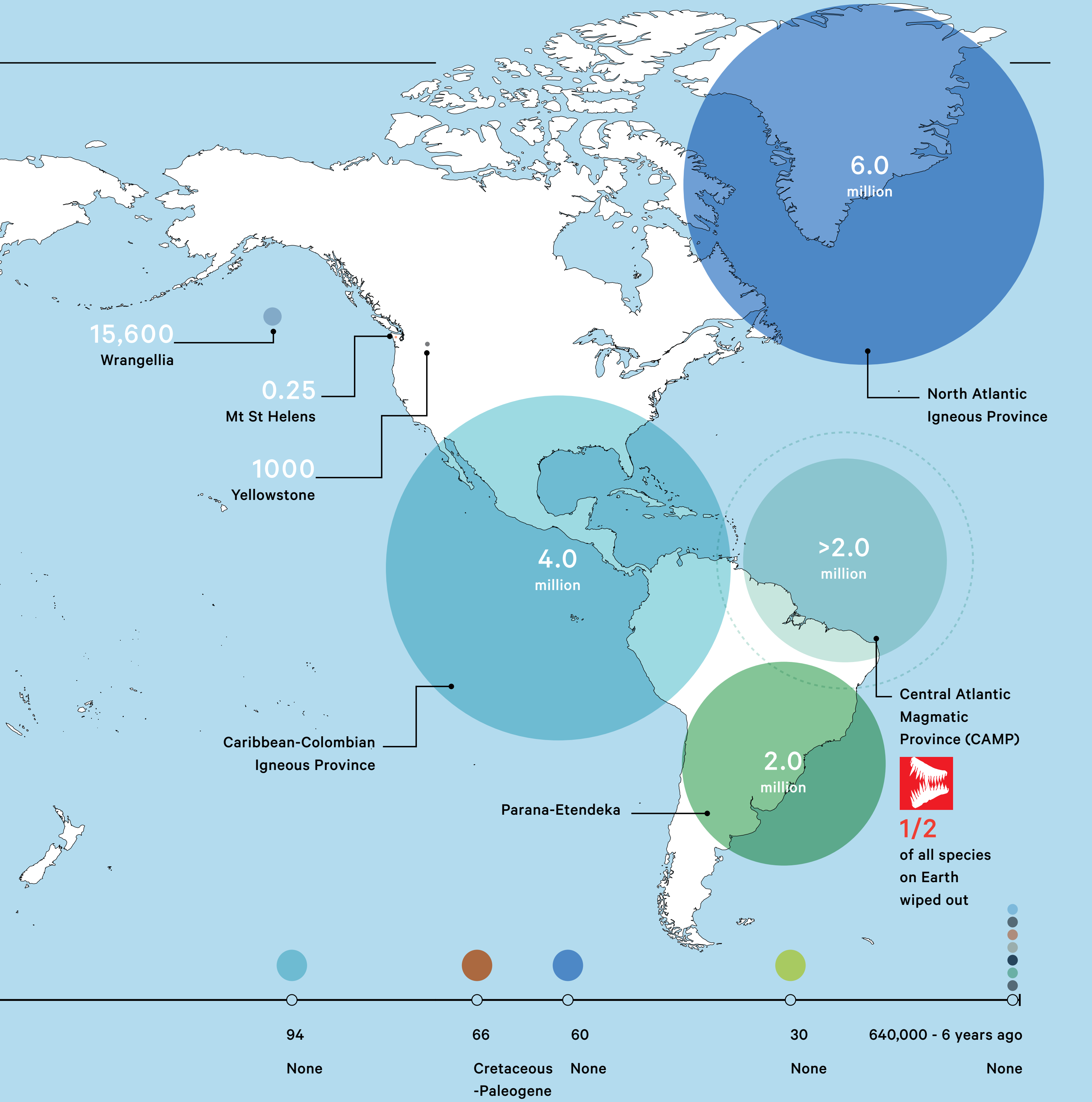
A CLOSER LOOK

EARTH'S LAVA FLOWS AND EXTICTION EVENTS



Lava flow events						
Million years ago	260	252	232	200	183	135
Mass extictions	Middle Permian	Permian -Triassic	Carnian	Triassic –Jurassic	Toarcian	None


15,600
Wrangellia
0.25
Mt St Helens
1000
Yellowstone
6.0
million
North Atlantic
Igneous Province
4.0
million
Caribbean-Colombian
Igneous Province
>2.0
million
Central Atlantic
Magmatic
Province (CAMP)
2.0
million
Parana-Etendeka
1/2
of all species
on Earth
wiped out
94
None
66
Cretaceous
-Paleogene
60
None
30
None
640,000 - 6 years ago
None

KR: *What's the best evidence to support your idea?*
PW: I think it's the 100% correspondence between volcanism and extinction during the time of Pangea. That's a six-out-of-six hit rate. Since Pangea broke apart there have been another six major phases of eruption, but only one coincides with a mass extinction – and that's at the end of the Cretaceous, when a giant meteorite hit.

PW: Volcanic extremists believe that all large-scale volcanism causes extinctions and they downplay the role of Pangea because it only existed for 80 million years. It is true that all the largest volcanic eruptions caused climate change. But those that occurred at the time of Pangea were much more intense and it is only these that coincide with widespread extinctions. Some scientists also

03

Flowing in fits and starts, flood basalts in Central India created the steps of these Deccan Traps 66 million years ago.

IF THE METEORITE IMPACT HADN'T OCCURRED AT THE SAME TIME I THINK THE DINOSAURS MIGHT HAVE MADE IT THROUGH.

KR: *So how do you explain that extinction event, which occurred when the continents were spread out?*
PW: The Cretaceous-Paleogene mass extinction, which wiped out the dinosaurs 66 million years ago, occurred at a time when Earth's continents were widely dispersed. The extinction coincides with the eruption of the Deccan Traps, flooding the west coast of India with one million cubic kilometres of lava. But it also coincides with a giant meteorite impact at Chicxulub in Mexico. Disentangling the role of the Deccan eruption and the meteorite impact is really tricky, but it is likely that the combination of the two events was what made it so fatal to life on Earth. If the meteorite impact hadn't occurred at the same time I think the dinosaurs might have made it through.

KR: *What have critics said about this idea of a link between extinctions and supercontinents?*

criticise the theory because as we go deeper back in time, there are some mass extinctions that aren't as clearly related to volcanism – for instance the Ordovician-Silurian extinction 443 million years ago. But the situation [there] was different, because there were no plants on Earth, so the carbon cycle didn't work in the same way.

KR: *What key evidence are you lacking to support your hypothesis?*
PW: There's lots we don't know about the actual details of mass extinction. Some are caused by oxygen starvation in the ocean and warming, but others are more enigmatic. We particularly need to know more about the environmental changes on land during extinction events.

KR: *What are the challenges in trying to understand this?*
PW: Ideally we'd like to have more examples

04
Hawaiian volcanoes: small fry! The flood basalts that created the Siberian Traps deluged an area the size of Western Europe in lava 1 km thick.

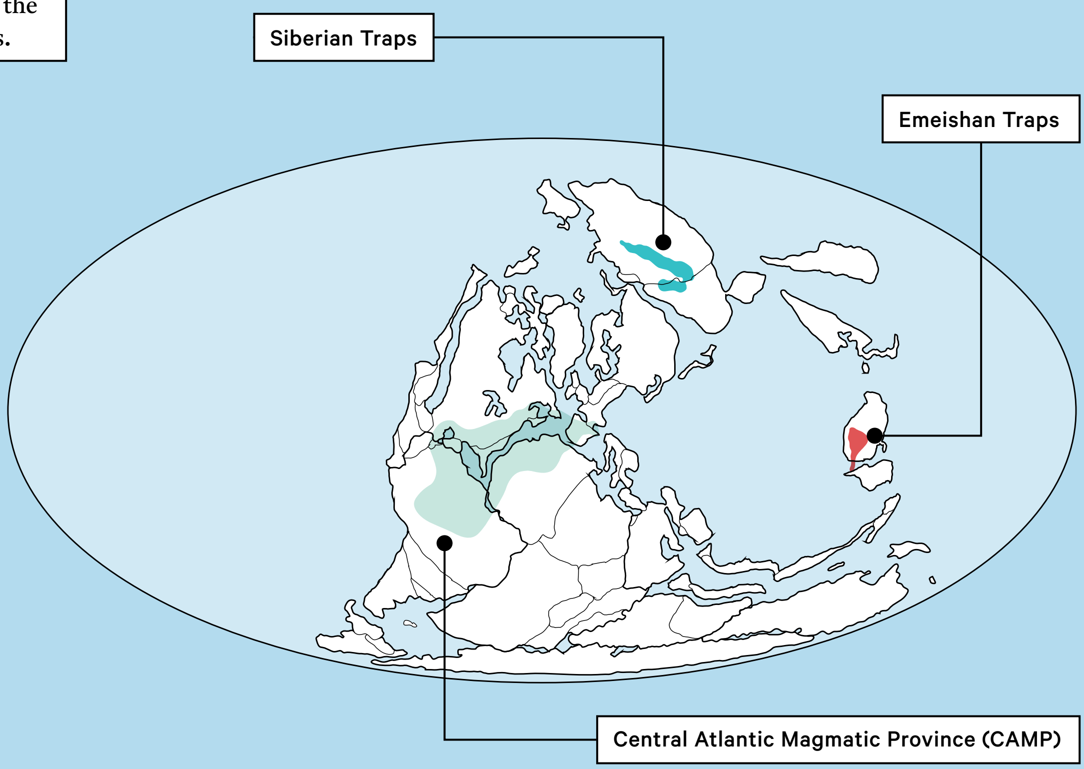
Issue 70

A CLOSER LOOK

THE SUPERCONTINENT – MASS EXTINCTION LINK

Paul Wignall found a correlation between mass extinctions and the arrangement of the continents.

1 — Massive volcanic eruptions caused mass extinctions between 200 and 260 million years ago, when a supercontinent stretched across Earth.



2 — But 60 million years ago an equally vast eruption in the North Atlantic did not cause a mass extinction. The Deccan traps eruption 66 million years ago did contribute to the mass extinction of dinosaurs, but a meteorite impact may have pushed them over the edge.

of massive volcanism, but once we go back beyond a few hundred million years, the lava fields tend to have been lost to erosion and so [those events] have to be inferred from other things. The dating techniques available for these ancient eras are also much less precise, making it harder to line up the dates of volcanic activity with the dates of known extinction events.

KR: *The most notable example of a mass extinction during the period of Pangea was the end-Permian extinction 252 million years ago, which wiped out most life on Earth and is the worst extinction in Earth's history. Why was it so singularly catastrophic?*
PW: It's difficult to answer that – a trite answer would just say that there was a lot more gas released from volcanoes during that crisis.

But it may have triggered runaway global warming. It's the only mass extinction to have seen the complete loss of terrestrial forests. Forests are a great way of removing CO_2 from the atmosphere, and without them the crisis in effect got past the point of no return.

KR: *How certain is it that the mass extinctions you've got in your sights were in fact triggered by volcanism? Other researchers have suggested that asteroid impacts, cosmic ray blasts or reversals of Earth's magnetic field could all be culprits.*
PW: Yes, much effort is being expended on looking for evidence of other extinction styles but none have yet received much support. One of the aspects of mass extinctions we understand better nowadays is that they occurred over several thousand years. This makes it difficult to invoke a "single strike" cause like an impact or cosmic ray blast from a supernova.

KR: *Why is it valuable to understand why some historic volcanoes triggered mass extinctions while others did not?*
PW: It gives us much more insight into how life on Earth has evolved. The gigantic volcanic eruptions that occurred when Earth only had one massive supercontinent – Pangea – caused a series of crises that fundamentally changed the course of life and removed vast numbers of animals and plants that would otherwise have thrived. By contrast, the dinosaurs evolved during a climate-buffering phase as Pangea was splitting apart. Perhaps that explains how they took centre stage for such a very long time. Massive volcanic eruptions from the past are also the only natural process to provide an analogue for our current impact on the atmosphere.

KR: *What can we learn from these climate-induced extinctions of the distant past about how modern-day warming will affect life?*
PW: We are pumping CO_2 into the atmosphere at a far faster rate than any previous volcanic eruption, and species are going to have to shift poleward to cope with warming – something that happened after the North Atlantic volcanism 60 million years ago. However, shifting polewards is more difficult for today's wild plants and animals because natural habitats are so fragmented by urban build-up and agriculture.

In the oceans, the clear story from past mass extinctions is that global warming goes hand-in-hand with oxygen starvation. That's because global warming results in less oxygen dissolved in the water. The increased temperatures favour the rapid decay of plankton and other plant life, which uses up the oxygen. Modern oceans are showing the first signs of these changes, and modelling predictions suggest that we may only be a few hundred years away from seeing large expanses of lifeless seas.

A warm climate-induced mass extinction is probably inevitable, but our dispersed arrangement of continents will help to moderate the climate change. If we lived on a supercontinent world, it would most likely be much worse. We've now passed the peak of dispersed continents – that was around 100 million years ago – and we are heading towards the next supercontinent. Africa and India have both bumped into Asia and started to form the beginnings of the next supercontinent. In around 100 million years from now we can expect all the other continents to have joined up with Asia too, and we'll be in the next supercontinent cycle.

MODELLING PREDICTIONS SUGGEST THAT WE MAY ONLY BE A FEW HUNDRED YEARS AWAY FROM SEEING LARGE EXPANSES OF LIFELESS SEAS.

KATE RAVILIOUS is an award-winning science journalist based in York, UK.

IMAGES
01 Arctic-Images / Getty Images
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ILLUSTRATIONS
Anthony Calvert

SEEDS OF PROMISE

An ancient African crop could meet a very modern need: food as well as biofuel. JAMES MITCHELL CROW reports.

→

SWEET SORGHUM is a highly nutritious and versatile plant.

01

BLAME IT ON THE SUGAR. It's early May 2015, the middle of southern India's mercilessly hot dry season, and I'm sheltering from the sun under a huge jerry-rigged shade cloth, pitched on a tractor-width finger of land between two fields.

JOINING ME UNDER THE CLOTH are 40 or so Indian farmers, chatting excitedly as they graze on packets of sugary sweets.

But the sugar they're buzzing about is not in these packets. It's behind us, accumulating in the stems of towering sweet sorghum plants. Each stalk is almost twice my height, arrow-straight and reaching toward the cloudless sky.

Domesticated thousands of years ago in north Africa, sweet sorghum thrives here. But the farmers gathered amid these stalks don't grow it. This is sugarcane country: the land we're standing on belongs to the Madhucon sugar mill, which looms on the horizon.

The mill's owners want to conduct an experiment. Working with scientists from the nearby International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), they're hoping to sweet-talk the farmers into growing sweet sorghum during the dry season when sugarcane won't grow. Leading the charm offensive is ICRISAT scientist Pinnamaneni Srinivasa Rao. Rao, tall, slim and clean-shaven, gestures toward the sweet sorghum he bred for the trial as he lists the plant's merits.

It's a long list. The sweet sap in its stalk is a high-grade starter for making environmentally sustainable bioethanol, Rao tells the farmers. Its fluffy seed head is packed with highly nutritious grain for hungry farmers, and all that towering foliage provides fodder for livestock. What's more, it grows on meagre amounts of water. Sweet sorghum could be the first genuinely green biofuel – one that can help cut carbon emissions without competing for land with food crops.

In four more weeks, Rao's little test crop of sweet sorghum will be harvested and tested for its sugar content. The best-performing plants will be taken on to the next step in the trial. And that's the purpose of today's outdoor meeting – to get 20 to 30 local farmers to grow sweet sorghum for the mill. Unless these farmers can be persuaded to try the new crop, there won't be enough sweet sorghum to warrant starting up the mill, and the experiment will be over before it's begun.

But the farmers are cautious. Any crop – even a super-crop – must obey the bottom line. From farmer to farmer, the same question rings out: what will the mill pay them for the crop? As India's farmers are acutely aware, the biofuel industry is still reeling from the failure of jatropha, the last miracle crop. Not to mention the 2014 oil market crash, which took the price consumers would pay for biofuels down with it.

But the scientists and entrepreneurs behind the Madhucon sweet sorghum trial believe they have a way to make biofuels pay even if oil prices stay low. That would be good for the environment, and good for the farmers.

"Our research focus has been on improving the economics of sweet sorghum cultivation," says Rao, which as well as improving the obvious traits such as the yield of sugary juice, has meant improving its resilience to salinity, drought and disease.

For the mill owners, sweet sorghum is a business opportunity – a way to keep the mill running when sugarcane isn't available. For the ICRISAT scientists, establishing the plant's commercial credentials is a way to empower some of the world's poorest farmers. For the rest of us, it's a small step – but one that could ripple outward – in the journey toward a fossil fuel-free future.

PICTURE THE TROPICS, and it's tempting to envisage a verdant landscape blessed with bountiful rainfall. In fact, there's a swathe of sub-Saharan Africa and central Asia where the wet season is brief and unreliable, and the dry season long and hot. Officially known as the semi-arid tropics, but often referred to as the drylands, the region is home to over 2 billion people, 644 million of them the "poorest of the poor".

At the heart of this region, on a 14-square-kilometre research station on the outskirts of Hyderabad in southern India, lies ICRISAT – a three-hour drive from the Madhucon mill.

It's here that Rao's and his team bred the supercharged seeds for the sweet sorghum trial.

Pulling off the jostling, dusty Hyderabad arterial road and easing through the gates into the ICRISAT grounds is like entering another world. A long driveway passes broad fields as we approach a cluster of buildings – a celebration of concrete. It's like sweeping into a 1960s-built university campus. A jackfruit tree stands guard by the main entrance, and mighty mango trees shade the courtyards of the accommodation blocks.

02

Pinnamaneni Srinivasa Rao talks to farmers about the benefits of sorghum.

ICRISAT is one of a network of public good institutions devoted to improving the world's most important crops – and the lot of the developing world farmers who grow them. There's the International Maize and Wheat Improvement Centre (CIMMYT) headquartered in Mexico, and the Philippines-based International Rice Research Institute (IRRI).

High-value cash crops like those won't grow in the semi-arid tropics. ICRISAT is charged with improving the crops that will grow here. In its fields grow low water-demand crops including chickpea, peanut, millets – and sorghum.

As a multi-use crop that grows reliably in the drylands, providing food for a subsistence farmer's family plus fodder for its animals, sweet sorghum has always been a focus for ICRISAT. Add in its biofuel potential, and it's an even better fit for the ICRISAT mission. The big promise? "Income generation," says Rao, who led the sweet sorghum program until late 2015, when he left ICRISAT to join the University of Florida. Subsistence farmers could keep the grain for their own use and sell the rest of the plant for bioenergy production, Rao explains. "We're trying to help farmers move from self-sufficiency to excess production."

Rao and his colleagues have calculated that a little over 2 million hectares of sweet sorghum cultivation – about half the area on which grain sorghum is currently grown in the wet season in India – could provide almost 10% of the country's gasoline requirements.

The strategy is to start small, establish the process at a few sugar mills, and build from there. But even that first small step might falter if the local farmers gathered at the Madhucon mill can't be convinced to embrace the crop.

GROWING BIOFUELS in a way that benefits everyone has proved far harder than many first thought. In fact, in the beginning, biofuels were downright bad news for the world's poor.

In the early part of the last decade, governments including the EU were beginning to introduce policies aimed at curbing their carbon emissions. Biofuels seemed like a quick win. By mandating that these carbon-neutral fuels must be blended into petrol and diesel, the transport sector's carbon footprint would shrink at a stroke.

But where would these crops grow? Land was diverted from food to fuel production, helping precipitate a global spike in food prices that led to riots across the developing world in 2007 and 2008, from Egypt to Bangladesh. The same policies led farmers in countries such as Indonesia and Malaysia to cut virgin rainforest to create fields.

The EU was forced to scale back its biofuel targets. Governments and scientists – as well as investors keen to make a buck – cast around for ways to produce biofuels without compromising food security or valuable natural habitats. The spotlight fell on jatropha.

This scrubby-looking small tree originated in Central America, but today is found growing all over the tropics – including on land so marginal even the poorest farmers don't try to grow crops on it. Jatropha's pod-like fruit contains large seeds that release a good quantity of oil when crushed. That oil can be converted into biodiesel.

GROWING BIOFUELS IN A WAY THAT BENEFITS EVERYONE HAS PROVED FAR HARDER THAN MANY FIRST THOUGHT.

In the late 2000s, investors piled in. Oil prices were at an all-time high; global warming remained high on the global political agenda; and here was a biofuel crop that didn't compete for land with food crops. Huge plantations were established around the tropics. In India, the national government set a target that 20% of its diesel should be biodiesel by the end of 2012.

ICRISAT's scientists could have foretold what would happen next, but in the headlong rush to commercialise the plant, they were not consulted. Jatropha will grow in very poor dry soil, but it won't fruit, and so it won't produce any oil. Even in better soils, the plants sometimes still return disappointing yields, for reasons scientists are still trying to understand.

India planted an estimated half a million hectares of jatropha. But according to the government Ministry of Petroleum and Natural Gas, biodiesel production from jatropha was essentially zero.

The jatropha miracle turned out to be a mirage.

SWEET SORGHUM HAS BEEN GROWN AS A CROP FOR MILLENNIA, HONED BY GENERATIONS OF FARMERS

IT'S HARDLY A SURPRISE, then, that the farmers gathered at the Madhucon mill are wary of what they're hearing. What's to stop the sweet sorghum dream evaporating too?

What makes sweet sorghum different, the plant's champions say, is that it provides fuel and sustenance. And where the jatropha rush was almost akin to attempting to commercialise a roadside weed, sweet sorghum has been grown as a crop for millennia, honed by generations of farmers. "It's not like we're introducing a new crop," Rao says.

"I don't think jatropha's failure should be seen as any indicator," adds Ian O'Hara, a bioenergy researcher at Queensland University of Technology. "There are – and always were – far more important and scalable opportunities for biofuels."

And where jatropha had been virtually untouched by crop scientists, sweet sorghum has undergone intensive improvement. Over the past four decades, Rao and his predecessors at ICRISAT have scoured the drylands region for the best performing sorghum varieties – from the most drought tolerant to the highest yielding.

By crossbreeding these local heroes, ICRISAT scientists have developed sweet sorghum super-hybrids with grain and sugar yields up to 160% higher than traditional varieties – and they are still only scratching the surface of the natural genetic diversity of the crop.

If ICRISAT can make a success of the crop, the payoff could be huge – kickstarting the biofuel industry in a part of the world where progress has stalled, and meeting the world's need for sustainable fuels while simultaneously meeting the needs of the world's poorest people.

Can the economics stack up? If sweet sorghum can get a toehold anywhere, it's the Madhucon mill, where the key factors seem to be in its favour.

VISIT THE MADHUCON SUGAR MILL late in the year, at the end of the wet season, and it will be humming with noise and activity, processing sugarcane. The mill site is dominated by a vast building several storeys high, containing the huge machinery to chop and crush the sugarcane, squeeze out and boil up its juices, and then evaporate the remaining liquid to leave pure white sugar crystals.

Adjacent to the main structure stands a new building. Sugarcane juice that will yield no more sugar crystals is sent here, entering bioreactors that will ferment the sweet liquid into bioethanol.

At the moment, neither the bioethanol nor the sugar price is strong. "The sugar industry is not happy," says Nama Nageswara Rao, the company's founder who, in smart shirt and neatly combed hair, looks every inch the Indian entrepreneur. "We're losing 1,000 rupees per tonne of sugar," he says. To stay in business, the Madhucon sugar mill relies on a third income stream: a small, 25-megawatt electricity plant that generates renewable power by burning sugarcane waste. "We're surviving by selling power".

Now, in late May, last year's monsoon is a distant memory and the mill sits shuttered and silent. Sugarcane needs about 36,000 litres of water per hectare to grow. In the dry season, that amount of water simply isn't available. And when the supply of sugarcane waste runs out, the electricity plant must be switched to run on coal.

A sweet sorghum crop yields only about one-third the bioethanol of sugarcane. But it does so on just 4000 litres per hectare. It's fast-growing, too. The local farmers could easily produce a sweet sorghum crop during the sugarcane offseason.

For the mill's management, sweet sorghum is a way to keep the mill running when sugarcane is not available. Sweet sorghum doesn't yield nice white sugar crystals like sugarcane does, so all its sugary juice would be sent to the fermentation plant for making bioethanol. And the leftover leaves and stalks could keep the power plant running on renewable biofuel, rather than coal.

03

Pinnamaneni Srinivasa Rao examines the sweet sorghum crop.

04

Sweet sorgham is processed into biofuel.

05

The Madhucon sugar mill

SWEET SORGHUM IN AUSTRALIA

Ian O'Hara of the Centre for Tropical Crops and Biocommodities at QUT.

CREDIT: ERIKA FISH / QUT

A CROP THAT THRIVES in hot, dry conditions with minimal water requirements? And can be processed in idle sugarcane mills? Sounds like sweet sorghum might do well in Australia.

Winter never comes to the Pilbara. Only the Atacama Desert receives more sunshine and less rain. This remote region of Australia's northwest is prized for its palette of rusty reds, burnt orange and yellow hues.

Now Lawrence Kirton wants to introduce a new colour: green. Despite the parched conditions, Kirton, who heads Perth-based company AgGrow Energy, thinks the place is perfect for sweet sorghum. And he's grown the crop here to prove it.

And Ian O'Hara, a researcher from the Centre for Tropical Crops and Biocommodities at QUT, recently completed a three-year study confirming sweet sorghum's potential in Australia.

In Queensland, as in India, a lot of sugarcane factories sit idle several months a year. "Sweet sorghum may have some opportunities as a crop to extend the sugarcane crushing season in Queensland," O'Hara says. "But the companies really seriously looking at sweet sorghum are looking in areas where sugarcane is not currently grown."

Such as AgGrow Energy and their Pilbara project. The mineral-rich region is better known for mining than farming, and Kirton sees an opportunity in the wastewater from mining. At the height of the mining boom, companies were pumping almost 300 billion litres of water a year out of their mines and into the river: the pumps consumed 3 billion litres of diesel.

Kirton plans to use that water to irrigate a biofuel crop that the mines could use as a renewable alternative to fossil fuels to drive their pumps and trucks. The plantation would provide employment opportunities for traditional owners looking to move back to their lands.

The company assessed several energy crops, but sweet sorghum was a clear favourite. "We planted the seed at just under 50 degrees, and everyone said it wouldn't grow. What happened was the seed germinated in 48 hours – normally sorghum takes a week," Kirton says. The plants thrived under the Pilbara irrigated conditions, growing so fast it was possible to produce three crops per year.

The end of the mining boom has slowed Kirton's expansion plans, however. In February 2016, the Woodie Woodie manganese mine AgGrow Energy had partnered with throughout the trial was mothballed, after manganese prices collapsed from US$5 per tonne in 2014 to $1.80 per tonne. "We're in discussions with other mines," Kirton says.

Kirton – a Zimbabwean by birth – says sweet sorghum could be grown anywhere the weather is warm enough. "I'd love to take this technology back to central Africa," he says. "As a biofuel crop, if the climate is correct, we don't believe there's anything to touch it."

FOR THE OWNERS of the mill, the motivation for introducing sweet sorghum to the region is clear. For the scientists at ICRISAT, this field trial is one small step in a wider mission to alleviate poverty across the drylands.

The commercial farmers gathered at the Madhucon mill are relatively well off. They aren't the subsistence farmers ICRISAT would ideally target. "The major purpose of this initiative is to make the best use of the existing infrastructure," Rao explains. Once sweet sorghum is established as a commercially viable crop, subsistence farmers could grow it to share the benefit.

Like any would-be superhero, the plant has its weaknesses. It thrives in heat, but can't tolerate cold – growing it outside the tropics is not an option. Keeping insect pests away from its juice can be a challenge. And its use as a dual-purpose crop that can feed humans as well as their cars could be undermined by the decreasing human consumption of sorghum grain. Though consumption in Africa is increasing, in India the locals see it as a poor man's food and aspire to eat wheat or rice, even though sorghum is nutritionally superior to both.

ICRISAT is trying to address this end of the sweet sorghum value chain too, creating demand through its Smart Foods marketing initiative to incorporate it into Western-style food products such as breakfast cereals. Perhaps sorghum might one day grace the menu of fashionable Western cafes, the way traditional grains such as quinoa and faro now do.

AT THE MEETING by the mill, the farmers want to know what price they will get for the sweet sorghum they grow. It's a fair question. Even by exploiting the existing infrastructure at the mill, when oil prices are low – as they were at the time of writing – biofuel margins are likely to be vapour thin. Just how thin, at this stage in the trial, is a chicken-and-egg question. Until the trial has progressed, and they know how much sugar the crop will yield, the amount the mill will be able to pay the farmers long-term is unknown.

In the end, though, the towering sweet sorghum plants practically sold themselves. As we strolled between the rows, the scientists cut a few stalks and measured the sugar content of the juice with a handheld device known as a refractometer. Sweet sorghum may be new to the sugarcane farmers, but sugar content is a concept they know. In the end, the mill was able to strike a deal with enough farmers – helped by the free seed from ICRISAT during the trial phase – to move the project forward.

At the time of publication, the gradual scale-up of sweet sorghum production around the Madhucon mill was progressing. The initial test with a few local farmers had promising results, says Ashok Kumar, who now leads the ICRISAT sweet sorghum team. "Some farmers got very high yields," he says, beating typical sweet sorghum yields by almost 20%. But the farmers are new to the crop, and some will need a little more help. "The farmers need to be trained on sweet sorghum cultivation to achieve higher yields," he adds. Sweet sorghum crushing at the mill was a success, requiring no modification to the machinery used to crush sugarcane. Kumar and his colleagues plan to enrol more farmers in a larger-scale trial, although persuading farmers to grow the unfamiliar crop remains a challenge. Meanwhile, other sugar mills in the region are joining the project.

So far, the Madhucon sweet sorghum experiment seems to be working. It's slow progress – but then, jatropha is a salient reminder of what happens to those who rush in.

India is far from the only country on the cusp of commercialising sweet sorghum as a biofuel crop. The US, Brazil and China are all weighing its potential as part of the transition to a low-carbon economy – as is Australia (see box).

"Will sweet sorghum ever be the main crop for biofuels? Probably not," concludes Peter Carberry, ICRISAT's deputy director general – research. "But for filling niches, there might be an opportunity. Sweet sorghum adds another option for small farmers."

SO FAR, THE MADHUCON SWEET SORGHUM EXPERIMENT SEEMS TO BE WORKING.

JAMES MITCHELL CROW, is a contributing editor at *Cosmos*.

James' trip to India was funded by the Crawford Fund, whose mission is to increase Australia's engagement in international agricultural research, development and education for the benefit of developing countries and Australia, after he won the 2014 Food Security Journalism Award.

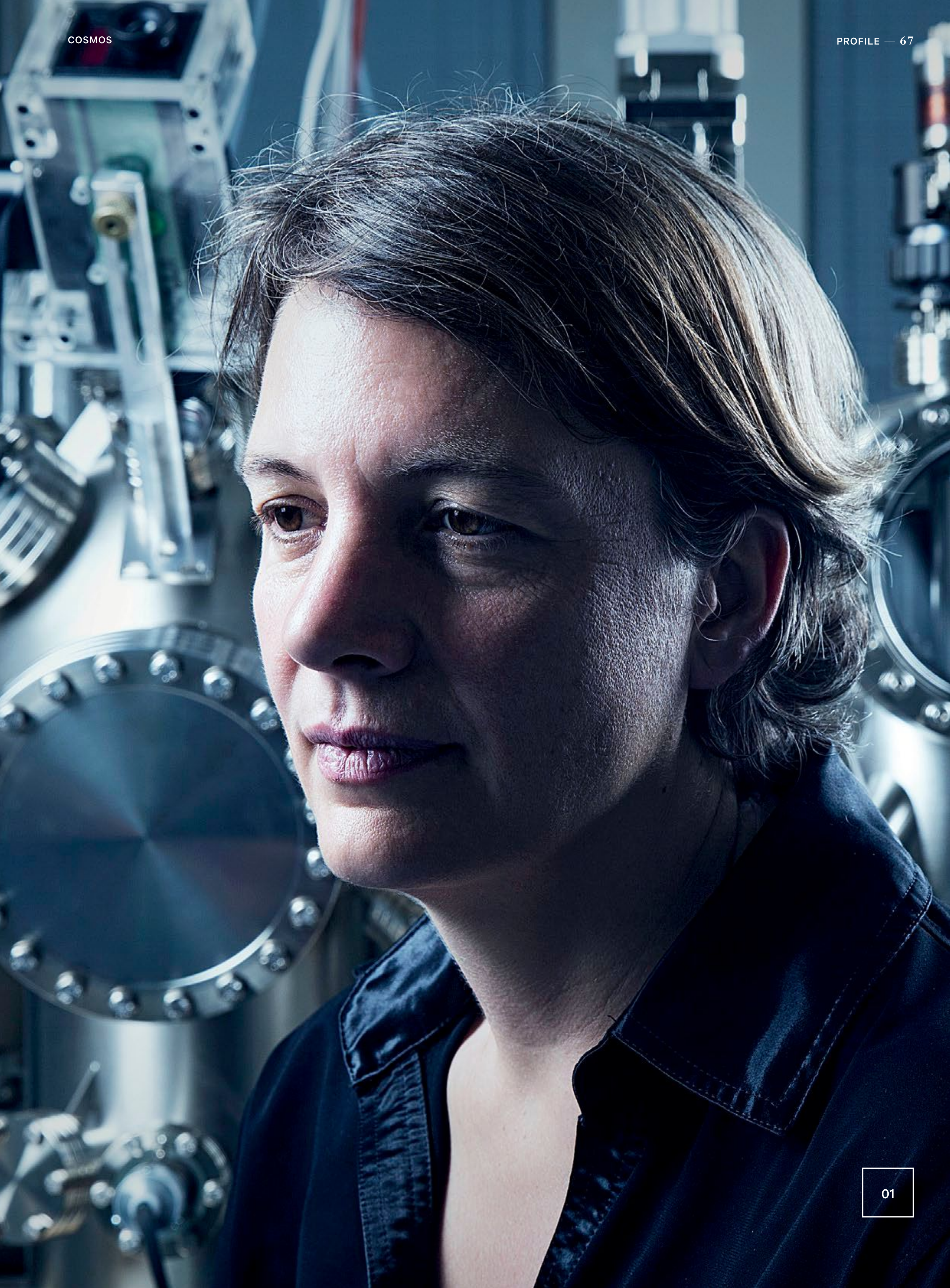
IMAGES
01 Christopher Scott / Getty Images
02 James Mitchell Crow
03 ICRISAT
04 ICRISAT
05 James Mitchell Crow

A QUANTUM LEAP

Can Michelle Simmons lead Australia to the finish line in the race to build a reliable quantum computer? ELIZABETH FINKEL reports.

→

SIMMONS is using a scanning tunneling microscope (pictured behind her) to build silicon-based quantum devices atom by atom.



01

BUILDING A QUANTUM COMPUTER is not for the faint-hearted.

These blazingly fast machines could revolutionise computing by ripping through big data, improving everything from tracking financial markets to weather forecasting. But the technology requires shrinking computer bits to the size of an atom.

"I'M NOT OUT THERE TO RECREATE INTEL, BUT I HONESTLY BELIEVE OUR DEVICES WILL WIN IN THE LONG TERM."

AND UNLIKE THE ROBUST BITS of your laptop, quantum bits or *qubits* are weird and fragile. Trying to corral them is like trying to harness a flock of butterflies.

And then there is the competition: IBM, Google and Microsoft are all in the race.

None of this fazes physicist Michelle Simmons. She is confident the team she leads – the Australian Centre for Quantum Computation and Communication Technology – can deliver the most reliable type of quantum computer ever emerge victorious. In their machine, the quixotic qubit is made of stable silicon.

"I'm not out there to recreate Intel, but I honestly believe our devices will win in the long term," she says. "They are the most reproducible ones that are out there."

Simmons' audacity is paying off.

This year the Australian Centre garnered A$45 million from the federal government and businesses. Backing the "space race of the century", telecommunications company Telstra and the Commonwealth Bank each put in A$10 million; the federal government, A$25 million.

The boost should allow the Australian team to shrink their timeline for building a 10-qubit processor from 10 to five years.

They need to work fast: using different types of qubits, MIT and IBM already have a five-qubit processor, Google's has nine, and Canadian company D-wave controversially boasts 1,000. The Australian team may be behind, but Simmons believes they will win the distance race.

And she is not the only one.

"I think in the long term, for any number of reasons silicon will be the winner," says electrical engineer John Randall, president of Texas-based Zyvex labs, an atomic-scale manufacturing company. "Australia can be a big player."

THE WAY SIMMONS SEES IT, she is tracking a path not unlike the one that conventional computers followed. It took about a decade to advance from the first transistor bit in 1947 to the first silicon chip. The Australian group achieved the first qubit in 2010; if they get to 10 bits in five years, they will be well on track.

Simmons' team is used to her blithe confidence. "Michelle is just mapping it out step by step," says lab head Tony Raeside as he takes me on a tour through two floors of glass-walled, state-of-the-art rooms of the fabrication centre at University of New South Wales (UNSW). Some of the rooms are brand new – the first fruits of the new funds. The big contraptions, like steel monsters in glass enclosures, are scanning tunneling electron microscopes (STMs). Like a blind person's fingers scanning braille, their fine tips detect the contours of individual atoms.

These finely tuned electron microscopes allow skilled operators like Simmons to fulfill a vision imagined 30 years ago by Nobel prize-winning physicist Richard Feynman: to sculpt matter atom by atom. They are also the key to making the silicon qubit.

Many remain skeptical about the promise of quantum computing. But things are changing. Two years ago, Simmons was invited to give a tutorial at a satellite conference of the International Electronic Devices Meeting, the premier gathering for the electronics field. The organisers vetted every word of her talk to make sure it didn't contain anything too mind-bending. They needn't have worried. Her talk was a hit, and last December, they invited her back to give the keynote lecture.

SIMMONS HAS ALWAYS HAD an audacious streak. She tells a story about how, as an eight-year-old, she sat silently week after week watching her father, a high ranking policeman in London, play chess with her elder brother. One day she asked her father if she could play. Her father reluctantly acquiesced and played without paying much attention – until she took his first pawn. By then it was too late. She checkmated him.

Simmons' mother was a bank manager, and her grandparents included diplomats and members of the military. She describes her family as "take-responsibility kind of people". The family DNA also includes a sense of adventure. Her father would always tell her, "don't take the easy route. Do the most challenging thing".

I am sitting opposite Simmons, now 49, in the Quad café on a sunny wintry day at UNSW. She has rushed in for a snatched lunch and is clad in her signature look of casual black, draped across her tall, solid frame. Her hair is short and practical; she wears no jewellery or make-up. There is a soft, gentle femininity about her. As we talk, I wait for a glimpse of the iron fist that must surely reside inside the velvet glove. Leading a team of brilliant physicists bent on world domination must take some doing.

It was by popular demand that in 2010, 11 years after joining the group, Simmons became their leader, overseeing the entire consortium of 180 researchers from UNSW, University of Queensland, University of Melbourne, Griffith University and Australian National University. The UNSW headquarters hosts four scientific teams, each with its own research leader: Andrew Dzurak, Sven Rogge, Andrea Morello and Simmons. Like mountaineers navigating a maze of crevasses and cliffs, they are trying different paths but are united in their push to scale the peak of silicon-based computing. (See figure.)

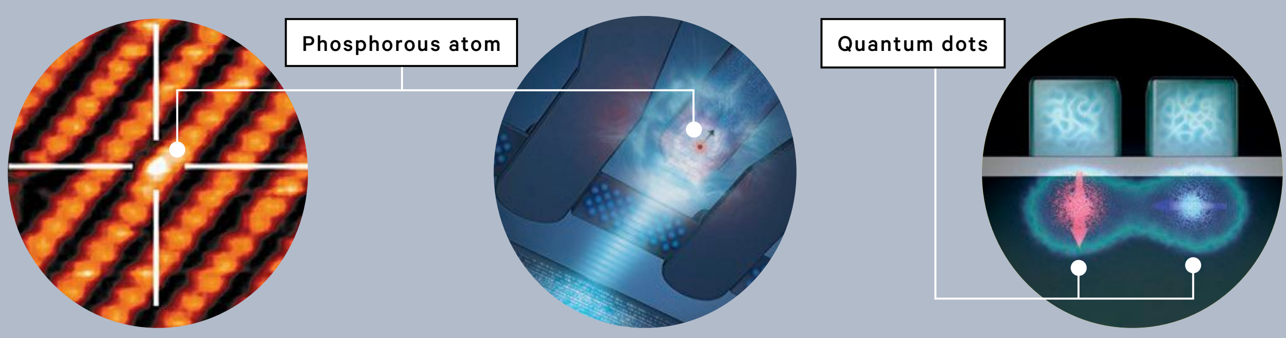
"The strength of our centre is that we have three parallel pathways marching forwards. Of course we all love our own children, but we a have respect and regard for the others," says Dzurak. Leadership here requires the ability to rally and unify the team while belaying your own rope.

Simmons revels in the different strengths and perspectives of her colleagues. "Physicists have very unique ways of seeing the world," she says. She also enjoys pushing them out of their comfort zones and seeing them scale new heights. The key to her leadership is her clarity of purpose. "I could always see the obvious way to go forward," she says.

There is the eight-year-old anticipating all the moves ahead. Only today, she is navigating her way through the chessboard of quantum computing.

QUBITS MAY BE WEIRD, but the day-to-day work of building one is very down to earth. The process starts with a commercial computer chip, a pure silicon crystal wafer about 3 millimetres by 10 millimetres, which is placed inside the ultra-high vacuum chamber of the STM. A trickle of hydrogen gas is bled into the chamber, coating the surface of the wafer with a mask of hydrogen one atom thick.

THREE WAYS TO MAKE A SILICON QUBIT



1 Simmons' group builds the P-atom into the silicon crystal.

2 Morello and Dzurak fire phosphorous atoms into the silicon crystal.

3 Dzurak's group tweaks silicon transistors to produce quantum dots.

Guided by a scan of the atomic landscape, the tip of the microscope probe becomes a nanoscale etching pen. By varying its voltage, it can be used to poke a single hole through the hydrogen mask or scratch out a line of millions of atoms.

When phosphene gas seeps in, one phosphate atom will parachute into the hole to become the qubit, while others will fill the long scratch to become the wire that measures the qubit's signal. Next, the crystal wafer is heated to 350 °C for one minute to bond the phosphate atoms. Then the crystal is coaxed to grow over its new components by sprinkling it with a light soot of silicon atoms – a technique known as epitaxy.

This phenomenon is termed "superposition". Even more mind-bending, two electrons could influence each others' spin even if they were at opposite ends of the universe. They were said to be "entangled". Eisntein referred to it as "spooky action at a distance".

It was these two properties, superposition and entanglement, that led Feynman to speculate that a quantum computer would be able to perform a massive number of calculations in parallel.

The bits of a classical computer have a value of either 1 or 0 (because they either pass current or not). But a qubit would also have the value of 1 or 0 simultaneously. The long and short of this

03

Leading different routes to a silicon-based quantum computer (left to right): UNSW's Sven Rogge, Andrea Morello, Michelle Simmons and Andrew Dzurak.

Simmons pioneered this two-day, 25-step manufacturing technique. "Her ability to position atoms with this accuracy is unique," says Klaus Ensslin, who heads the nanophysics lab at the Swiss research institute ETH in Zurich. Learning to master it is tough; typically it takes a student a half a year.

RICHARD FEYNMAN PROPOSED a basic model for a quantum computer in 1982. The Caltech physicist had been part of the tail end of the quantum mechanics revolution that revealed how strange the universe was at the atomic scale. An electron or the nucleus of an atom has a magnetic orientation called "spin" and can exist in one of two spin states: up or down.

But in the quantum world, the spins can also exist in these states at the same time.

quantum logic is that hundreds of qubits are predicted to have the same crunching power as billions of classical bits.

When it comes to problems that stump modern computers, such as finding the prime factors of huge numbers (the basis of encryption) or finding the optimum path between destinations from billions of possible ones, quantum computers would ace it. That's why banks and companies that deal with vast databases are so keen on the technology.

But for two decades, quantum computing remained stuck on the drawing board. Computing requires that calculations are done many times to correct errors. But that's a problem for quantum computers because each time you read the result you influence it.

In 1995 several people, including Peter Shor at Bell Labs in the US, figured out how to solve the error correction problem. Shor had also written an algorithm for a quantum computer to factorise prime numbers. Galvanised by the possibilities, labs around the world dove in to try to build a quantum computer. For qubits, MIT used ions trapped in a vacuum; IBM used tiny loops of superconducting metal; others tried quantum dots of gallium arsenide.

The Australians tried something entirely different: silicon.

THERE IS AN OBVIOUS QUESTION to be asked. If silicon really is the clear winner for reliable quantum computing, then why did Australia end up with it, and not MIT or IBM?

Three things seem to have conspired to make Australia the germination ground: good timing, a core group of visionary physicists, and the exceptionally receptive environment of UNSW.

Australian physicist Bob Clark founded the group in the late 1990s after returning from Oxford where he had helped pioneer low-dimensional physics. Advances in fabricating silicon and gallium arsenide crystals for the semiconductor industry, using extremely low temperatures and strong magnetic fields, were revealing remarkable new states of matter. So-called "electron gases" with novel behaviours lay between the layers of the crystals. Nobel prizes were awarded for those discoveries.

To continue the work at UNSW, Clark established a silicon nanofabrication facility and the National Magnet Lab. His reputation attracted bright young physicists from around the world, including Andrew Dzurak, an Australian who had completed a PhD at Cambridge.

Around 1996, Bruce Kane, a junior scientist from Bell Labs in the US arrived to work on the low-dimensional physics of gallium arsenide crystals. Clark also suggested that he try working with silicon.

Months later, Kane appeared in Clark's office bearing a hard-back notebook filled with calculations. In his spare time at UNSW, Kane had worked out a design for the basic elements of a quantum computer.

Kane's idea was entirely different from the other approaches in play. He conceived a way to make a qubit using the computer industry's standard materials. Kane's qubit would be a single phosphorous atom embedded in a silicon crystal. Because the phosphorous atom is very close in size to the silicon atom, it should cause minimal disturbance to the silicon crystal. Pure silicon, whose atomic nuclei have zero spin, would provide a noiseless background against which to read the spin of the phosphorous nucleus.

By the time Kane was scribbling in his notebook, it was clear that noise was a limitation of other types of qubits; it was interfering with the ability of the qubit to hold its signal long enough to do some processing – its so-called "coherence" time. While other systems had coherence times of a 1,000th of a second or less, in theory silicon would provide the qubits with entire seconds to carry out its processing.

Clark stayed up all night reading Kane's paper. By morning it was clear to him this was a work of genius. It was also clear to him that he would move heaven and earth to bring the idea to fruition. The team filed a patent and published a paper in *Nature* in 1998. Physicists read it and were enthralled. But there weren't many who were eager to give it a try.

Manipulating single atoms to build the qubit was only the start. No-one knew how to read the spin signal of a single electron or nucleus; the available technologies read signals from a million of them.

"It was a theory on paper but I never thought it would work," recalls Ensslin.

But there was one person who did. She was just a junior scientist at Cambridge, but she had a reputation as a world leader in fabricating quantum electronic devices. Dzurak, her former Cambridge colleague, had already regaled her with tales of sunny Sydney skies and the blues of Bondi Beach. In 1999, Simmons joined the budding group of UNSW visionaries.

"IF WE COULD DO IT, YOU COULD GET SCALE UP BY THE WORLD'S EXISTING COMPUTER INDUSTRY."

WHEN SIMMONS ARRIVED at UNSW, she was no stranger to daunting problems.

She encountered one of the first as a 16-year-old at a rough inner London comprehensive school. In her final two years, the school decided to road-test "independent learning"; it was so independent her class had no chemistry teacher. Most of her classmates failed the year. But Simmons unpacked boxes with the textbooks and chemistry experiments and figured out a DIY chemistry course. It was an experience that forged her signature trait: self-reliance. " I still believe the best way you learn is by yourself," she says.

Years later, that self-reliance got her a dream collaboration with NASA while still working on her PhD. "I love everything space," she says. Simmons was to test the potential of perfectly symmetrical

3-D crystals grown on the space shuttle to advance solar cell technology.

But tragedy struck. In 1988, her supervisor, who was fond of taking a weekend swim between two bays in Northeast England, didn't make it to the second bay. Simmons thought of moving on to another university but her supervisor's wife entreated her to continue her husband's work. She stayed. But then the space crystals didn't cooperate – what came back on the shuttle was a sludge. Seeking help from other Durham professors, she took a different tack. It required combining cadmium sulphide and cadmium telluride – an unusual combination of a cubic and hexagonal crystal. The resultant material was superior to silicon, achieving a record efficiency for solar cells at that time.

> "ALL OUR AUSTRALIAN FRIENDS ARE PIONEERS. THEY PUSHED THIS TECHNOLOGY WHEN OTHERS GAVE UP."

Her success took her to Cambridge, where her modest project was to build the world's fastest transistor using crystals of gallium arsenide. Known as "the material of the future", unlike silicon, it could be fabricated as a single crystal, not just in a horizontal layer but also the vertical layer, offering the possibility of 3-D computer chips.

Simmons became a master fabricator. Even so, she struggled. Out of 10 chips, they all behaved differently. She could not see how the gallium arsenide crystal could ever be useful at an industrial scale or how it could deliver reproducible results as a qubit.

But when Simmons read Kane's paper, she sniffed a game-changer. And so when the call from UNSW came, she enthusiastically accepted. It was a place, she recalls, where "peoples' eyes didn't glaze over" at crazy ideas.

PHYSICISTS SAY THERE IS no way to underestimate the difficulty of what Simmons and the group have achieved so far. "All of our Australian friends are pioneers. They pushed this [silicon-based] technology when we gave up," says Ensslin. But, he adds, "Michelle is truly courageous. She pushed through with amazing tenacity for 10 years".

Somehow, Simmons manages to have a life beyond work. She is the mother of three children, aged eight, 11 and 12. Her husband also has a high powered career as an academic consultant. Her husband's family makes it all possible, she says. Each time she gave birth, she moved into her husband's family home for a couple of weeks. Now her kids are older, with different needs. "They are all terrific, but it doesn't get any easier," she says. The relentless travel is difficult, but "they believe what I am doing is important", she adds.

Her unwavering dedication has not gone unnoticed by the scientific community. Simmons has won a string of Australian and international awards. Last May, she received the prestigious Feynman prize. The judges credited her with creating "the new field of atomic electronics".

04

A chilled chamber cools the silicon qubits to 0.02 degrees above absolute zero, which allows information to be read and written onto them.

But Simmons spends little of her own time fabricating atomic electronics now. Her energies are directed towards leading the team's ascent.

There's still a long distance to travel from two qubits to 10. And the pressure to deliver over the next five years is huge.

Simmons is undaunted. Ever the policeman's daughter, she remains focused, driven by a sense of responsibility and unafraid to face a challenge. "All my life, I've always thought, 'well this is another little problem, this is what we've got to do' and I've always wanted to get on with it," she says. "It's all working the way Bruce Kane imagined. That's what gives me that audacity."

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

IMAGES
01 Nic Walker / Fairfax Syndication
02 UNSW
03 UNSW
04 Marcus Enno

PEOPLE, CULTURE
& REVIEWS

SPECTRUM

ZEITGEIST

Trial by spin and bad science

Doctor, researcher and acadmic Ben Goldacre is determined to reform how clinical trials are conducted and reported. On the eve of his speaking tour to Australia, he explained his venture to ANDREW MASTERSON.

01

ZEITGEIST

Trial by spin and bad science

→ Ben Goldacre is on the phone from London and he's getting exercised about statins.

"Statins are the canary in the cage for problems in modern medicine," he says.

They are also the subjects of his next book – yet to be completed – and were addressed at some length in his last one, *Bad Pharma* (2012).

His continued focus is not surprising. For a host of reasons, research into statins and the prescribing patterns that research catalyses pretty much epitomise his concerns about medical academia.

They are concerns that, since he qualified as a medical doctor in 2000 after studies in Oxford, Milan and Los Angeles, have seen him move from GP, to author, to researcher, to, now, medical activist.

Goldacre, UK-born to Australian parents, fronts two long-term campaigns designed to bring about root and branch reform of the ways clinical trials are conducted and reported.

The first, AllTrials, has been running since 2013. It seeks to ensure that every trial is both registered with an appropriate authority and then published, regardless of result. At present, perhaps as much as 50% of trial write-ups never see the light of day.

The second campaign, CompareTrials (CT), kicked off late last year and aims to enforce procedural transparency in trials. At issue is the matter of switched priorities: trials that start by researching one outcome, but then change to another before the exercise is concluded.

WE HAVE FAILED, SO BADLY, TO COMMUNICATE THE MODEST BENEFITS OF THESE TREATMENTS TO THE PUBLIC.

Earlier this year, the CT team checked every trial published between October 2015 and January 2016 in five major publications, including the *British Medical Journal* and the *Annals of Internal Medicine*. The results reported were compared to the outcomes specified when the trials were initially registered, or the founding protocols published. Out of 67, only nine did what they set out to do. In the rest, 354 stated outcomes were not completed, and 357 new ones were added.

Goldacre happily admits that CT is a "preposterously nerdy venture". That said, however, it doesn't diminish its importance.

"There's a real problem in the way that clinical trials report their results. You can measure the outcome of your trial in hundreds of different ways," he said.

He poses the hypothetical example a drug aimed at improving cardiovascular health. How baseline and improved health are assessed are matters of great complexity. Blood tests can measure perhaps 20 applicable lines of evidence, each set against potentially hundreds of cut-off points. Symptom questionnaires can be measured against a plethora of ratings scales. Hospital admissions can be recorded by treatment, code, doctors' notes or length of stay. Patients can be monitored over days, weeks, years, decades.

02

Ben Goldacre says that statins are the "canary in the cage for problems in modern medicine".

"So you potentially have thousands and thousands of ways of measuring something like cardiovascular health," he says, "And because there are so many ways of measuring it, that means the results are really vulnerable to cherry-picking.

"That's why traditionally we ask people at the beginning of a clinical trial to specify exactly what they are going to measure as the success criteria, and exactly how they are going to measure it."

Tradition, obligation, and principle, however, are not unbreakable bonds (as any subscriber to Retraction Watch can testify). Much of Goldacre's *Bad Pharma* comprises a detailed and depressing catalogue of the many ways in which researchers – sometimes at the behest of the pharmaceutical companies sponsoring the work – recalibrate their initial intentions and generally fiddle with the data.

Sometimes this is merely a matter of spin – such as expressing a benefit as a relative rather than absolute risk reduction – but sometimes it is much more organic.

Outcome priorities are changed; negative results are omitted; trials are foreshortened or extended to better massage the data. In the book, Goldacre terms these tactics "a quiet and diffuse scandal".

Perhaps this would not matter quite so much if it weren't for the fact that published trial results feed into pharmaceutical marketing and doctor prescribing choices.

In *Bad Pharma*, Goldacre relates a trial featuring a new painkiller, celecoxib, that was tested against two other pills to assess side-effect gastrointestinal complications. The published study showed clearly that over a six-month period the new drug was way better than the old ones, leading many GPs to preference it in prescribing.

But it eventually came to light that the original intention of the trial was to test the three pills for a 12-month period – over which celecoxib performed no better than its rivals.

At the other end of scale, in the late 1990s pharmaceutical company GSK investigated anecdotal reports of deaths associated with its asthma inhaler drug Salmeterol. It set up a large clinical trial, with participants monitored intensively for 28 weeks. It then asked participating doctors to keep an eye out for adverse events for another six months – but did not actively search for cases.

Not surprisingly, the period of intensive monitoring revealed a higher number of negative outcomes (measured against a placebo) than the follow-up period when no one was looking too hard. Changing its initial trial protocol, GSK reported the figure for the two periods combined, thus reducing the apparent severity of the problem.

Which brings us back to statins, the most commonly prescribed medication in the developed world, and Goldacre's canaries.

In *Bad Pharma*, he points out that the two most popular prescribed statins, atorvastatin and simvastatin, both work well, but no one has ever tested them against each other to determine which one works *better*. This is an important point, because if one works only slightly better than the other it's still a result that could convert into the prevention of thousands of strokes and heart attacks every year.

In the absence of this data, prescribing, Goldacre points out, is effectively a random act. But attempts to formally constitute that randomness as a countrywide trial in England met with a farcical level of bureaucratic complication. That makes statins "one of the most

03

Ben Goldacre's book *Bad Pharma* probes the shoddy science that influences doctors' prescribing choices.

fascinating problems in medicine right now".

"Over 100 million people take a statin every morning and yet there are huge gaps, firstly in our knowledge about which is best, and gaps in our knowledge about side-effects," he says.

"But also, we have failed, so badly, to communicate the modest benefits of these treatments to the public that there is huge widespread panic and anxiety among not just patients but also doctors, in many cases, about what the benefits of these treatments are.

"If we can't get this stuff right for [statins] the single most commonly prescribed class of drug in the whole of the developed world – a tablet that is taken every day by 100 million people – then that's a real window into our failures to do appropriate clinical trials throughout the whole of medicine."

It's a subject to which he will no doubt return, not only in his forthcoming book, but also in his upcoming speaking tour of Australian capital cities, kicking off in Brisbane on 22 September.

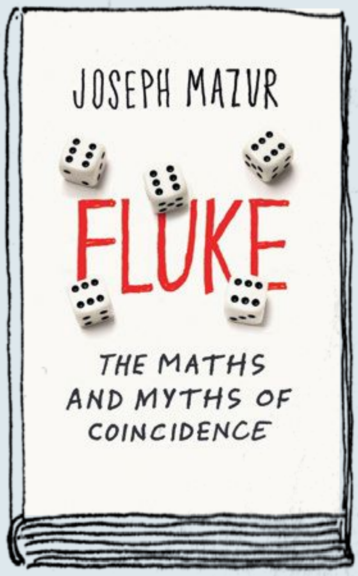
→ Dates and tickets can be found at www.thinkinc.org.au/events/ben-goldacre

ANDREW MASTERSON is an author and journalist based in Melbourne, Australia.

IMAGES
01 Ben Gilbert
02 Science Photo Library / Getty Images
03 Harper Collins

REVIEWS

Leaving luck out of the equation



NON-FICTION
Fluke: The Maths and Myths of Coincidence
by JOSEPH MAZUR

Basic Books, NY (2016)
RRP $29.99

JOSEPH MAZUR introduces *Fluke* with two childhood stories about accidents: one that blighted the life of his uncle and another that left Joseph himself blind in one eye when he was only 12. Young Mazur tormented himself with questions about chance, the most poignant being: "What if I hadn't stopped to look around?" The answer is all too clear: the stone would not have hit his eye. This is a hallmark of Mazur's writing: the human touch in a book about mathematics. In *Fluke*, he sets out to mathematically disentangle such coincidences from our all-too-human notions of fate and destiny. I say "too human" because we all love a happy coincidence story: as Mazur puts it, "in this enigmatic galaxy, [such stories] validate our longing for individuality". This is another Mazur hallmark: discursive forays into psychology, physics, philosophy, and history.

Indeed, he is careful not to let the mathematics of chance rob us of any meaning we may ascribe to our own coincidence stories, and introduces Carl Jung's famous "synchronicity" concept: that coincidental events can be "meaningfully related in significance, but not causally connected". In other words, magic can happen for us on a psychological level, but we don't have to suspend the laws of physics or probability. Many seemingly impossible coincidences turn out to be fairly likely: it is their timing that is key, and the fact that we happened to notice them. Meanwhile, myriad coincidences occur without us noticing: in the mathematics of chance, the number of "failures" must be counted, as well as the amazing "successes" (to use the language of the binomial distribution, a cornerstone of Mazur's 70 pages of mathematical explanations for the general reader).

Mazur stresses that it is the numerical vastness of the world – 7 billion people, and "gazillions" more atoms – that makes probability theory work. It is astonishing that we can estimate the likelihood of seemingly random events whose chains of causality and multitudes of hidden variables we can never know. Yet mathematics enables us to skip straight to the big picture, thanks to the weak law of large numbers. Mazur explains that by choosing a large enough sample, the actual probability of an event will be approximately the same as its mathematical probability. In other words, "If there is any likelihood that something could happen, no matter how small, it's bound to happen sometime."

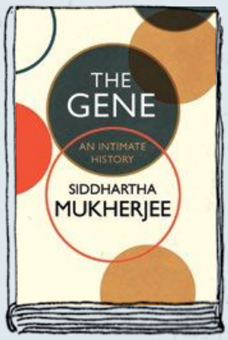
Of course, nothing is certain in the real world. Mathematics tells us what is probable, but it does not predict our own individual futures. Rather, it teaches us not to resort to magical explanations of seemingly miraculous happenings: multiple lottery wins and chance meetings are far more likely than they seem when viewed only from a personal or local perspective. Mazur illustrates this by telling 10 true coincidence stories early in the book, and then revisiting them after the mathematical tools are in place. This later section uses numerical guesstimates to relate real events to the chances of, say, getting a royal flush in a poker hand.

IF THERE IS ANY LIKELIHOOD SOMETHING COULD HAPPEN, NO MATTER HOW SMALL, IT'S BOUND TO HAPPEN SOMETIME.

The final section is a group of essays that broaden the discussion. In showing that there is a tiny chance that random combinations produce the same DNA pattern for two unrelated people, and in outlining problems of contamination and interpretation, Mazur offers a passionate plea for the scientific education of jurors, and a challenge to the logic of the death penalty. In other essays, he highlights the riskiness of globalisation in light of the coincidences that helped bring on the Global Financial Crisis; Wilhelm Röntgen's serendipitous discovery of X-rays; cerebral magnetic fields, and the role of chance in telepathy "experiments"; and the psychological importance of chance meetings in fairy-tales.

All in all, Mazur writes in a chatty and accessible way, putting maths at the centre of an entertaining and informative read.

— ROBYN ARIANRHOD



NON-FICTION
The Gene:
An Intimate History
by SIDDHARTHA MUKHERJEE

Penguin Random House (2016)
RRP $35.00

A BOOK OF BOTH HISTORY and science, this couldn't have a better title – it's quite simply the comprehensive story of the discovery, disentanglement and manipulation of the gene.

From the first pea-breeding experiments of Gregor Mendel to the potential for gene editing (by way of Charles Darwin, the Nazis and many others), *The Gene* is by the Indian-American oncologist famous for the 2010 book *The Emperor of All Maladies: A Biography of Cancer*.

Mukherjee writes beautiful prose that has an edge of florid beauty and an unexpected sense of humour: when describing Mendel's attempt to extend his experiments to mice, Mukherjee writes that the abbot of his monastery refused but that he "didn't mind giving peas a chance".

Even if you're only passably familiar with genetics, it's a treat to learn the origins of words such as "genetics" and "mutant". Among the tidbits of interesting trivia is that genetics generated the first effective chemical insulin treatment in the 1950s, and the first genetic hybrid organism was built in the 1970s, with concerns about the safety of genetic engineering raised soon after.

Among the fascinating dimensions the book brings to light is the history of the gene as a political tool. As early as 1905, one of the early purveyors of the science wrote that since genes were discrete particles, we might one day have the means to manipulate the "composition of individuals" and "leave a permanent mark on human identity", adding ominously that "when power is discovered, man always turns to it".

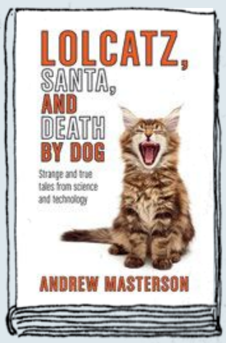
Such efforts have of course been used to justify mass race-specific slaughter everywhere from 1940s Europe to 1990s Rwanda. Mukherjee deftly suggests that the gene has some of the characteristics of technology or money – a morally neutral framework we can use to enable both our best and worst social behaviours.

There's also plenty of fascinating science on offer. An example is the phenomenon of gene transition – where cells close to each other can spontaneously transmit genes between them with no need for sexual reproduction.

As the story gets closer to the present day, the science gets more complicated and some of the deeper principles and equations might go over the head of the lay reader. But the descriptions of the human characters, their collaborations and rivalries and the socio-political scene that swirled around them, bring the story vividly to life.

It's long, but the lightness of the prose makes it very readable. By the time you finish you'll understand more about the history and potential of genes than you ever thought you could.

— DREW TURNEY



NON-FICTION
Lolcatz, Santa, and Death by Dog: Strange and true tales from science and technology
by ANDREW MASTERSON

Ebury Press (2016)
RRP $34.99

ANDREW MASTERSON has an unerring ability to winkle out the oddball from the avalanche of research that hits a science writer's desk each week.

Included in this collection are answers to how Twitter has expanded our swearing vocabulary, a caution over the poison-laden death-trap that is your cat, and a warning that the rise of the machines might just be starting in your broom closet.

But while his taste for the absurd is well-honed he also has a keen eye for serious science. An interview with Brian Greene, for example, does a masterful job of explaining the physicist's insights into string theory in a way that leaves you thinking you truly understand at last.

Elsewhere there is an entertaining encounter with the work of Bill Nye "the science guy" (and Nye's unexpected quarrel with physicist Brian Cox), a meeting with astrophysicist and television superstar Neil deGrasse Tyson and a tryst with that infamous exposer of secrets, Edward Snowden.

This witty, informative, and sometimes laugh-out-loud-funny book is a tremendous diversion for dipping in and savouring its bite-sized pieces.

Masterson, a regular contributor to *Cosmos* magazine, has an engaging, sardonic style of writing that lends itself to his unexpected lines of inquiry – such as when he explains how chilli is the common link between rap music, cancer and obesity, or how to scientifically stick a pin in a can of Guinness.

But there is also his clear curiosity for the world around him as he explains the common thread through the eclectic subjects packed between the covers of Lolcatz.

It is, he says, the "wide tapestry of research – of science and its children applied across a dizzying variety of cultural activities".

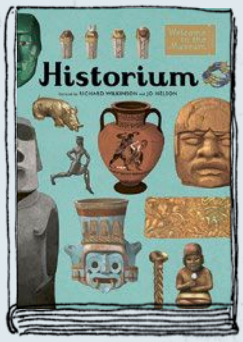
Some hold promise for a better world, others are amazing discoveries, still more raise disturbing questions about how humanity can live with the ubiquitous technology it has become so addicted to.

Highly recommended.

— BILL CONDIE

→ facebook.com/LolcatzSantaandDeathbyDog

REVIEWS



NON-FICTION
Historium
by RICHARD WILKINS
and JO NELSON

Five Mile Press (2015)
RRP $39.95

THIS IS A WELCOME addition to the collection of gloriously illustrated books from Five Mile Press. This time the subject is antiquities with a collection of objects from ancient civilisations around the world.

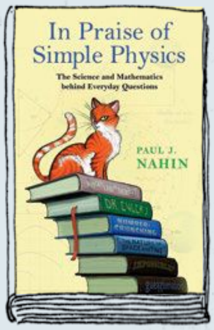
The books shares the exceptional production values of its sister volumes such as *Animalium* and *The story of Evolution*, with high quality paper and coloured pen and ink illustrations by Richard Wilkins.

The book is arranged as if it were a museum with different rooms representing different exhibitions from regions around the world.

The clear and informative text puts each of the 130 objects into archaeological context.

As with other Five Mile Press books in the series, it is targeted, one suspects, at children, but plenty in this classy volume will appeal to adults as well.

— BILL CONDIE



NON-FICTION

In Praise of Simple Physics: The Science and Mathematics behind Everyday Questions
By PAUL J. NAHIN

Princeton (2016)
RRP US$29.95

THIS WONDERFUL BOOK takes physics back to its most approachable – explaining the world around us, be that sitting in traffic and working out how to beat the red light, learning the best way to improve your baseball or explaining why the sky is dark at night.

Nahin begins with the simple, and the problems become more complex as he goes on.

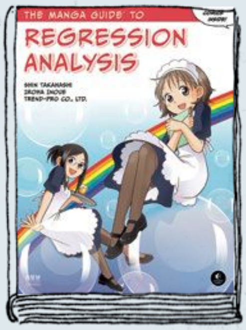
Nahin, professor emeritus of electrical engineering at the University of New Hampshire, is the author of many best-selling popular-math books, including *Digital Dice, Chases and Escapes, Dr. Euler's Fabulous Formula, When Least Is Best, Duelling Idiots and Other Probability Puzzlers*, and *An Imaginary Tale* (all published by Princeton).

This book would be a wonderful companion for a serious physics student, to put in context the concepts learnt in the classroom.

But it is equally as much fun for anyone curious about what the makes the world tick. OK, so that's a curiosity PLUS a nodding acquaintance with calculus, but nothing too severe.

While he doesn't shy away from mathematics when it is needed, his writing is clear, entertaining and humourous, as readers of his other work will know.

— BILL CONDIE



NON-FICTION

The Manga Guide to Regression Analysis
By SHIN TAKAHASHI
and IROHA INOUE

No Starch Press (2016)
RRP A$32.99

REGULAR READERS WILL KNOW that we at *Cosmos* are great fans of the Manga Guide to Science series co-published by No Starch Press in San Francisco and Tokyo-based technical publisher Ohmsha.

While "Regression Analysis" may at first appear an incongruous subject for Japanese comic treatment, the book is the familiar mix of manga and serious science we have come to expect.

As in most of this series, tough concepts are delivered with humour and a story. In this case Miu has had trouble learning regression analysis, but is helped out by her brilliant café co-worker, Risa, and a handsome customer.

But first the guide begins with a review of the maths needed: inverse functions and differential calculus. It goes on to explain quite sophisticated statistical processes including regression equations, hypothesis testing, variance, and how to perform chi-squared and F-tests.

The author, Shin Takahashi, graduated from Kyushu University with a master's degree in information technology and has worked as both a data analyst and an instructor but now specialises in writing technical books full-time.

It's a great little book if you need to know regression, without doing a full-on mathematical course.

— BILL CONDIE

TOP 5

Bestsellers

1

When Breath Becomes Air
by PAUL KALANITHI

Random House (2016)
RRP $32.99

2

The Gene:
An intimate history
by SIDDHARTHA MUKHERJEE

Penguin Random House (2016)
RRP $35.00

3

The Wright Brothers
by DAVID McCULLOUGH

Simon & Schuster (2015)
RRP $32.99

4

Grunt: The curious science of humans at war
by MARY ROACH

Norton (2016)
RRP $53.95

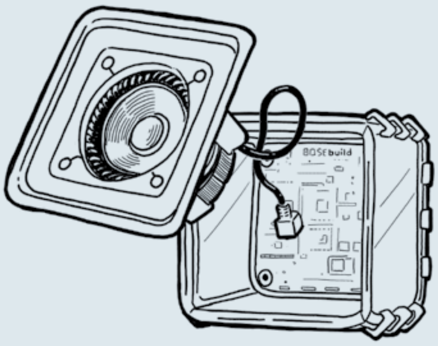
5

The Power of Habit:
Why we do what we do,
and how to change
by CHARLES DUHIGG

Random House (2013)
RRP $19.99

— FROM THE NEW YORK TIMES SCIENCE BESTSELLER LIST

GADGET



SPEAKER

BOSEbuild Speaker Cube

BOSE

IF YOU LIKED taking things apart and reassembling them as a kid, you'll appreciate this gadget. Designed to educate children on the science of sound, this build-it-yourself Bluetooth speaker from BOSE may just tickle the fancy of any tech-inclined parent, too.

The $150 kit includes a control and a speaker panel, a magnet, a coil, side panels and some clips. Putting these together is not exactly rocket science. An iOS app companion runs through step-by-step instructions – all you'll need is a pair of scissors and some tape.

But it's less about the destination and more about the journey, as builders learn everything from how a simple magnet makes sound, to how a speaker creates music. The app also guides users through experiments that explore the science behind the speaker – frequency, waveforms, magnets and the general physics of sound.

The BOSEbuild Speaker Cube is also customisable with LED lights and silhouette covers, and pairs to any smartphone or tablet. So kids – or adults – won't have to wait long to reap the acoustic rewards.

— VIVIANE RICHTER

→ bit.ly/cos70gadget

REVIEWS

Eyes in the sky

DOCUMENTARY

Telescope

Discovery (2016)

The documentary will air on Foxtel's Discovery Channel on August 28 at 11.30 am.

THIS IS AN AWE-INSPIRING primer on the James Webb Space Telescope and an inspirational journey through the history of space exploration.

Everyone knows our understanding of the Universe has come a long way since astronomers believed Earth was the centre of the Solar System. But *Telescope* delves into an entertaining selection of tales along the astronomy timeline that got us to where we are now.

You'll find out why over four tonnes of French wine bottles were smashed to solve the debate over whether our galaxy is alone in the universe. There's the story of how an observation at the Mount Wilson Observatory uncovered Einstein's biggest blunder. You'll also learn what the Hubble Space Telescope discovered after staring into seemingly blank space for 10 days.

The documentary builds to the most ambitious feat in telescope technology ever attempted – the James Webb Space Telescope, Hubble's successor.

Unlike Hubble, it has the ability to observe infrared light, allowing astronomers to see further than ever. Scientists hope it will spot exoplanets with signatures which may flag life, and bring the evolution of the universe into focus.

But unlike Hubble, this space telescope will be deployed much further from Earth. With no second chance to service the telescope or fix mistakes, the scientists have one shot to get it right.

Telescope explores an uncertainty lingering amongst the scientists alongside their passion, as it goes behind the scenes of the telescope's construction. After its launch, currently scheduled for October 2018, the James Webb telescope will unfurl in space like giant origami – where, as you can imagine, a lot could go wrong.

But rolling footage of spectacular images collected by Hubble – set to become even more breathtaking through James Webb – are there to remind us why it's all worth it.

— VIVIANE RICHTER

EVENT
Plants in Space
AUSTRALIAN ACADEMY OF SCIENCE

Wednesday 21 September, 2016 at The Shine Dome Canberra.

IF YOU WERE INSPIRED by the resourcefulness of botanist-come-astronaut Mark Watney in Andy Weir's *The Martian*, you'll want to attend this talk.

Plants are not just a nostalgic gimmick in space. Sure, they may brighten up the rather technical decor of any space station. But they also have the potential to provide fresh food, remove carbon dioxide and produce oxygen for astronauts. And over the past 30 years, NASA has been working hard to make that happen.

And you can hear about the exciting developments direct from expert speakers – NASA scientists Gioia Massa and Ray Wheeler, and Purdue University's Cary Mitchell.

Massa works on food production for the International Space Station, heading a group that studies fertiliser and light impacts on nutrition and flavour on crops grown in space. She hopes her work with plants will one day improve the quality of life for Mars habitat residents.

Wheeler leads Advanced Life Support research at NASA's Kennedy Space Centre. During his postdoctoral research, he studied potato cultivation for life support in space. If you're curious: potatoes are a good candidate, Wheeler says, as they can produce twice the amount of food as other seed crops, given an equivalent amount of light. They also require minimal processing and, if worst comes to worst, can be eaten raw.

Mitchell has been director of two NASA research centres in bioregenerative and advanced life support and was program scientist for the Gravitational Biology and Ecology program at the Ames Research Centre. NASA research on crops, he says, has not only made advances for food production in space – it's also taught us about cultivation on Earth.

— VIVIANE RICHTER

→ bit.ly/cos70event

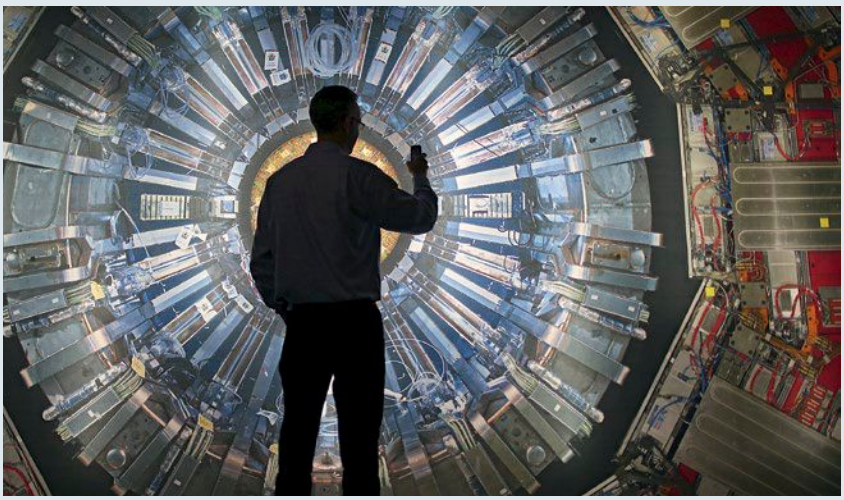


EXHIBIT
Collider
POWERHOUSE MUSEUM, SYDNEY

Saturday 6 August – Sunday 30 October, 2016

IMMERSE YOURSELF in a collision between art and science as you step inside the world of experimental particle physics.

Even if you're well-versed in all ground-breaking Large Hadron Collider (LHC) discoveries, this blend of theatre, video and sound, alongside real European Organization for Nuclear Research (CERN) artefacts, will offer a unique perspective.

The LHC is all about testing the extremes: subatomic particles hurtle towards each other at near the speed of light. While collisions create temperatures over 100,000 times hotter than the sun's centre, the LHC's magnets operate at freezing, near absolute zero, temperatures.

As the world's largest scientific experiment, the LHC may be intimidating. But this pocket-sized version allows you to get up close and personal.

In Collider, you'll walk the tunnels and stand right at the heart of a particle collision, following the search for the fundamental building blocks of the universe. It's set up as a visit to CERN, allowing you to walk through reconstructed LHC spaces. Projections of scientists describe their work and give insight on discoveries, like the Higgs boson, that have changed the face of physics.

The Museum of Applied Arts and Sciences curator Andrew Jacob will give tours in August. For the inside scoop on working at CERN, join researchers Mark Scarcella, Yi-Ling Hwong or Curtis Black on a tour between 13–21 August.

"It is the greatest experimental endeavour in science," said Alison Boyle, curator at London's Science Museum, which hosted the exhibition in 2013.

"The LHC was designed and built to answer a lot of fundamental questions about the Universe – it's about the value of pure human curiosity and I think that's something that can inspire everybody."

Collider is part of the 2016 Sydney Science Festival.

— VIVIANE RICHTER

→ bit.ly/cos70exhibit

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

Abacus

The big 10^{40}

How one huge ratio helps explain two very different phenomena.

SCIENTISTS ARE USED to dealing with very large and very small numbers. Take the age of the universe, for example. Dated at 13.8 *billion* years old, it has existed for a hundred thousand times longer than *Homo sapiens*. At the opposite end of the number spectrum, the rapid speed of atomic and subatomic processes are measured in tiny slivers of time. It takes light a mere trillion-trillionth of a second to cross an atomic nucleus.

The ratio of these two time scales, macro and micro, is itself a very big number – about 10^{40}.

In the 1920s, British astronomer Sir Arthur Eddington became fixated on a curious coincidence regarding this huge number. An atom of hydrogen – the simplest atom of all – consists of one electron, negatively charged, bound by electric forces to a positively charged proton. But there is a tiny gravitational attraction between these two particles as well. The ratio of these two forces is also about 10^{40}.

Why should the two numbers – one concerning the age of the universe, the other the strength of two fundamental forces of nature – be so nearly the same? Is there something that connects them?

Years later, physicist Paul Dirac came up with a possible explanation. He pointed out that the age of the universe is not a fixed number, but grows over time. At one second after the Big Bang, for example, the time scale ratio was not 10^{40} but 10^{24}. Dirac thought it was too much of a coincidence that humans just happened to live when the two ratios were about the same.

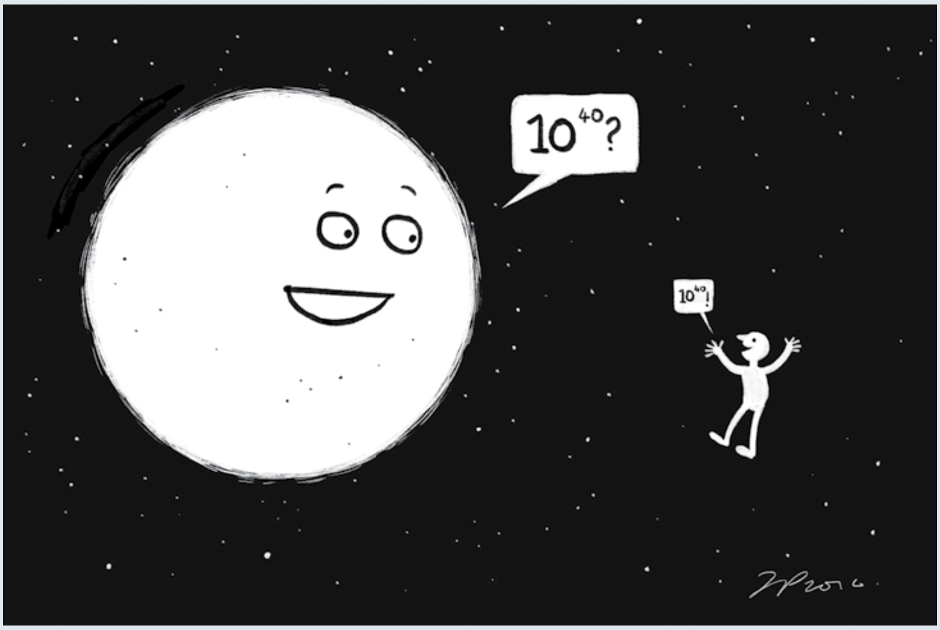
He was convinced there was an unseen link between the two. As the universe changes over time, Dirac proposed, the ratio of gravitational and electric forces must change along with it. Each year, he suggested, gravity weakens by about one part in 10 billion.

When Dirac published his theory in 1937, it became the subject of much discussion. If the force of gravity really did decline with time, it would have a profound effect on the structure of stars and galaxies. It would also mean that the orbits of the planets grow slowly larger; Earth, for example, would gradually move away from the Sun. But at the time, there was no accurate way to test this prediction.

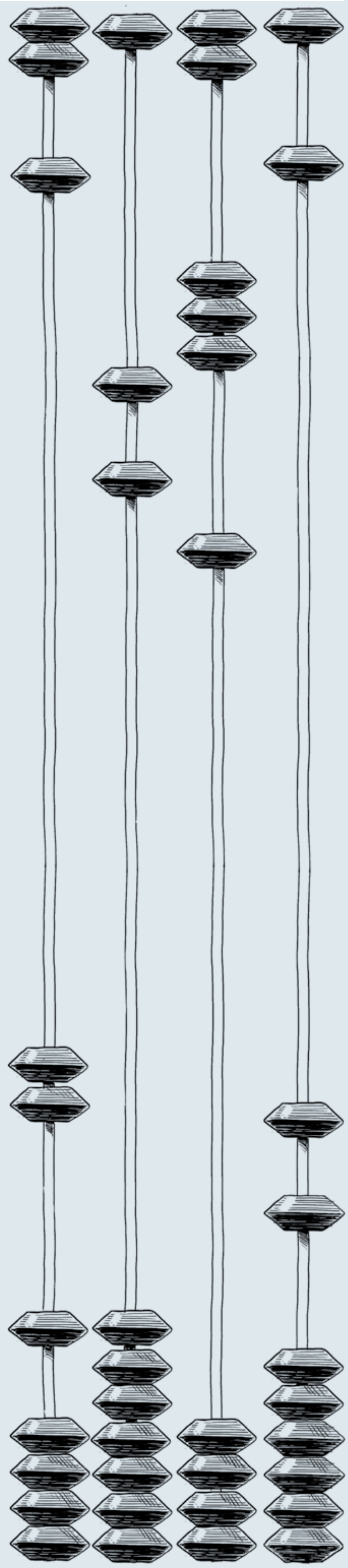
A few decades later, in the 1960s, Princeton astrophysicist Robert Dicke offered a very different explanation for the big number coincidence. The starting point for his theory was the connection between biological evolution and the evolution of the universe. The current age of the universe *now*, he reasoned, is not some random moment; it's the moment when life has evolved enough to produce beings able to measure it. Dicke wondered what the pre-requisites were for intelligent life in the universe, and how that might relate to the mystery of 10^{40}.

All known life is based on the element carbon. But carbon did not exist in the early universe; it was formed later by nuclear processes inside stars. When large stars grow old and die, they explode, and their life-encouraging carbon can end up in the next generation of stars and their planets. That meant, Dicke reasoned, that life in general, and intelligent beings in particular, could not exist until at least one generation of stars had lived and died.

Stars are made mainly of hydrogen – a form of nuclear fuel – held together by gravity. They burn steadily through this



The number 10^{40} has fascinated scientists throughout history. ILLUSTRATIONS: JEFFREY PHILLIPS



fuel until it is spent and the energy released has radiated away.

If gravity were stronger, the stars would consume their nuclear fuel faster, because they would be squeezed harder and burn brighter. But a star only dies once all the heat produced from burning its fuel has radiated into space, and its escape depends on electromagnetism: photons formed deep inside the stars have to plough through a thick soup of electrons and protons, scattering this way and that.

Dicke showed that the lifetime of a typical star hinges precisely on the ratio of electric to gravitational forces in the hydrogen atom.

The upshot of Dicke's calculation is that the current age of the universe is about the same as the ratio of electric to gravitational forces. If gravity were weaker, stars would live longer and carbon-based life would have emerged later. And if gravity were stronger, life would have arisen sooner.

So there is a simple explanation for the otherwise baffling big-number coincidence – without the need for Dirac's new theories of gravitation. A 1976 NASA mission to Mars helped prove it. While the Viking mission's primary aim was to look for life, it produced a useful by-product. By accurately timing the radio signals between the landers and Earth over several years, astronomers could determine whether the orbit of Mars was slightly changing.

By 1984, it was clear that it wasn't. Dirac died the same year. The theory that he loved was laid to rest at the same time.

While Dicke's argument tells us why the two ratios should be roughly the same, it says nothing about why those ratios are so big – that is, where the number 10^{40} comes from. Scientists may be adept at handing huge numbers, but this one continues to baffle even the biggest brains.

WHY IS IT SO?

WHY IS EARTH'S AXIS SHIFTING?

Humanity has now burned enough fossil fuel to tip the earth slightly. KARL KRUSZELNICKI explains.

01

WE ARE ONLY A LITTLE WAY into the 21st century, but signs of a warming planet are already evident around the globe: More frequent droughts in East Africa; stranded polar bears in the Arctic; bleached coral reefs in the tropics; and retreating glaciers in the high latitudes. Along the coasts, sea levels are rising.

Even so, a new study really surprised me. By burning huge quantities of fossil fuels, we humans have tipped the Earth off its axis by a tiny amount.

Let me emphasise how tiny the tipping is. Each year since 2005, we have shifted the spin axis from its previous path by centimetres – not kilometres.

The north-south spin axis of the Earth runs through the North Geographical Pole in the Arctic Ocean, and the South Geographical Pole in the Antarctic. (I'm not talking about the North and South Magnetic Poles, just the Geographical Poles.)

But as the Earth spins on its own axis, the position of the North Pole is not dead true – it wobbles a little, for several reasons.

For one, the Earth is not perfectly spherical. Instead, it's a bit flattened at the poles, and a bit bulging at the equator. And the surface is not smooth – it's pretty bumpy. Mountains poke up towards space, while oceans dip down into the solid crust.

Our planet is not perfectly rigid, either – it's somewhat elastic. Yes, it does have a solid crust at the surface – but it's very thin. Earth is made mostly of molten rock and then liquid iron, with a core of solid iron. So even today, parts of the crust that carried heavy ice sheets 20,000 years ago are still slowly rising (an effect known as the "isostatic rebound" or "post-glacial rebound"). As a result of these (and other) factors, when Earth rotates on its own axis over the course of a day, that spin axis wobbles a little.

There are lots of individual wobbles. A major one is the so-called Chandler Wobble, which American astronomer Seth Carlo Chandler discovered in 1891. During a period of slightly more than a year (about 433 days), the Chandler Wobble shifts the North Pole over a rough circle or ellipse – about several metres across. About two-thirds of the Chandler Wobble seems to be caused by ocean currents, and about one-third by winds in the Earth's atmosphere.

From 1982 to 2005, scientists found that the North Pole was drifting slowly south towards Labrador, about six to seven centimetres each year. But in 2005, the motions of the North Pole suddenly flipped in three unexpected ways. First, the North Pole chucked a leftie and started heading east, parallel to the equator. It's still heading east. Second, the North Pole more than tripled its drift speed to about 24 or so centimetres per year. It's still drifting at this speed. Third, the Chandler Wobble changed phase, and so far, scientists have no explanation for why.

But they do have a good answer for the tipping of the spin axis. Rapid melting of ice on land has made the drift velocity of the North Pole accelerate, and has changed its direction of travel to the east. This solid ice is now liquid water spread across the planet. We know where the ice was, we know where it's gone – and the maths all fit with the observed changes to motions of the North Pole.

Since the early 1900s, we've used satellites to accurately measure these land ice changes many tens of millions of times. Recent analysis shows that between 2011 and 2014, Greenland, Antarctica and mountain glaciers were losing about 600 billion tonnes of ice per year. (Most of the ice came from Greenland.) This was an increase of two to three times the loss rate between 2003 and 2009.

It's hard to imagine something as small as we humans being able to shift something as massive as our whole planet. But we used global warming as a force multiplier.

We dumped billions of tonnes of carbon dioxide into the atmosphere, heating it along with the oceans. The combination of hotter atmosphere and ocean water then melted over half a trillion tonnes of ice, which flowed into the oceans. This redistribution of water shifted the north-south spin axis.

Why did both the Chandler Wobble and the spin axis shift suddenly, instead of gradually? We don't know – yet. Perhaps it's like slowly pushing a pencil towards the edge of a table. You push and you push and you push, and it's still on the table. But then you give it just one more tiny push. The table no longer supports its centre of gravity, and it suddenly falls to the floor.

So if we push and push at the balance of our planet, it may well respond by throwing a real wobbly of its own.

KARL KRUSZELNICKI is an author and science commentator on Australian radio and television.

CREDIT: Edited extract from *Short Back and Science*, Macmillan 2015.

IMAGE
01 SPL / NASA / NOAA / Getty Images

ILLUSTRATIONS
Jeffrey Phillips

WHERE IN THE COSMOS?

Alison Jones from Lake Heights in New South Wales took time out from her trip to McBride Glacier in Alaska's Glacier Bay National Park in May this year to catch up on her *Cosmos* reading.

McBride is one of 11 glaciers in the park. They are remnants of the Little Ice Age which began about 4,000 years ago.

COMPETITION

What year was the Human Genome Project declared complete?

Email competitions@cosmosmagazine.com the answer with your name and address by 12 September. Four correct entries will win a DVD copy of *DNA Nation*, courtesy of Madman Entertainment.

DNA Nation features Australia's greatest Olympian Ian Thorpe, iconic Indigenous actor Ernie Dingo and TV presenter and Queen of Eurovision Julia Zemiro as they set off on an epic journey of genetic time travel across 12 countries to discover their DNA and unlock their past to answer the big questions about the human family and our place in it.

MIND GAMES

Quiz

Q1. What is causing thousands of earthquakes in New Zealand's Bay of Plenty?

Q2. Which tectonic plates are underlying New Zealand?

Q3. What is another name astronomers give to "near-Earth companions"?

Q4. How long has the asteroid 2016 HO_3 orbited Earth?

Q5. How is cutaneous leishmaniasis, a disease sweeping through Syrian refugee camps, transmitted?

Q6. How many diseases are on the World Health Organisation's list of Neglected Tropical Diseases?

Q7. Where was the Oesterplana 065 fossilised meteorite found?

Q8. The asteroid belt orbits the sun between which planets?

Q9. Are Neanderthals heavyset from birth or do they grow stocky at puberty?

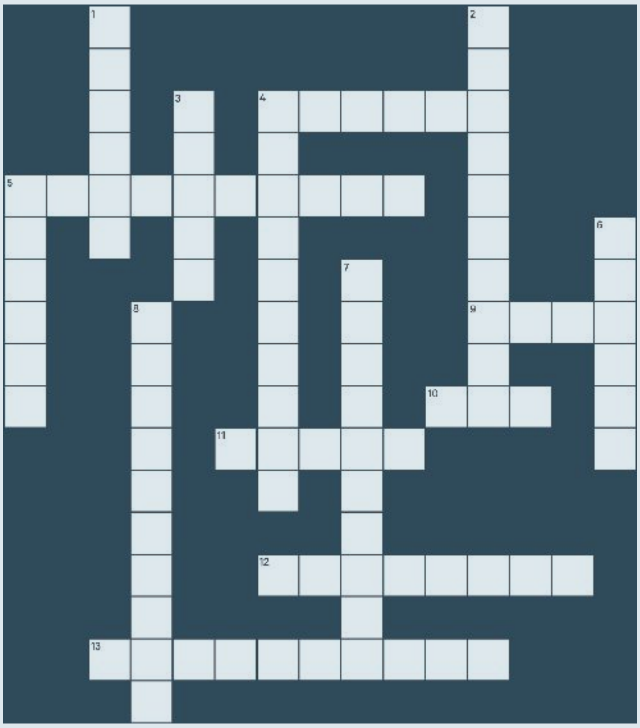
Q10. What is the maximum distance the asteroid 2016 HO3 can drift from Earth?

Q11. What is an 'extinct meteorite'?

Q12. Compared to modern humans, do Neanderthals have large or small hips relative to thigh-bone length?

Answers will be published in issue 71.

Cosmos crossword



Answers will be published in issue 71.

ACROSS

4. The thick, hot rock layer below the Earth's crust
5. The country that sits above a hazardous subduction zone of the Indian and Sunda tectonic plates
9. The supervolcano that some scientists believe killed most humans when it erupted 74,000 years ago
10. Number of years the Rosetta spacecraft travelled in space to land on comet 67P
11. The name of the largest object in the asteroid belt
12. The name of the group of carnivorous dinosaurs that walked on two legs and had bird-like characteristics
13. If a computer is labelled "human" or "unsure" three times out of 10, it passes the _ (6,4)

DOWN

1. First NASA mission to successfully land a spacecraft on Mars in 1976
2. This insect uses energy stored in its back legs to jump hundreds of times its body height in one millisecond (4,6)
3. What is the tiny organism that builds coral reefs?
4. An amphibious fish that uses its tail and front pectoral fins to venture onto mudflats
5. An element with an isotope recently discovered to have a pear-shaped nucleus
6. Pluto's largest moon
7. The region on the edge of the solar system where there are hundreds of dwarf planets (6,4)
8. A nickname for faecal transplantation in 16th-century China (6,4)

SOLUTIONS: COSMOS 69

CROSSWORD

QUIZ

1. Neutrino
2. The motor cortex
3. Play Guitar Hero, grasp a glass and stir a drinking straw
4. 473 genes
5. 1 trillion
6. 99.999%
7. *Mycoplasma mycoides*
8. Iron-60
9. A supernova
10. Production of biofuels or drugs
11. Orchids
12. A supernova near Earth

WINNERS

COMPETITION: COSMOS 69

The part of the brain that has a role in memory and emotion, and was named after a small fish which resembles its shape, is the hippocampus.

Congratulations to our winners for answering correctly:

Bob McCrossin, Cooroy, QLD; Mehul Gajwani, West Pennant Hills, NSW; Brian Edwards, Springwood, NSW and Kade Johnstone, Buddina QLD; will each receive a DVD copy of *The Brain* 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.

EXPLAINERS

Got a burning question that needs explanation? We want to hear from you. Visit cosmosmagazine.com/explainer to see the topics we've alreadycovered then send your requests to competitions@cosmosmagazine.com. Our favourite five will win a *Cosmos* prize pack and will also have their question answered.

PORTRAIT

Thijs Dhollander, neuroscientist

THIJS DHOLLANDER deftly spins a 3-D technicolour jumble of wiry connections on his computer screen. At first glance, it looks something like an electrical circuit diagram, but it's actually an image of millions of connections in a human brain.

The colourful model is part of a day's work for Dhollander, a neuroscientist with the Florey Institute of Neuroscience and Mental Health in Melbourne, who is helping refine a new brain imaging technique called diffusion MRI, or dMRI.

Where fMRI snaps images of blood flow in the brain, the diffusion method tracks water movement inside the cable-like bundles formed by wiry nerve cells.

Dhollander, who holds a PhD in engineering and medical imaging from Belgium's Leuven University, helped write software that can show a 3-D model of this wiring.

"One really cool use is for pre-surgical preparation," he says. If a tumour is pressed against a cable, a surgeon might see a kink in the image that helps her decide where to cut. But if a cable appears fuzzy, it may mean a growth has infiltrated the cable, and it may not be safe to remove it.

Dhollander hopes that with the help of his software, dMRI will one day become a standard diagnostic tool.

— BELINDA SMITH

IMAGE
Peter Tarasiuk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