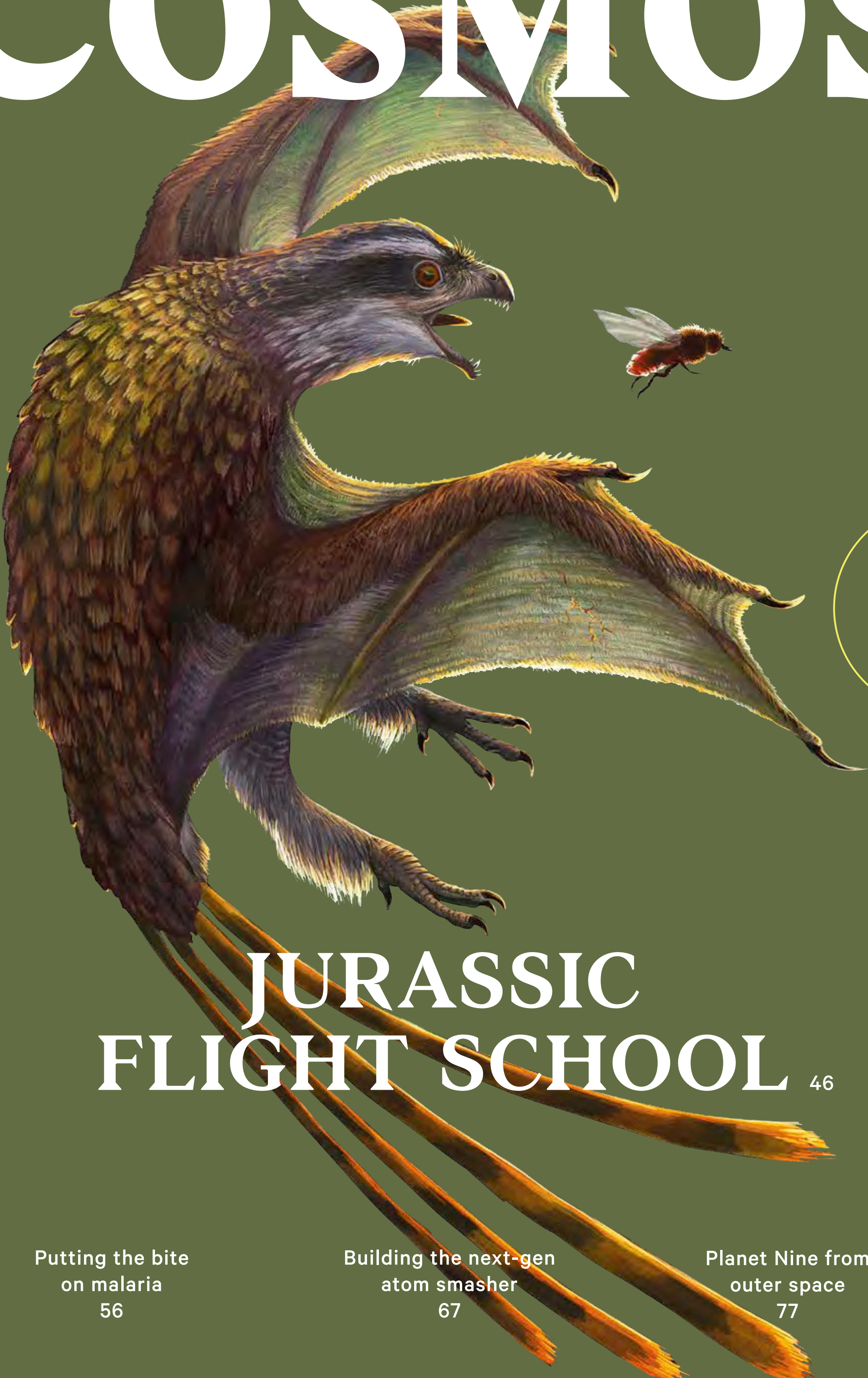
Issue 74 THE SCIENCE OF EVERYTHING Autumn 2017

COSMOS



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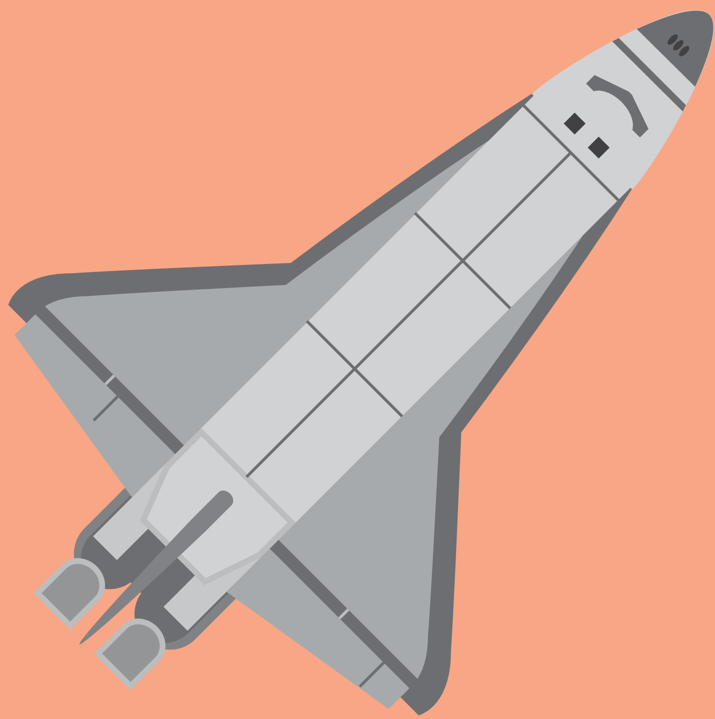

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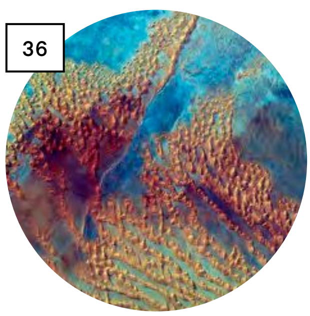

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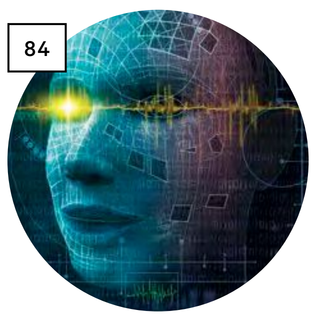

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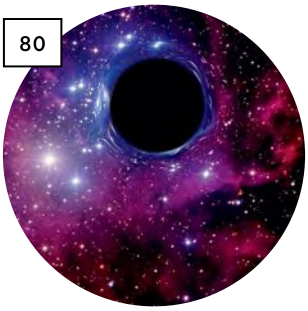

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DISNEY DEVELOPS WIRELESS ELECTRICITY

Soon you might be able to charge your phone just by entering a room, and it's not a Mickey Mouse idea. Cathal O'Connell reports.

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EDITOR'S NOTE

ELIZABETH FINKEL
Editor-in-chief

Time to rewrite the textbooks

WELCOME TO THE first quarterly issue of *Cosmos* magazine. I hope you're sitting down, because there's a lot of head-spinning stuff in here. So many things you thought you knew that just ain't so.

Here are a few samplers.

At high school you probably learnt the Solar System had nine planets. Eleven years ago, with the banishment of Pluto, we were down to eight. Now astronomers believe there's almost certainly a ninth after all. Quaintly, they are using the same logic that led them to search for Pluto a century ago.

Pluto's existence was deduced from the skewed orbit of Uranus; now it's oddities in the orbits of objects in the Kuiper belt (where Pluto resides) that point to a lurking lone giant up to 1,200 times more distant from the Sun than the Earth. Ten teams are training giant telescopes on its likely orbit and expect to nab it within the year.

So you may soon be learning new planet mnemonics along with the kids. You'll also be discussing our new sister solar system: that of the red dwarf star Trappist-1, just 8% the size of our sun, and its seven "Earth-like" planets.

Trappist-1 is 39 light years or 369 trillion kilometres away – too far to travel to but close enough for space telescopes to get a good view of it while its planets whirl by, dimming its light. What is so exciting is that at least three of the seven planets are the right distance from the star for liquid water to exist. Life has a chance – especially since red dwarves, being so small, burn very slowly. Ten trillion years from now, when our solar system is long gone, Trappist -1 and its seven planets will still be around.

While we're in space, let's think about black holes. Hard to fathom, but at least I thought I understood one thing about them: they were the final stage of a very large star, after it had exploded and contracted its mass down to the size of something less than an atom. In other words, black holes were presumed to be the final chapter in the life of stars and galaxies.

Now, however, astrophysicists have evidence that supermassive black holes existed in the infant universe when galaxies were just being born. Instead of being epitaphs, black hole behemoths seem to have shaped our baby universe.

Finally to dinosaurs. Most of us know them from Steven Spielberg's 1993 blockbuster *Jurassic Park*. Velociraptor was *sort of* accurate at the time (though about twice as large as the true Mongolian Velociraptor, more like North America's *Deinonychus*). But the *Jurassic* sequels should have made the raptors fluffy, like baby chicks. Of course, that might have taken away their star power.

We know this largely from shocking discoveries that have taken place in China since 1996. The shocks have kept on coming.

Just when we thought dinosaurs couldn't get any weirder, in 2015 Chinese palaeontologist superstar Xu Xing discovered a bird dinosaur with bat wings. It's a brave palaeontologist who dares write a textbook these days.

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COVER
Imagining *Yi qi*, the bat-wing dinosaur, in full flight. Another intepretation of the surprising theropod, by artist Lida Xing, is shown on pages 46-47.
CREDIT: EMILY WILLOUGHBY

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"SCIENCE DOESN'T ALWAYS GO FORWARDS. IT'S A BIT LIKE DOING A RUBIK'S CUBE. YOU SOMETIMES HAVE TO MAKE MORE OF A MESS WITH A RUBIK'S CUBE BEFORE YOU CAN GET IT TO GO RIGHT."
— JOCELYN BELL BURNELL (1943)
ASTROPHYSICIST

CREDIT: DAILY HERALD ARCHIVE / SSPL / GETTY IMAGES

A CLOSER LOOK AT THE BIG STORIES

DIGEST

LIFE SCIENCES

How butterflies become blue

The Morpho butterfly uses nanotechnology to produce its luxurious blue tones.

Under the scanning electron microscope, the Morpho butterfly's transparent wing scales reveal ridges made of chitin plates. The plates reflect blue light because their spacing exactly matches that wavelength.

Marco Giraldo from the University of Antioquia, Colombia, and colleagues examined how different groups of Morpho butterflies achieve different shades. As reported in the *Journal of Experimental Biology*, they discovered a nanotechnology bonanza including a combination of pigmented and unpigmented scales, optical thin films and undulating scale surfaces. Their goal is to copy these structures to produce ever-lasting colours.

CREDIT: EYE OF SCIENCE / GETTY IMAGES

IN BRIEF

DEAD, OR DEAD WRONG?

Bringing back extinct species carries romantic appeal, but research by scientists from Canada, Australia and New Zealand suggests doing so would push several other species over the edge. A study, published in *Nature Ecology and Evolution* and led by Joseph Bennett of Carleton University in Ottawa, found that "resources expended on long-term conservation of resurrected species could easily lead to net biodiversity loss, compared with spending the same resources on extant species".

Money for conservation is always scarce. The high cost of reintroducing extinct species inevitably means less is available to protect existing endangered ones.

Funding 11 de-extinction targets in New Zealand, for instance, "would sacrifice conservation for nearly three times as many extant species".

Equally, they note, such species could become invasive, destroy environments or spread disease.

→ How does de-extinction work? See page 116

DISCOVERY

Scientists create the first supersolid

Not all solids are created equal. CATHAL O'CONNELL reports.

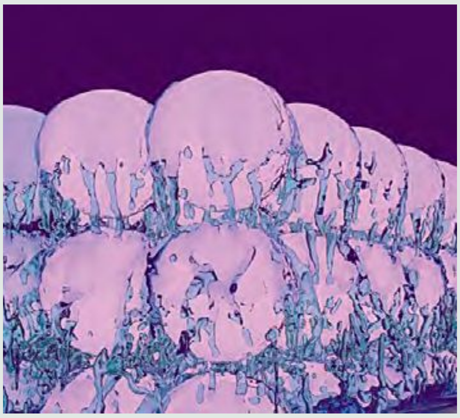
Nothing is certain in the quantum world, not even the distinction between a coffee cup and the liquid inside it.

After 60 years of trying, scientists have created an elusive and contradictory form of matter: one that simultaneously acts like a solid and a frictionless "superfluid".

The discovery was made by two groups, both reporting in *Nature*. One study was run by a team at the Institute for Quantum Electronics in Zurich, while the other, at the Massachusetts Institute of Technology, was led by Nobel laureate Wolfgang Ketterle.

The studies unveil a new state of matter that "marries solid and liquid properties in spectacular fashion", according to Kaden Hazzard, a quantum physicist at Rice University in Texas, who was not involved in the work.

Your morning coffee reveals the four common states of matter. The cup is solid, holding its shape. The coffee is liquid. Gas is the air you blow over it. Plasma fills the fluorescent tubes in the lighting above you.



Artist impression of a supersolid state, in which the properties of a frictionless fluid and a crystalline state coincide.

CREDIT: JULIAN LÉONARD / ETH ZURICH.

Besides these states, there are others, quantum ones where things get a little crazy. A superfluid, for example, flows totally without resistance.

"If your coffee was superfluid and you stirred it, it would continue to spin around forever," says Ketterle.

Superfluids have been known since 1937, when physicists noted the bizarre behaviour of liquid helium-4, cooled to within about two degrees of absolute zero. No open container could hold it – it would flow up the walls.

Did an analogous state exist for solids: a supersolid? Probably, but for six decades, nobody was able to observe one – until now.

A supersolid needs two key characteristics. Like a solid, it must retain a rigid structure. Like a superfluid, atoms within that lattice must hop between positions without resistance.

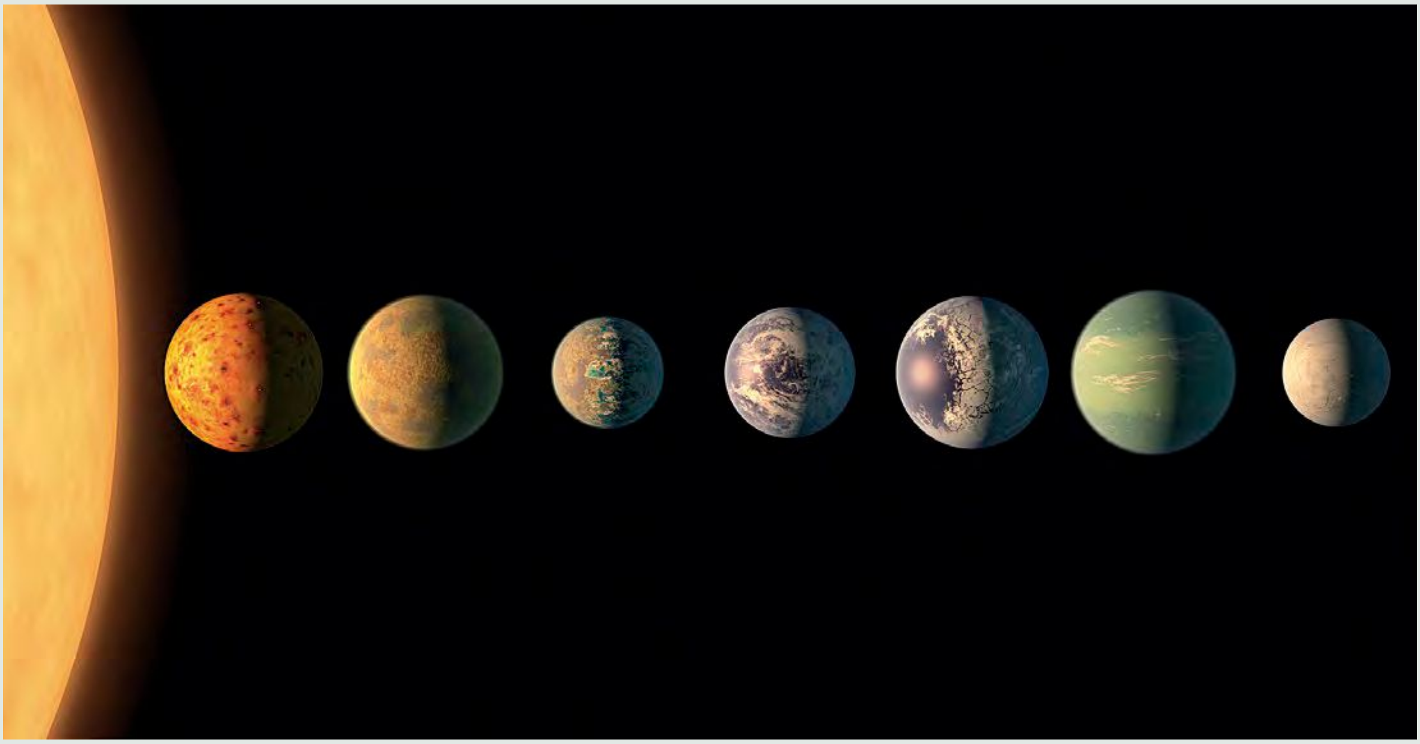
'BESIDES THESE STATES, THERE ARE OTHERS, QUANTUM ONES WHERE THINGS GET A LITTLE CRAZY. '

Both are reported by the Swiss and US teams. Ketterle and colleagues cooled sodium atoms in a vacuum close to absolute zero, where they became superfluidic. They then gave half the atoms a kick with a laser, which put them into a slightly different quantum state.

In this mixture, the two kinds of atoms lined up in a regular way – as in a solid. This was confirmed by measuring how a laser reflected at a particular angle, something that would not occur if the atoms were jumbled.

Meanwhile the Swiss group, led by Tilman Esslinger, also started with a superfluid, this time of rubidium atoms, arranged into a regular formation using a light wave bouncing between mirrors. Proof of the supersolid behaviour came by observing how the atoms moved.

Physicists hope that the contradictory new matter might provide insights into superfluids and superconductors. Whatever happens, it's super cool.



An artist's concept shows what the TRAPPIST-1 planetary system may look like, based on available data. CREDIT: NASA / JPL-CALTECH

SPACE

High habitable hopes

Excitement over a system of Earth-sized planets. RICHARD A. LOVETT and ELIZABETH FINKEL report.

Just when we were getting used to the idea of exoplanets – some 3,500 have been discovered since we started looking in 1988 – astronomers have blown us away with an entire new solar system. The star known as TRAPPIST-1 boasts seven rocky earth-sized exoplanets, with at least three close enough to contain liquid water.

Michaël Gillon, an astronomer at the University of Liege, Belgium and colleagues announced the discovery in Nature on 23 February. "It's beyond anything I could have dreamed of," says Nikole Lewis, a James Webb Telescope scientist.

TRAPPIST-1 is 39 light years away from Earth. It's a tiny red dwarf (the most common type of star), only the size of Jupiter and with a mass about 8% of our Sun. With their dim light, red dwarves make planet hunting easier because they significantly reduce in radiance when planets pass in front of them.

In 2010, Gillon's team first trained a Chilean-based robotic telescope called TRAPPIST (the Transiting Planets and Planetesimals Small Telescope) on the star. Last May the team announced the discovery of three planets; that number has now been updated to seven. "I was amazed," Gillon says. "Their very existence was a kind of a shock."

Although dim, the star is still able to keep its family warm because they huddle close to it. The inner six planets' orbits range from 1.51 days to 12.35 days – only a few million miles apart. The outermost orbit, yet to be finalised, is about 20 days.

The planets are also tidally locked, meaning one side permanently faces the star like our Moon – so one side is very hot and the other very cold. Life might have a chance in the narrow band in between.

Although TRAPPIST-1 does not radiate a lot of visible light, its infra-red radiation is 1,000 times brighter – ideal for detection by the Spitzer Space Telescope, which allowed astronomers to measure how the individual planets distorted each other's orbits. From that, each planet's mass was calculated and then compared to its size (determined by how much it dimmed the star as it passed). This enabled planets' density to be computed.

'IT'S BEYOND ANYTHING I COULD HAVE DREAMED OF,' SAYS NIKOLE LEWIS, A JAMES WEBB TELESCOPE SCIENTIST

The next step will be to analyse the atmospheres of the planets by looking for spectral fingerprints of gases.

Already, says Lewis, scientists using the Hubble Space Telescope have determined that two of the innermost planets in the system do not have atmospheres dominated by hydrogen or helium. "That's great, because that's one more step along the path in having habitable worlds."

LIFE SCIENCES

Crustaceans in very deep water also in very deep trouble

The deepest parts of the ocean have long been considered pristine wildernesses.

"Extraordinary levels" of pollutants have accumulated in amphipods living in the world's deepest ocean trenches, according to new research.

A study, led by Alan Jamieson at the University of Aberdeen in Scotland and published in *Nature Ecology and Evolution*, found contaminant levels 10 kilometres below the surface were "considerably higher" than those found in much shallower seas bordering nearby heavy industry zones.

Jamieson's team used a deep sea lander to set baited traps in both the Mariana Trench in the western Pacific and the Kermadec Trench near New Zealand. The traps were used to capture three species of small crustaceans called amphipods that were then tested for 14 different chemical markers. The results revealed that some of the world's nastiest pollutants have reached "the most remote and inaccessible habitats on Earth", the researchers report. Of particular concern, they noted, were a class of chemical compounds known as persistent organic pollutants (POPs), known to disrupt endocrine systems.

POPs comprise a broad range of manufactured carbon-based products, all noted for their ability to persist within the environment for very long periods, and for their habit of accumulating in living organisms. The first POP to become the focus of public and scientific concern was the insecticide DDT – the subject of Rachel Carson's *Silent Spring*, published in 1962. The POPS of central interest to Jamieson and colleague were polychlorinated biphenyls (PCBs), once widely used as dielectric fluid, and polybrominated diphenyl ethers (PBDEs), used as flame retardants.

The research found multiple varieties of both in all samples, across all species, at all depths in both trenches.

"In the Mariana, the highest levels of PCBs were 50 times more contaminated than crabs from paddy fields fed by the Liaohe River, one of the most polluted rivers in China," say the researchers.

"The only Northwest Pacific location with values comparable to the Mariana

You are what you eat: which is bad news even for the ultra-deepwater amphipod *Hirondellea gigas* living in the Mariana Trench. CREDIT: DR. ALAN JAMIESON / NEWCASTLE UNIVERSITY

SPACE

Did space weather just fritz your phone?

Never mind malware, worry about space particles instead, reports JAMES MITCHELL CROW.

Ever had your phone shut down in the middle of an important message, or your computer crash as you're about to click save? It may not be a software bug that's to blame – your device might just have been the unlucky victim of a particle from outer space, say researchers from Vanderbilt University in Tennessee.

Earth is continually pelted by powerful cosmic rays, which strike the atmosphere, creating cascades of subatomic particles that shower down on us. Millions of these particles pass harmlessly through your body every second.

For electronic circuitry, however, the particles can be damaging, engineering professor Bharat Bhuva told the audience at the annual meeting of the American Association for the Advancement of Science in Boston in February.

A strike from a particularly energetic particle can carry enough force to corrupt a device's memory – a mishap known as a 'bit flip' – or even burn out a component. Pinning the cause of a computer malfunction on a rogue particle means first ruling out all other possibilities – but in some cases that has been done.

THE SMALLER A TRANSISTOR, THE LESS ENERGY A PARTICLE NEEDS TO TRIGGER A BIT FLIP.

In 2008, one third of the passengers on a Qantas flight from Perth to Singapore were injured when a particle strike deactivated the autopilot, sending the plane into a dive. In the 2003 elections in Schaerbeek, Belgium, a bit flip to an electronic voting machine added 4,096 extra votes to one candidate – a malfunction only detected because it exceeded the number of votes possible in that electorate.

Trench is Suruga Bay (Japan), a highly industrialised area with historically heavy usage of organochlorine chemicals."

'THE RESEARCH FOUND MULITIPLE VARIETIES OF IN ALL SAMPLES, ACROSS ALL SPECIES, AT ALL DEPTHS.'

The scientists offer a few explanations for the presence of pollutants at such extreme depths, known technically as hadal zones. They suggest sinking plastic debris and water-surface carrion consumed by the deep-sea scavengers as potential sources. Whatever the exact mechanism, they add, the findings imply that "that these pollutants are pervasive across the world's oceans and to full ocean depth."

Katherine Dafforn, a biologist at the University of New South Wales in Sydney, says the report is startling.

"At more than 6000 metres, hadal trenches are a remote wilderness, largely unexplored and widely considered safe from human disturbance," writes Dafforn in *Nature*.

"This [finding] is significant since the hadal trenches are many miles away from any industrial source and suggests that the delivery of these pollutants occurs over long distances despite regulation since the 1970s."

"This is a really big problem, but it is mostly invisible to the public," Bhuva says.

It's also growing. As chip-makers squeeze more and more transistors of ever smaller size onto the processors in phones and other devices, personal electronics are increasingly affected.

The smaller a transistor, the less energy a particle needs to trigger a bit flip. The more transistors a processor has, the greater the odds of a strike.

Thankfully, it's a problem that industries such as aviation, medical equipment, transportation and power are taking steps to address, says Bhuva, by making circuitry less vulnerable.

"It is only the consumer electronics sector that has been lagging behind in addressing this problem," he adds.

CAPTURED

ABSORBING STUFF

This is the doorway to serenity. The European Space Agency's Hybrid European Radio Frequency and Antenna Test Zone – known as the Hertz chamber – is located at its Netherlands base. The chamber recreates the silence of space to test the next generation of space antennae.

Radio waves from TV and radio broadcasts, aircraft and ship radar and mobile phones can penetrate most things. They are kept out of the chamber by its metal walls, which form a "Faraday cage", and a lining of radio-wave-absorbing and echo-proof, or "anechoic", foam pyramids. This allows technicians to conduct tests involving a wide range of radio frequencies free from external interference.

The photograph was taken by Portuguese-born Edgar Martins, who is collaborating with the ESA to produce a comprehensive photographic survey of its facilities around the globe.

CREDIT: EDGAR MARTINS

EARTH SCIENCES

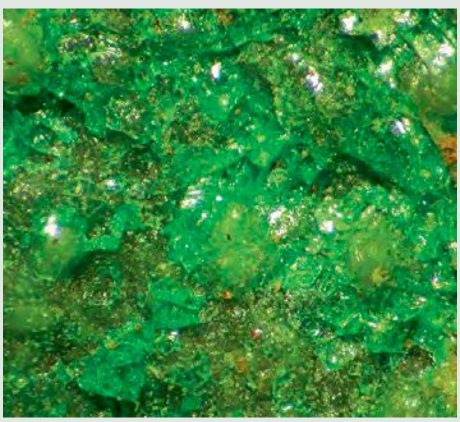
Widgiemoolthalite and 207 more

Mines and museums manifest man-made minerals. RICHARD A LOVETT reports.

Humans are adding to our planet's catalogue of mineral types at a rate never before seen. It's happening so fast that anthropogenic minerals now total 208 of the 5,208 types recorded by the International Mineralogical Association (IMA) – and there are probably hundreds more currently not acknowledged.

Not all these substances are laboratory curiosities created by bored scientists.

"We make bricks," explains Robert Hazen, a mineralogist at the Carnegie Institution for Science in Washington DC. "We make cement. We make reinforced concrete. We have porcelain in glassware. We have all sorts of crystals in technology, batteries and magnets. We have pigments and paints and glues and things that include mineral-like crystal substances which never before existed in the history of the world."



One of a kind: widgiemoolthalite, a brittle mineral formed on weathered nickel sulfide that has been found only at a mining site near Widgiemooltha, Western Australia.

CREDIT: LEON HUPPERICHS

Other substances are created by accident. "Many are associated with mining," says Edward Grew, a mineralogist and petrologist from the University of Maine, who collaborated with Hazen on a paper published in *American Mineralogist*.

"Mining disturbs the environment under the earth or at the earth's surface," he says, "and that disturbance makes for environments where new minerals can form. Some have been dated from the Bronze Age, but for the most part they are much newer."

To figure out when minerals first appeared, the scientists went through geological databases, looking for the time when each officially recognised mineral first appeared in the geological record.

"This one formed in a mine tunnel, this one in a shipwreck, and this one in an old Egyptian statue," Hazen says, adding that his favourite – calclacite –formed in a museum drawer where a mineral specimen reacted with acetic acid from the wood to create an entirely new substance.

The new minerals are important, scientists say, because the only other time in history when there was a remotely comparable growth in the number of mineral types was during the "Great Oxidation," which occurred when oxygen began to build up in the Earth's atmosphere about 2.2 billion years ago.

This caused the oxidation of pre-existing minerals, producing the first appearances of up to two-thirds of the minerals currently in the IMA's catalogue. Iron ore is one example.

The Great Oxidation lasted hundreds of millions of years. Today's minerals have arisen in a tiny fraction of that time. That's important, Hazen says, because minerals are durable and will outlive the civilisation that produced them.

"They will be preserved for billions of years in the sedimentary record," he says.

And that, he adds, bolsters the argument for designating modern times as a new geological epoch: the Anthropocene.

Naming epochs might seem arcane, but in the long-run view of geologists it is anything but. The issue, Hazen says, is the sediments laid down in our era.

"Cubic zirconium, laser crystals, silicon chips and stuff like that are very stable materials," he says. "Future geologists will be able to hammer out chunks of materials and say, 'Look at this.'"

Other scientists have suggested a similar worldwide stratigraphic layer might be created by fallout from nuclear testing, or from the fumes of leaded gasoline. But that, Hazen argues, is nothing compared to "minerals that are being produced in huge volumes all around the world".

Other scientists agree. Richard Alley, a geoscientist at Pennsylvania State University, calls the new study "one more demonstration of the large and growing human impact on the planet".

BY THEIR NAMES SHALL YOU KNOW THEM

Here are just a few of the 208 human-made minerals officially recognised by the International Mineralogical Association. These ones are all associated in various ways with mines and mining.

acetamide
albrechtschraufite
andersonite
barstowite
bayleyite
canavesite
chalconatronite
dypingite
hoelite
hoganite
hydromagnesite
kladnoite
lansfordite
línekite
nesquehonite
paceite
phosgenite
rabbittite
ravatite
shannonite
swartzite
tinnunculite
wheatleyite
widgiemoolthalite
znucalite.

SPACE

Mars may erupt again

Among the volcanoes of Mars, one really stands out. ANDREW MASTERSON reports.

Mars has long been considered a geologically inert planet, silent and still since the massive volcanic eruptions that fashioned much of its surface ended more than three billion years ago.

However, new findings derived from images obtained by the Mars Orbiter Camera aboard the Mars Global Surveyor Mission have raised the intriguing possibility that lava may one day soon flow fresh across the Red Planet.

A team led by geology and geophysics graduate researcher David Susko, from the Louisiana State University, focused on a Martian volcano dubbed Elysium, the second-highest on the planet and more than twice as high as Everest. The findings are published in *Nature Scientific Reports*.

A solidified lava flow over the side of a crater rim of Elysium, the second-highest volcano on Mars.

CREDIT: NASA HIRISE IMAGE / DAVID SUSKO / LSU.

Combining the satellite imagery with data acquired by the Mars Rover, Susko's team determined that parts of Elysium's lava deposits were only three to four million years old, three orders of magnitude younger than the lava laid down by Mar's other volcanoes.

The data also revealed that Elysium's more recent deposits were very low in thorium and potassium when compared to the levels present around other volcanoes and in non-volcanic sections of the planet's crust. The paper terms the finding a "major depletion".

The reasons for the big drop in these two radioactive elements remains unknown, but the team speculate that it may be evidence that Mar's more recent eruptions have differed chemically from older ones.

If so, write the researchers, it's a conclusion with "major implications for the history of Martian mantle evolution, such as how volcanic provinces were built up over time, and motivates future investigations into this province".

Commenting on the observation that Elysium had erupted much more recently than the planet's other volcanos, Susko says that three million years in geologic terms is "like yesterday".

"At least, we can't yet rule out active volcanoes on Mars," he adds. "Which is very exciting."

LIFE SCIENCES

Soy linked to breast cancer survival

Evidence hints tofu might be good for you. ANDREW MASTERSON reports.

Taken at first blush, it sounds like pseudo-science: soy can treat breast cancer.

While the science is still far from settled, there is growing of evidence of a correlation between soy intake and breast cancer survival. This is remarkable because oestrogen-mimicking isoflavones in soy products were once considered cancer risk factors.

The most recent findings, published in the journal *Cancer*, come from a team led by Fang Fang Zhang of Tufts University in Massachusetts. The team set out to resolve the apparent contradiction between laboratory and epidemiological studies that found a link between higher isoflavone intake and reduced mortality, and other research that suggested the same compounds might reduce the effectiveness of hormone therapies.

Soy represents by far the largest source of isoflavones in the human diet.

The researchers studied the diets of 6,235 American and Canadian women with breast cancer. Over nine years, the women who consumed large amounts of isoflavone had a 21% lower risk of dying than those who didn't.

The result was largely confined to hormone receptor-negative cancers – tumours that did not contain a protein to which oestrogen will bind. These cancers do not need oestrogen to grow, and usually don't stop growing when treated with oestrogen-blocking hormones.

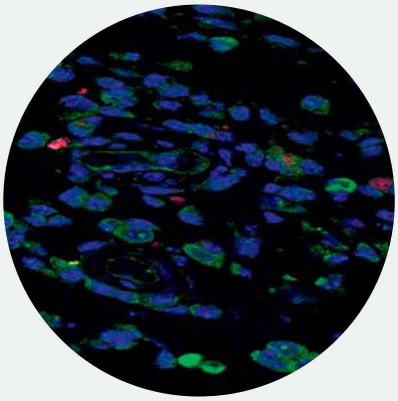
The study adds to other 2017 reports suggesting soy has other cancer-fighting properties. In February, researchers from the Universidade de Lisboa in Portugal reported its ability to inhibit enzymes linked to cell degradation in cancer growth. In a third study, biochemists from Aligarh Muslim University in Uttar Pradesh, India, revealed possible cancer-fighting properties of a specific soy phyto-oestrogen called coumestrol.

WOMEN WHO CONSUMED LARGE AMOUNTS OF ISOFLAVONE HAD A 21% LOWER RISK OF DYING.

How isoflavones interact with cancer cells remains unclear. Nonetheless, says Zhang, "for women with hormone receptor-negative breast cancer, soy food products may potentially have a protective effect."

IN BRIEF

ZIKA TARGETS TESTES



An infected mouse: the internal structure of the testicle has collapsed and few developing sperm (pink) are present.

CREDIT: PRABAGARAN ESAKKY

Zika virus not only causes birth defects but may cause male infertility by shrinking the testicles, according to research published in *Science Advances*.

A team from Yale University injected mice with a non-lethal strain of the disease. The mice became ill five days later. Within 21 days their testicles had atrophied.

Further investigation revealed Zika particles in the epididymal duct, which stores sperm, explaining how male-to-female transmission may occur.

The virus was also present in Leydig cells which secrete testosterone. The virus may interfere with the cells' capacity to produce normal amounts of testosterone, leading to organ shrinkage.

The researchers worry that in humans, where Zika has been detected in testicles, the virus might have a similar effect.

SPACE

The first hours of a supernova

For the first time, astronomers have witnessed the beginnings of one of the most spectacular sights in the universe. AMY MIDDLETON reports.

An extremely rare recording of a massive star's explosive death reveals clues about the formation of supernovae.

Reported in *Nature Physics* by a team led by Ofer Yaronof at the Weizmann Institute of Science in Rehovot, Israel, recent spectroscopic imaging captured, just three hours after it began, the spectacular transformation of a star assumed to have been a red supergiant into a supernova.

It marks the first time a supernova has ever been seen in its infancy. Previously observed supernova – the predicted end-point for about 50% of supergiant stars – have all been recorded after the metamorphosis had been underway for several days, meaning that information about the start of the process was already destroyed.

The most recent event, capturing the fiery death of a star dubbed iPTF 13dqy, was captured by the Intermediate Palomar Transient Factory, an automated astronomical survey from Palomar Observatory in California, which has been monitoring the sky since 2013.

The survey snaps two images per night, over an hour period or longer, of a particular astronomical field and then compares them to identify any transient events. Any flagged are then confirmed and examined by a team of researchers.

Red supergiant stars themselves are not difficult to locate, because they tend to stand out. They are 10 to 70 times the size of the Sun, and can be hundreds of thousands of times brighter. They pay for their extravagance, however, burning all their fuel and going nova between a couple of hundred thousand and 30 million years after forming.

That said, and the universe being an enormously large sort of place, picking the ones set to explode is extremely difficult.

"Statistically, it is very likely that not even a single star that is within one year of explosion currently exists in our Galaxy," the researchers explain in their paper in *Nature Physics*.

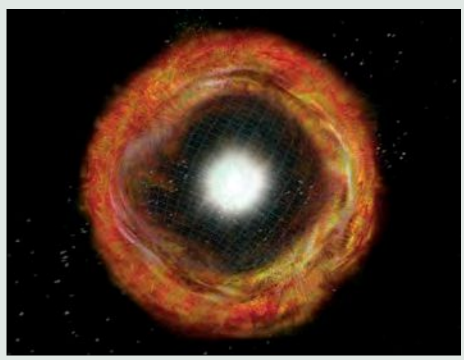
The team's analysis shows that before its death, iPTF 13dqy was surrounded by a cloud of gaseous matter, possibly ejected from its core in the last months before its explosion.

"The finding that the probable red supergiant ... ejected material at a highly elevated rate just prior to its demise suggests that pre-supernova instabilities may be common among exploding massive stars," the researchers write.

"Future flash-spectroscopy observations of a larger sample of events would allow us to determine exactly how common this phenomenon is, placing stronger constraints on the final stages of massive-star evolution."

Norbert Langer, an astrophysicist at the Argelander Institute for Astronomy at the University of Bonn, says the gas cloud possibly supports a theory that stars undergo a rapid restructuring of their core in these final phases before death.

"The gas shell could have been produced by a dramatic mass loss during the last decade or so of the star's evolution," Langer writes, also in *Nature Physics*, adding that we can expect more details to emerge in the coming years.



Timing is everything.

CREDIT: BILL SAXTON, NRAO/AUI/NSF

LIFE SCIENCES

Evolutionary gallopers

Secret of male pregnancy revealed by genome. ELIZABETH FINKEL reports.

Seahorses are enchanting but for a fish they are seriously weird.

Gone are fishy things like scales, pelvic fins and teeth. Instead their majestic bodies are covered in bony armour plates, anchored by a curling, prehensile tail, and their horsey heads end in long sucking snouts. Weirdest of all, it is the male that gets pregnant.

How did this happen to a fish?

Some of the answers have been revealed by an international consortium that analysed the genome of the tigertail seahorse, *Hippocampus comes*, as reported in *Nature* last December.

By comparing its DNA spec sheet to that of related teleost fish, the researchers found the seahorse had lost a set of genes (known as SCPP) for making tooth enamel proteins. Also gone was the tbx4 gene required to form rear appendages like pelvic fins.

The tigertail seahorse's DNA rapidly adapted for a quiet life in the coral.

CREDIT: FRANCO BANFI / GETTY IMAGES

We've seen evolution tinker with these genes before. Birds and turtles traded teeth for beaks by losing their SCPP genes. Snakes lost their legs when their tbx4 gene was inactivated.

But when it comes to male pregnancy, it's all about what the seahorse has gained. Males are impregnated when females deposit eggs into their pouch (in closely related stickleback fish, males merely lure females with a nicely made nest). Cells lining the male's pouch supply nutrients, remove waste and help the embryo hatch.

Compared with other teleost fish, the sea horse has gained six copies of a gene called patristacin involved in gestation and hatching. The gene is related to one that helps embryos hatch in platyfish (where females give birth to live young).

This remarkable set of features adapted the seahorse to a life spent hiding in seagrass or coral gardens, sucking in the occasional passing crustacean and, for the males, waiting for females.

And they evolved quickly. Comparing the number of DNA changes to that of their fishy cousins since they diverged from a common ancestor 103 million years ago, seahorses hold the speed record, says co-author Axel Meyer at the University of Konstanz in Germany.

LIFE SCIENCES

Surprise discovery shakes end-Permian certainties

A rich fossil find is confounding accepted theories about mass extinction. BELINDA SMITH reports.

The paleontological orthodoxy that the world took millions of years to recover from the end-Permian mass extinction has been powerfully challenged by the discovery of a rich and varied ecosystem dating to just after the event.

Soon after 96% of all marine species and 70% of terrestrial vertebrates were wiped out 250 million years ago, it seems that in some places life came roaring back.

A research team led by Arnaud Brayard at Université Bourgogne Franche-Comté in France analysed fossils uncovered near Paris, Idaho. It found "a phylogenetically diverse, functionally complex and trophically multileveled marine ecosystem", representing at least seven phyla – including a sponge thought to have gone extinct 200 million years before.

The haul, dubbed the Paris Biota, dates from immediately after the end of what historians call "the great dying".

As well as boasting a surprising 20 distinct Metazoan orders, the haul also contained primitive cephalopods, sponges and algae, some until now not thought to have evolved until 50 million years later.

"Unlike previous works that suggested a sluggish post-crisis recovery and a low diversity for the Early Triassic benthic organisms, the unexpected composition of this exceptional assemblage points toward an early and rapid post-Permian diversification for these clades," the researchers write in *Science Advances*.

Rare fossilised crinoids *Jimbacrinus bostocki* from the Permian.

CREDIT: PASCAL GOETGHELUCK / GETTY IMAGES

They described the find as "remarkable", touting it as "a new landmark for understanding the marine recovery dynamics" after the world's most severe mass extinction.

EARTH SCIENCES

Sparser Larsen

As a big chunk of the Larsen C ice shelf looks set to break away, we take a look at the remnants of its neighbours.

The Larsen Ice Shelf is situated along the northeastern coast of the Antarctic Peninsula, one of the fastest-warming places on the planet. In the past three decades, two large sections of the ice shelf , dubbed Larsen A and B, have collapsed. A third section (Larsen C, predictably enough) seems like it may be on a similar trajectory, with a new iceberg poised to break away soon.

This image shows the northern part of the Larsen Ice Shelf. The picture comprises four natural-colour images captured by NASA's Operational Land Imager (OLI) on board the Landsat 8 satellite. The images were captured in early 2016.

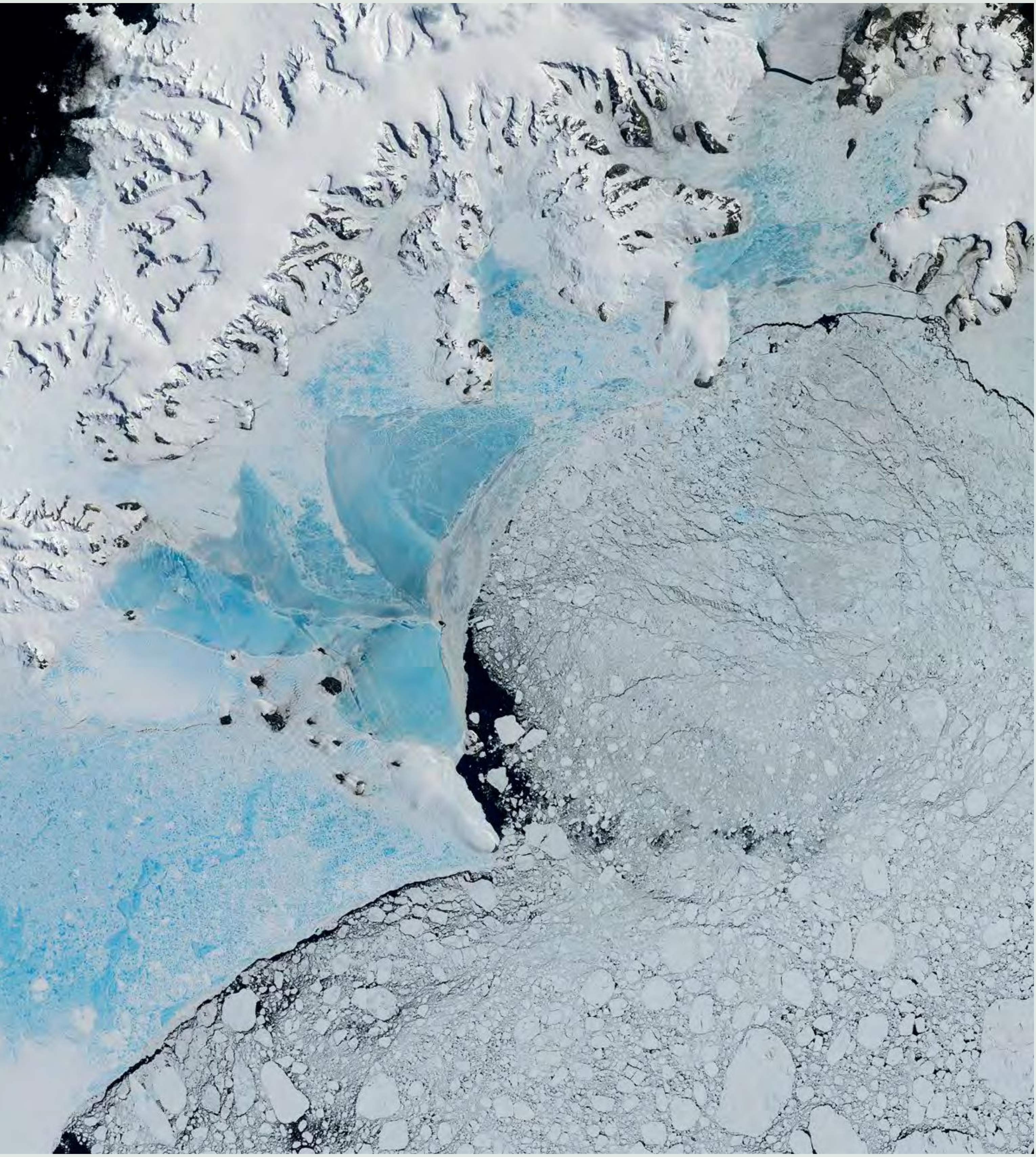
'THE WHITE AREAS NEAR WHERE GLACIERS MEET THE SEA HAVE MULTITUDES OF SMALL ICEBERGS, CALLED "BERGY BITS".'.

The resulting composite shows the remnant of Larsen B, together with the Larsen A. Also visible are smaller embayments to the north, covered by a much thinner layer of sea ice. The remaining shelf appears largely white, although some deep rifts are clearly visible within it.

Areas with sea ice anchored to the coastline or ice shelf – known as fast ice – are light blue where covered with melt water, and white where covered by wind-blown snow. The ocean is dark, nearly black, where it is not covered by sea ice. The white areas near where glaciers meet the sea have multitudes of small icebergs, called 'bergy bits', that broke off from land-anchored ice.

Going, going, gone: the Larsen ice shelf.

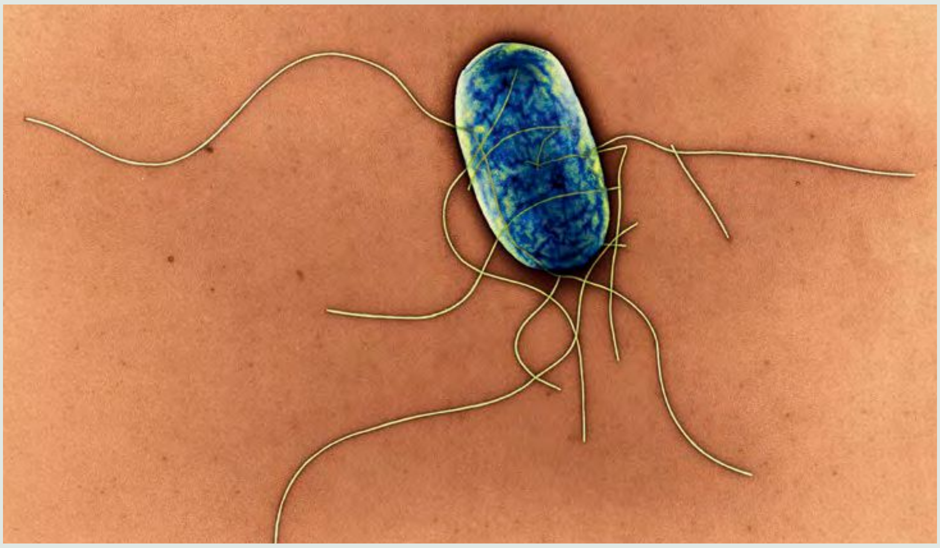
CREDIT: NASA EARTH OBSERVATORY / JESSE ALLEN



LIFE SCIENCES

Food poisoning bug enlisted to fight cancer

Like a beacon, modified *Salmonella* draws the immune system's attention to cancerous cells. ANTHEA BATSAKIS reports



Engineered *Salmonella* leads immune fighter to cancer cells.

CREDIT: EYE OF SCIENCE / GETTY IMAGES

A bacterium that causes food poisoning may be an unlikely hero in cancer treatment. Researchers, led by Jin Hai Zheng at Chonnam National University in South Korea, engineered a weak strain of *Salmonella typhimurium,* which causes gastroenteritis in humans, to invade cancerous colon tissue in mice and trigger an immune response.

The bacterial incursion caused the tumours to shrink, and prevented relapse, according to findings published in *Science Translational Medicine*.

One of the most effective ways of treating a patient's tumour is with their own immune system, says Thomas Cox, a cancer biologist at the Garvan Institute of Medical Research in Sydney, Australia, who was not involved in the study.

Cancer cells typically fly under the immune system's radar, so researchers try to find ways to draw attention to them. Pathogenic microbes such as *Salmonella* strains might just be one way to do so.

As a tumour expands it can outgrow its blood supply, leaving oxygen-deprived patches. Because *Salmonella* thrives in low-oxygen environments, it homes in on those regions and sets up shop.

The immune system then fights the bacterial infection – tackling the tumour along with it.

The idea of enlisting bacteria to make

LIFE SCIENCES

Horse study reins in evolutionary orthodoxy

Millions of years of horse development suggest that one of the key assumptions of evolutionary theory may be wrong. JANA HOWDEN reports.

The evolution of the horse has always been touted as a textbook case of how the appearance of new traits paves the way for evolutionary success. A new study published in *Science,* however, suggests that might not be the case after all.

The earliest horses appeared in North America 55 million years ago. They were dog-sized, three-toed forest dwellers. But as grasslands expanded 18 million years ago, many new species evolved.

They grew bigger, traded their three toed feet for one big fast hoof (derived from the middle toe) and developed strong grinding teeth – all good adaptations for life on the open prairie.

But did these adaptations indeed come first, as the textbooks suggest?

To find out, a team led by Juan Cantalapiedra from the Leibniz Institute for Evolution and Biodiversity Science in Germany carried out a study to see how horse traits changed over time and how they correlated with the emergence of geographically dispersed horse species and altered environmental conditions.

They made use of the rich fossil record to study the body size and tooth shape of 138 species of horses, all but six of them extinct, with the oldest dating from 18 million years ago.

They identified periods during which there were bursts of new geographically dispersed species, but these did not correlate with physical changes.

> 'THE RADIATION OF EQUIDS … HAS BEEN CITED AS A TEXTBOOK EXAMPLE OF ADAPTIVE RADIATION FOR MORE THAN A CENTURY.'

Instead new traits arose after changes in the environment and patterns of migration – the precise opposite of the prevailing theory.

This, they say, strongly suggests that evolution was driven by "extrinsic factors – such as geographical dispersals, increased productivity, or habitat heterogeneity – that release diversity tumours visible to the immune system has a history going back more than a century to physician William Coley, who treated cancer patients by injecting them with bacterial toxins. In the new work the scientists genetically modified the bacterium to release a protein that rouses an immune response, making the tumours even more visible. The protein is called FlaB, normally secreted from a marine-dwelling bacterium related to cholera.

CANCER CELLS TYPICALLY FLY UNDER THE IMMUNE SYSTEM'S RADAR, SO RESEARCHERS TRY TO FIND WAYS TO DRAW ATTENTION TO THEM.

Just three days after dosing cancerous mice with the FlaB-secreting *Salmonella*, the researchers noticed the bacteria invaded the oxygen-deprived cancerous tissue almost exclusively. In more than half the mice, the tumours shrank significantly.

Cox says the work, while still preliminary, is "something we'll certainly hear a lot more about, especially given the current hot trend of immunotherapy and the successes we've seen with immunotherapy drugs".

limits and promote speciation".

In other words, new traits and new species evolved after environmental changes created a new niche that allowed greater genetic diversification.

Cantalapiedra and colleagues note the irony of their findings, saying, "the radiation of equids ... has been cited as a textbook example of adaptive radiation for more than a century".

Alistair Evans, an evolutionary biologist from Monash University, in Melbourne, concurs

"We'd always thought you can only really become species-rich by adapting to new environments," he says, "but here it seems that the new species comes first, and then the anatomy changes later."

That said, he points out "there is much more to a species than just how big it is and how big its teeth are" – suggesting the complex evolutionary history of horses is far from a closed case.

BY THE NUMBERS

VARIABLE STARS

RS Puppis, a bright Cepheid variable star.

CREDIT: IMAGE CREDIT: NASA/ESA/HUBBLE HERITAGE (STSCI/AURA)-HUBBLE/EUROPE COLLAB.

ACKNOWLEDGMENT: H. BOND (STSCI AND PENNSYLVANIA STATE UNIVERSITY)

100 BILLION-PLUS

Stars in the Milky Way.

400,900

Stars classified as variable because their brightness fluctuates, due to pulsation or periodical eclipse by another celestial body.

7

Super-rare Triple Mode "high amplitude delta Scuti" variable stars in our galaxy, which pulsate in three directions at once.

1

Triple Mode "high amplitude delta Scuti" star discovered by an American high-school student. Formally announced in February, the star is 7,000 light years away and pulsates every 2.5 hours.

IN BRIEF

PAINKILLER THRILLER

CREDIT: DEA / A. DAGLI ORTI / GETTY IMAGES

DNA scraped from Neanderthal teeth suggests our extinct relative self-medicated, with traces of plants containing salicylic acid – the active ingredient in aspirin – found in tooth plaque.

Mineralised plaque traps microorganisms as well as bits of food, preserving the DNA for thousands of years. The *Nature* study sampled plaque from four Neanderthals in Spain and Belgium.

Not surprisingly, the Neanderthals ate what they found near where they lived. The Belgians feasted on rhinoceros, sheep and mushrooms, while the Spaniards made do with moss, mushrooms and pine nuts.

One plaque specimen told a medical detective story. It came from a tooth with a dental abscess and carried the DNA of a disease-causing bacteria. But it also carried DNA traces of poplar, a plant containing salicylic acid and the fungi Penicillium – which produces penicillin.

The authors suggest Neanderthals were wise to the medicine chest growing around them.

LIFE SCIENCES

Baleen whales have sung basso profundo for 34 million years

Surprisingly, the blue whale's deep voice was around long before its huge body. AMY MIDDLETON reports.

Baleen whales produce and hear the lowest frequency sounds of any animal alive. Among evolutionary biologists it was generally assumed that such extreme acoustic ability was an adaptation linked to huge body size.

In a surprising finding, Australian-led research published in *Proceedings of the Royal Society B* suggests the trait was around long before whales grew big.

Travis Park from Monash University in Melbourne set out to test the hypothesis that the big sounds of baleen whales had co-evolved with their size by investigating the fossilised earbones of their more diminutive ancestors – dolphin-sized toothed whales.

His team focused on fossils from 34 million years ago, the period during which filter feeders emerged as a distinct evolutionary line. Three-dimensional models were made of the whales' cochleae – the spiral, hollow, conical bone chambers in the ear that facilitate hearing. The precise architecture of the structures allowed Park's team to calculate the frequency ranges the whales could detect, and compare them with those heard by modern species.

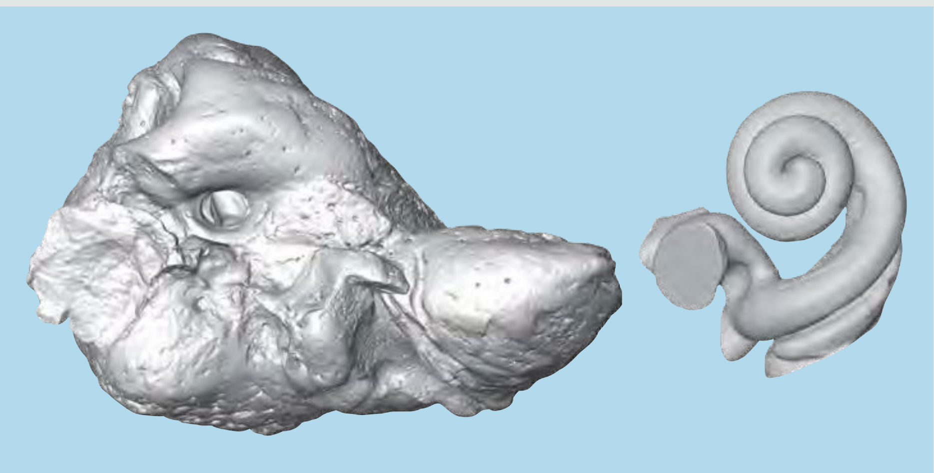
The results showed striking similarities. The cochleae of the whales, big and small, ancient and modern, were adapted to very similar ranges. This suggests that low-frequency hearing is not an emergent property of increased mass but a pre-existing ability.

The finding is controversial, contradicting earlier research.

Park's paper concludes that low-frequency hearing is of very ancient origin, emerging long before the high-frequency sensitivities and echolocation abilities associated with toothed cetaceans such as sperm whales, narwhals and porpoises.

PARK'S PAPER SUGGESTS THAT, CONTRARY TO CURRENT ORTHODOXY, LOW-FREQUENCY HEARING IN WHALES IS OF VERY ANCIENT ORIGIN.

"The similarities of baleen whale cochleae to older whales shows us that this ability evolved well before other extreme adaptations such as baleen, filter feeding and gigantic body size," says Park.



The reconstruction of the cochleae, right, from the 34-million-year-old fossilised ear bone, left, shows whale ancestors also had low-range hearing. CREDIT: TRAVIS PARK

Low down suprise: the blue whale's basso song evolved before it got so big.

CREDIT: FRANCO BANFI / GETTY IMAGES

CLIMATE WATCH

EARTH SCIENCES

Enlightened shelf interest

Forecasting global sea level rise is tough. The blame lies with Antarctica. JAMES MITCHELL CROW reports.

Estimates of global sea level rise by 2100 have fluctuated wildly in recent decades – from more than two metres to as little as 31 centimetres.

The rubbery figures have been a source of ammunition for climate change sceptics and consternation for policy makers – undermining their ability to plan ahead. Most of the blame can be levelled at Antarctica. Its 30 million km^3 ice sheet holds 90 per cent of the world's fresh water. If it all melted, sea levels would rise 60 metres. By contrast, a melt of the Greenland ice sheet, the world's second largest, would contribute six metres.

Predicting the rate of ice melt in Greenland is relatively straightforward; Antarctica's melt is anything but.

The stability of Antarctica's ice sheet depends on the floating ice shelves at its fringes. They act as plugs halting the movement of the ice sheet. It is the dynamics of that interaction that have been hard to fathom.

The most recent IPCC report (published in 2013) estimated Antarctic ice would contribute just 4 centimetres to global sea levels by the end of the century, leading to an overall rise of 70 centimetres by the end of the century under "business as usual" emissions scenarios.

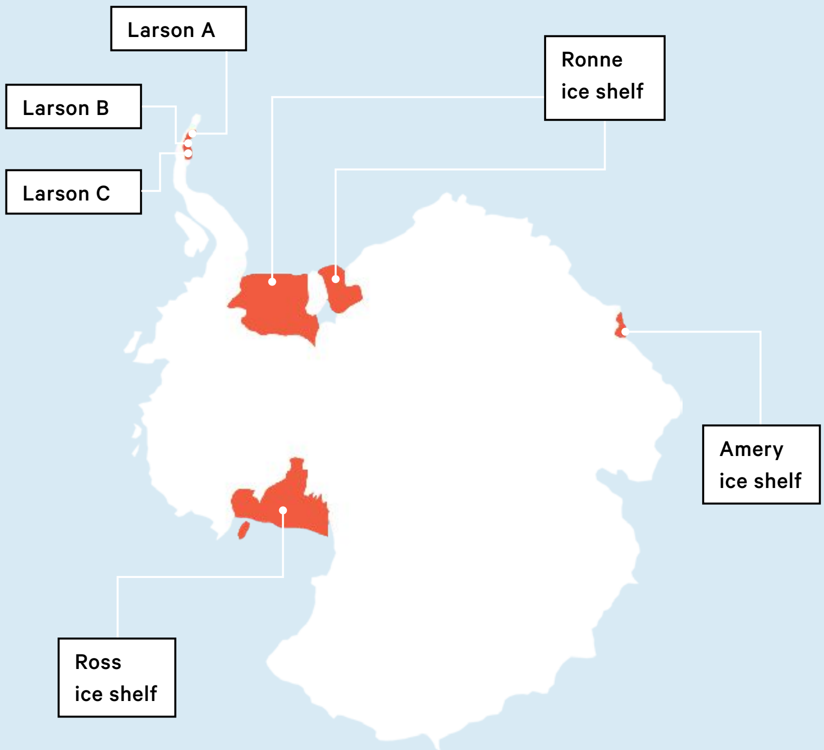
That estimate, according to Nick Golledge, an Antarctic ice sheet modeller at Victoria University of Wellington, in New Zealand, was extremely conservative, because the report's authors "just didn't know enough about fast dynamics in ice sheets". Scientific understanding has moved on since then, confirming Antarctica will contribute way more than 4 centimetres by 2100. "The latest research is converging on a figure more like half a metre," Golledge says.

Researchers discovered how unpredictable ice sheet dynamics could be in 2002 when a 3,500 km^2 chunk of the Larsen B ice shelf disintegrated. Located on the Antarctic Peninsula, the continent's most northerly and warmest point, it had appeared perfectly stable (see "Sparser Larsen", p20-21).

In the low-lying Netherlands, floating houses such as these in Ijberg, a suburb of Amsterdam, are ready for higher sea levels. Whether housing in other places should be built this way depends largely on what happens with Antarctica. CREDIT: ASHLEY COOPER / GETTY IMAGES

SLIP SLIDING AWAY: ANTARCTICA ON THE MOVE

The rate of movement of the ice shelves will have a big impact on the overall rate of Antarctica's ice sheet melt.



KEY ● Highest rate of movement

DATA SOURCE: DECONTO & POLLARD, *NATURE*, 2016.

While the melting of Larsen B didn't make any direct difference to sea levels (just as the melting of an ice block won't raise the level of your drink), it was the canary in the coal mine.

Before the Larsen B event, scientists thought the ice sheet moved in a very steady fashion, says Matt King, who researches Antarctica's contribution to sea level rise at the University of Tasmania. "You could kick it as much as you like and it didn't really do much... Now we have a completely different view."

What led to the collapse of Larsen B was the rising summer temperatures in the Antarctic peninsula, with the mercury spending more and more time above zero in the years beforehand. As a result, vast pools of meltwater formed on top of the thinning ice, fracturing it and pouring into cracks that ultimately broke apart the whole chunk.

Summer surface melting is a well-understood process, and the dominant factor in Greenland's melt – making it highly predictable. The process can explain what is happening in the northern tip of Antarctica, but it can't account for the changes seen in the rest of the southern continent, where temperatures perpetually remain well below freezing. Here the peril seems to come from below.

One "hotspot" in East Antarctica is the rapidly thinning ice shelf fringing the large Totten glacier. In a study published in *Science Advances* in December 2016, a CSIRO-led team confirmed warm water from the deep ocean is slipping up onto the Antarctic continental shelf and reaching Totten via deep canyons in the sea floor.

AS THE ICE WARMS, THINS AND CRACKS, YET ANOTHER FEEDBACK MECHANISM MIGHT COME INTO PLAY, ACCORDING TO MODELLING.

"If there's one thing ice hates, it's warm water – it's tremendously efficient at melting ice," King says.

That warm water is not just a threat to the floating ice shelves. In West Antarctica the ice sheet sits on bedrock that is below sea-level, raising the risk warmer water could stream in and undercut the ice sheet.

As the ice warms, thins and cracks, yet another feedback mechanism might come into play, according to modelling by Robert DeConto at the University of Massachusetts and David Pollard at Pennsylvania State University. Each time a piece of ice shelf breaks off, the remaining "ice cliffs" will be taller. "That's inherently unstable," says Tony Worby, who heads the Antarctic Climate and Ecosystems Cooperative Research Centre in Hobart. Sooner or later the cliffs will crumble under their own weight.

Understanding these processes is just the beginning of the ice modellers' work. Predicting when, where and how rapidly they will occur, to forecast how much sea levels will rise, is quite another. So far the estimates of Antarctic contribution to sea level rise by 2100 remain highly variable. A key challenge is the lack of data to feed into the models. Huge sections of East Antarctica's coastal zone remain effectively unmapped. "We don't know where the bedrock is or where the warm water can flow," King says.

In 2019, Australian researchers will take delivery of a new icebreaker able to map the seafloor on Antarctica's fringe. The ship will carry an unmanned underwater vehicle capable of navigating under the ice shelves. "Very quickly we'll start to build a picture of what the seafloor looks like around the continental shelf around Antarctica," King says.

Within a decade, researchers should be more confident in their predictions. "Assuming," King notes, "there's not more unknown aspects of the ice sheet."

We've been surprised before.

LISTED

EXTREMOPHILES: A BIOLOGIST'S BEST FRIEND

It doesn't seem to matter how inhospitable an environment, there is an organism adapted to live there.

Scientists have found life in every extreme environment you can imagine, from volcanic cauldrons to highly alkaline seas. These extremophiles are not just curiosities; they could show us how life might exist on other planets with more hostile conditions than Earth.

Some have led to innovations in materials science, pharmacology and energy generation. Here we look at four organisms that live in conditions that would kill most other forms of life and learn what they could teach us.

— JAMES MITCHELL CROW

1

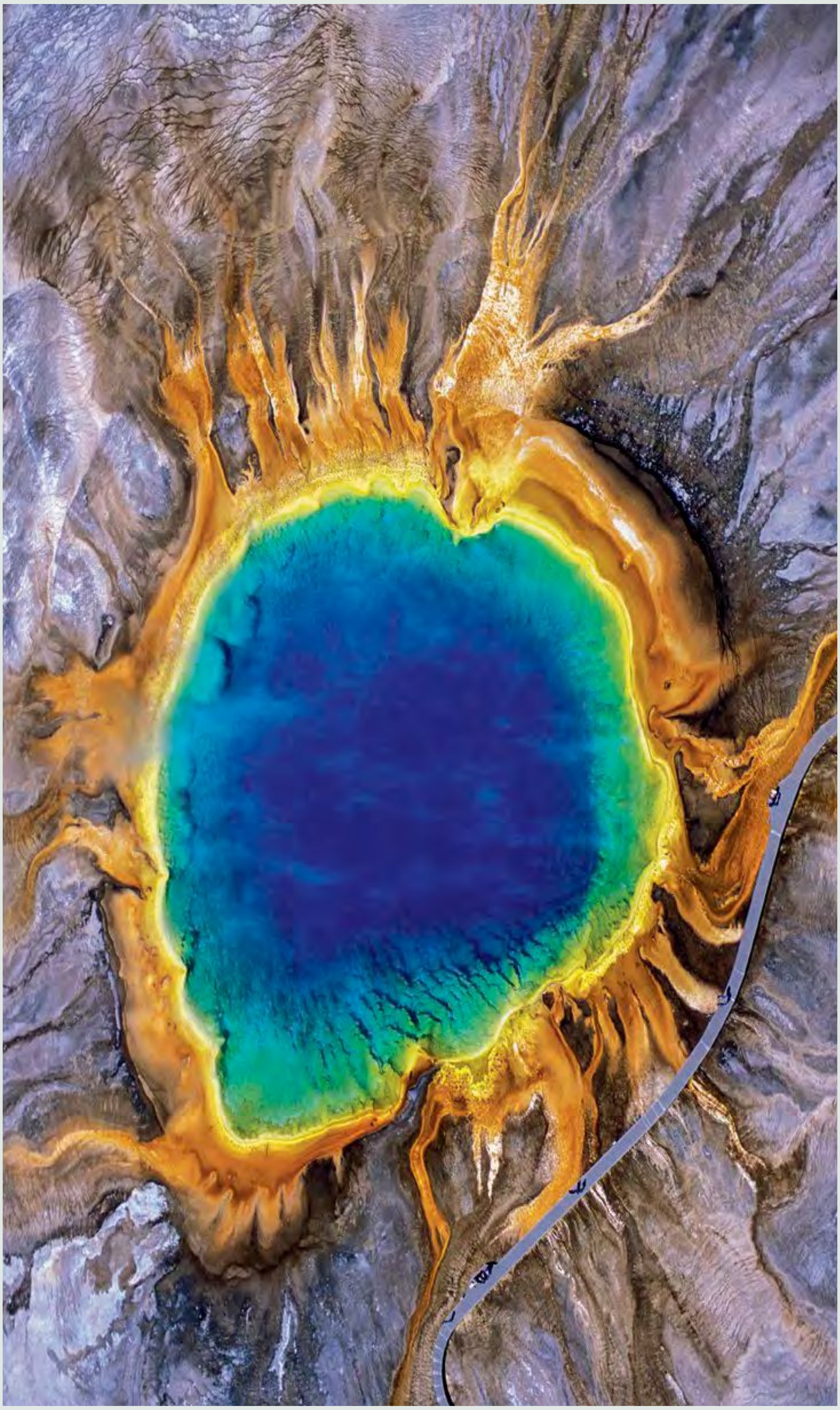
HEAT-SEEKING MICROBES

Heated by a subterranean supervolcano, the bubbling hot springs of Yellowstone can exceed 90°C, too hot for ordinary organisms.

In 1969, while studying the extremophile microbes that do live in Yellowstone's hotsprings – and give them their colour – Thomas D. Brock and Hudson Freeze of Indiana University discovered *Thermus aquaticus*. This microbe went on to underpin almost every genetics discovery ever made.

T. aquaticus contains a heat-tolerant DNA-polymerising enzyme that, once isolated, became a cornerstone of the polymerase chain reaction. PCR is how tiny DNA samples are amplified for analysis – crucial for everything from crime scene analysis to genome reading.

It's just one of the uses scientists have already, or hope soon, to develop by studying extreme organisms.



Grand Prismatic Spring in Yellowstone National Park. CREDIT: TOM MURPHY / GETTY IMAGES

2

A FROSTY RECEPTION

When winter arrives in Alaska, the local wood frogs freeze solid. Some seven months later, when spring finally arrives, the thawed-out frogs hop away.

Freezing once would kill almost any other vertebrate, their organs pierced by ice crystals. Yet as autumn sets in, Alaska's wood frogs can survive two weeks of night/day freeze-thaw cycles before finally freezing solid. The frogs, like certain other freeze-tolerant fish and insects, produce chemicals that stop ice crystals forming.

Researchers hope that by studying these species they'll learn how to mimic this ability to store human organs for transplant. Currently organs are destroyed by freezing, and can only be kept for a few hours in refrigeration.

The wood frog in warmer times. CREDIT: GLENDA CHRISTINA / DESIGN PICS / GETTY IMAGES

3

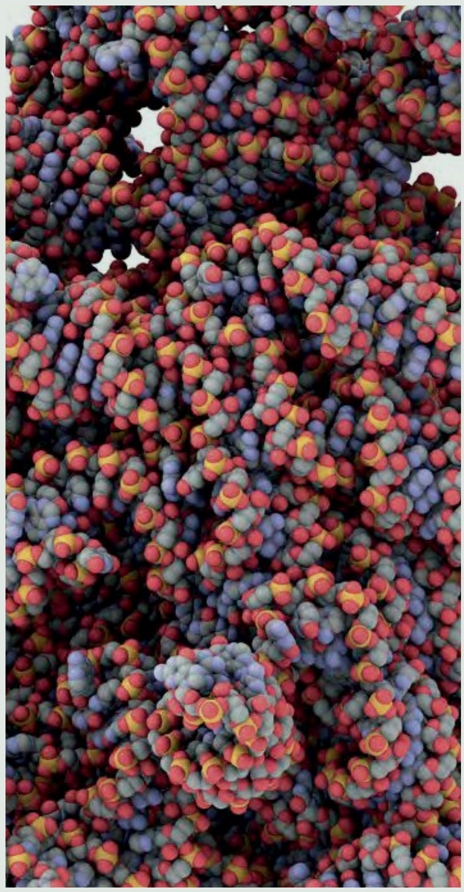
CONAN THE BACTERIUM

Deinococcus radiodurans can survive blasts of gamma radiation 3,000 times the lethal dose for humans.

In 1999, the US Department of Energy funded research to sequence the bacterium's genome, in the hope of developing waste-consuming microbes to clean extremely contaminated nuclear sites.

Surprisingly, *D. radiodurans*'s DNA has proved just as susceptible to radiation damage as a regular E.coli. The bacterium's secret is a set of antioxidants that protect its proteins from radiation damage. These proteins can then rapidly repair damaged DNA.

Last year, researchers showed that a peptide based on these antioxidants could protect mice from usually lethal doses of radiation – a promising first step toward developing an effective radiation recovery pill for humans.



Deinococcus radioduransis.

CREDIT: LAGUNA DESIGN / GETTY IMAGES

4

MULTI-EXTREMOPHILES

The microscopic tardigrade, or water bear, can survive heat, cold, desiccation, lack of oxygen and radiation. The tiny animal has even been shown to survive a 10-day trip into space, prompting some to suggest it's the kind of creature that could live on Mars.

Not so. To survive these conditions the tardigrade puts itself into a form of non-reproductive suspended animation.

Some extremophiles, however, really do seem equipped for life on the Red Planet. Subterranean micro-organisms found in Earth's deepest mines and caves seem to have what it takes to survive below the surface on Mars (*Cosmos* 61, p70). Studying Earth's extremophiles offers a possible glimpse of what alien life may look like – and where to look for it.

A water bears or tardigrade. CREDIT: EYE OF SCIENCE / GETTY IMAGES

TECHNOPHILE

The Hitchhiker's Guide to the Solar System

Space missions used to be so expensive only superpowers could afford them. No longer, writes CATHAL O'CONNELL.

"Any man who can hitch the length and breadth of the galaxy, rough it, slum it, struggle against terrible odds, win through, and still knows where his towel is is clearly a man to be reckoned with."
– Douglas Adams

Exploring the solar system is absurdly expensive. Even a single mission, such as NASA's US$675 million InSight probe to Mars, scheduled to launch in May 2018, would eclipse the total science budget of most nations. But with tiny, hitchhiking satellites called CubeSats, there may finally be a way to explore other planets on a shoestring.

Tagging along on that InSight mission will be two CubeSats – small, boxy satellites the size of a carry-on suitcase. Built by NASA's Jet Propulsion Laboratory, these Mars Cube One (or MarCO) probes will be the first CubeSats to voyage to another planet. If they pull off their US$13 million mission – peanuts compared with any previous interplanetary mission – MarCO could lead to a shift in how we explore the solar system, even opening the doors to smaller nations to stake a claim. Space travel finally has an economy-class fare.

CubeSats were originally designed as a training tool, so university students could design and build satellites in the timeline of a semester. The basic idea was to cram the instrumentation into a standard template: a cube with 10 cm sides.

Almost 20 years on, more than 500 cubesats have been launched successfully into orbit, with another 600 launches planned for 2017 alone. CubeSats have turned into the great leveller of modern space exploration, achievable within the budget of schools, universities, or even crowdfunding campaigns.

Stacking cubes together delivers the flexibility to make larger, sophisticated CubeSats such as LightSail-1, which hoisted a 32 m^2 solar sail in 2015 (*COSMOS* 65, p26). But so far, no CubeSat has ever left low earth orbit, which is within 160 km of the Earth's surface.

The MarCO mission requires two CubeSats to fly, by themselves, across more than 200 million km of deep space during their six-and-a-half-month mission. To survive in deep space, they'll need a serious upgrade on the standard model.

Each MarCO is a six-unit CubeSat stuffed with two deployable solar panels, two antennas and a radio the size of a tennisball. Special mini-thrusters, using the same kind of propellant as in some fire extinguishers, will help the MarCOs make course corrections during the journey. To survive the bombardment of cosmic rays and solar wind, they'll use robust, radiation-resistant electronics.

MarCO's job is to receive data from the InSight lander during its so-called "seven minutes of terror" as it punches through the Martian atmosphere on its way to becoming the first seismometer on Mars. During this critical period of atmospheric entry and landing, InSight can't communicate with Earth directly, so MarCO will relay the data. While this job is not mission-critical for Insight, it is the perfect demonstration of the feasibility of CubeSats far from Earth orbit.

If successful, MarCO could alter the way we explore the solar system generally. NASA envisions launching swarms of CubeSats, each carrying a single instrument or performing a single task. Each becomes a low-cost, highly specialised probe, rather than a jack-of-multiple-trades as with conventional space probes.

Steven Hobbs, a planetary scientist at the University of New South Wales, says sending a bunch of low-cost missions might end up giving more bang for buck compared with typical, multi-tonne probes that are very difficult to build and "that only superpowers could afford." Another possibility is to send sacrificial CubeSats to the solar system's most hellish places, such as the surface of Venus, the plumes of Europa or inside the volcanoes of Io.

At least a dozen other deep space CubeSat missions are in the works. Even before MarCO, the INSPIRE project could be the first CubeSat to escape Earth orbit, some time in 2017. It will carry two instruments: a magnetometer to measure magnetic fields – useful for probing the the solar wind in fine detail – and a simple camera so it can orient itself by the stars.

In 2018 NASA will send its new Orion spacecraft around the Moon and back, with 13 CubeSats tagging along for the ride. After the Orion capsule's separation from its upper stage, the CubeSats will be be ejected to take on a range of missions: searching for ice on the moon, studying how yeast deal with space radiation, scouting near Earth for asteroids, measuring space weather and more.

Hitchhiking could be the new way to see the solar system. No towel required.

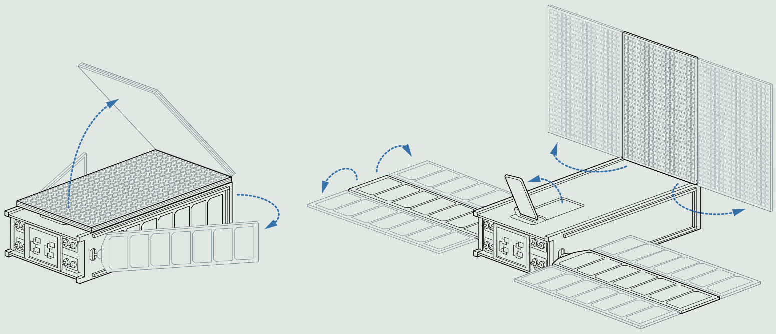
→ See the MarCO deployment here: bit.ly/cos74MarCo

ILLUSTRATIONS: ANTHONY CALVERT

SPECIFICATIONS
NAME: Mars Cube One (MarCO)
DESTINATION: Martian orbit
MISSION COST:
(MARCO) US$13 million,
(INSIGHT) US$425 million
LAUNCH DATE: 20 May 2018
MARS ARRIVAL: 26 November 2018
DIMENSIONS (WHILE STOWED):
36.6 x 24.3 x 4.6 x 11.8 cm.
MASS: 14 kg

UNFOLDING

MarCO will deploy from the Atlas V rocket carrying InSight one week after launch. MarCO's first challenge as an independent spacecraft will be to unfold its two wing-like solar panels, and its flat-packed communications systems.

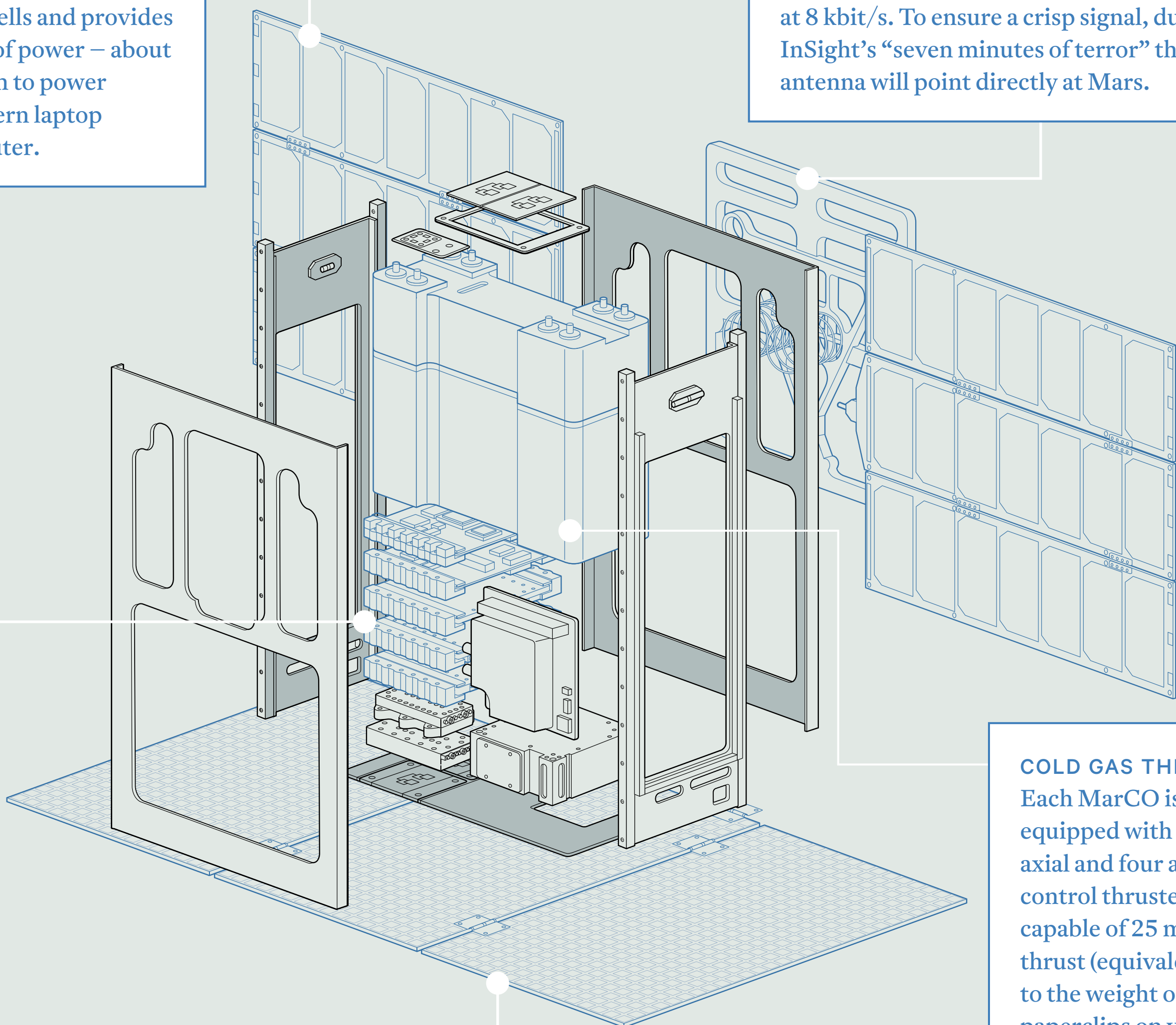


SOLAR ARRAYS

Each solar array contains 42 individual solar cells and provides 35 W of power – about enough to power a modern laptop computer.

UHF ANTENNA

This small ultra high frequency (UHF) antenna is capable of receiving data from InSight at 8 kbit/s. To ensure a crisp signal, during InSight's "seven minutes of terror" this antenna will point directly at Mars.



X-BAND TRANSPONDER

This transponder converts the UHF signal received from InSight to the X-band signal (in the microwave range) for sending back to Earth.

HIGH GAIN REFLECTARRAY

This flat panel relays X-band signals at 8 kbit/s to the Deep Space Network dishes back on Earth. During the InSight landing, MarCO will rotate so the reflectarray can transmit direct to home base.

COLD GAS THRUSTERS

Each MarCO is equipped with four axial and four attitude control thrusters, each capable of 25 mN of thrust (equivalent to the weight of two paperclips on your palm). That may not sound like much, but it's enough to make the minor course corrections needed on the 6.5-month-long journey to Mars.

OPINIONS, IDEAS & PERSPECTIVES

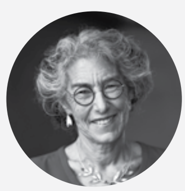
VIEWPOINT

"WHEN TEXTBOOKS ARE PROVEN WRONG, WE SCIENTISTS CAN'T HELP BUT CELEBRATE"

ALAN DUFFY — ASTROPHYSICS

NORMAN SWAN
BODY TALK

ALAN DUFFY
ASTRO DUFF



LAURIE ZOLOTH
PHILOSOPHER'S CORNER

ALAN FINKEL
INCURABLE ENGINEER

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

BODY TALK

The meningitis mystery

The spread of meningococcal subtypes is complex and poorly understood.

IT'S EVERY PAEDIATRICIAN'S nightmare. A child arrives in the Emergency Department with a high fever, a rash whose spots don't go white when you press them under a glass and who turns their head away from the light. The toddler was well until a few hours before and, from the parents' story, things are going downhill fast. If you get the diagnosis wrong, the child could be dead within hours.

The safest assumption is that meningitis-causing bacteria are coursing though the patient's bloodstream (septicaemia) and infecting the membranes (meninges) around the brain. The imperative is to get intravenous antibiotics into the child as soon as possible.

Several types of bacteria can cause meningitis but one of the most common is meningococcus. Meningococcal subtypes are identified by single letters, such as A, B, C and Y.

What has been concerning health authorities is the increase in cases of Meningococcus W or MenW. In Britain eight years ago MenW represented only 1% of meningococcal disease; today it's 25% and growing. In Australia the number of cases, while small, is also growing. Such is the concern that two states (Western Australia and New South Wales) have started offering immunisation to teenagers.

The anxiety is amplified because MenW affects older age groups, and meningitis is generally a disease doctors expect to see only in children or young adults. So clinicians' antennae aren't up when someone older comes into the surgery sick. MenW also doesn't necessarily present as meningitis. It can cause infected joints, pneumonia and a dangerous condition called epiglottitis, where the flap that seals the upper airway when we swallow (the epiglottis) becomes inflamed and swollen and may suddenly and unpredictably block the airway completely. The death rate from MenW is 13% compared to about 5% for other subtypes. In South America, mortality can be as high as 28%.

The mystery is why MenW is spreading. One theory is the "niche hypothesis" – that meningococcus occupies an ecological niche, like sparrows in the city. If someone came along and knocked off all the sparrows, common mynahs might take over the sparrows' nooks and crannies. With meningococci, there are vaccines that target various subtypes. In Australia, for example, every infant receives MenC vaccine in their first year of life. MenC disease is thus now much rarer. So has MenW just muscled in to the vacancy?

It's a possibility but there may be other factors operating. For instance, after MenC immunisation was introduced into Australia for some reason MenB also started to decline, whereas the niche hypothesis suggests it should have risen.

The spread of meningococcal subtypes is complex, poorly understood and not uniform around the world. In the United States there has been a rise in MenY, and no one is sure why. New Zealand has had a nasty form of MenB, and again no one knows why.

The annual Hajj pilgrimage to Mecca where massive numbers of people from all over the world congregate, mix, then go back home has, in the past, been implicated in MenW spread.

Given the mystery, the main strategy to control meningococcal disease is immunisation. The two most common age groups affected by the bacteria are the under fives and teenagers, many of whom will carry meningococci in their noses without coming down with the disease. Why some people are carriers while others fall sick is another puzzle, probably answered by a combination of good health and good genes.

THE DEATH RATE FROM MENW IS 13% COMPARED TO ABOUT 5% FOR OTHER SUBTYPES. IN SOUTH AMERICA, MORTALITY CAN BE AS HIGH AS 28%.

With MenC the policy is to get in early and vaccinate infants. With MenW, given the older age groups affected, and the need to get good coverage quickly countries like Britain and Australia have opted to focus on teenagers.

Is there anything the rest of us can do? Meningococcal disease is rare in wealthier nations, so panic or fear are not useful responses. Doctors need to be vigilant and make the diagnosis as early as possible so that the person can be treated effectively and families and close contacts can be protected with prophylactic antibiotics.

ALAN DUFFY is a professional astrophysicist and passionate science communicator who specialises in using supercomputers to understand how galaxies form.

ASTRO DUFF

Dawn of the living dead

The pulse of a white dwarf has astrophysicists questioning what we thought we knew about the life of stars.

WHEN TEXTBOOKS are proven wrong, we scientists can't help but celebrate. So let's raise a glass to the white dwarf!

We have always dismissed these aged fellows as defunct relics of a sun-sized star. Now one has surprised us. Instead of going off gently into that good night, it is zapping the universe with a spinning beam of radiation. For astrophysicists like me, this is like hearing a retired centenarian has entered the world heavyweight boxing championships and is punching with the best of them.

This unexpected behavior was reported in a January issue of *Nature Astronomy* by David Buckley at the South African Astronomical Observatory and colleagues from the University of Warwick.

The white dwarf, AR Scorpii, and a larger companion star (a red dwarf) are located 380 light years away. Separated from each other by just three times the distance between the Earth and Moon, they orbit each other every four hours.

Till now, if you had have asked me to describe the typical life story of a white dwarf, my explanation would have gone something like this.

Fast-forward the next five billion years to see the Sun age before your very eyes. Its surface reddens and bloats as fusion reactions relocate to the outer layers; its shapely edges blur as its atmosphere drifts off into space. Now known as a red giant, it engulfs Mercury and Venus, almost certainly Earth and possibly Mars.

At the end of those five billion years, the Sun's nuclear fusion furnace has used up its fuel. Absent the outward pressure, it collapses under its own gravity.

The result is an Earth-sized object – about one millionth its original size. After 10 billion years of fusion, the Sun is gone, the remaining carbon atoms crushed till they form a near-perfect lattice akin to a diamond. Each teaspoon's worth of material equals a ton in mass.

It is now a white dwarf. Though the star's surface continues to glow white hot at more than 100,000 Kelvin, it is effectively dead, slowly fading to leave a black dwarf, with no more role to play in the evolution of the galaxy.

AR Scorpii, however, is different. Rather than fading away, it has been acting more like a lighthouse, spinning on its axis every two minutes and emitting a tightly focused beam of radiation along its magnetic poles. Like a giant dynamo, the beam is powered by a magnetic field a 100 million times that of Earth's.

In emitting its regular rotating beam, AR Scorpii is behaving like a pulsar, albeit a slow one. These cosmic beacons usually spin with a period of seconds rather than minutes and were previously thought to be powered only by neutron stars, the end state of a star with a mass at least three times that of the Sun. Even more dense than a white dwarf, a teaspoonful of neutron star weighs a billion tonnes.

Even more unusually, the beams from the feisty AR Scorpii tear across the face of its companion star, accelerating material to close to the speed of light and causing it to shine measurably brighter.

Just how AR Scorpii acquired the superpowers of a neutron star is a mystery that has astrophysicists bemused. White dwarves are not supposed to be able to do this! Only neutron stars were thought to be able to power the pulsars seen in their thousands across the galaxy. Now we know different.

This isn't the first time researchers have suggested a white dwarf might not just be a silent senior citizen. In 2008, Japanese astrophysicist Yukikatsu Terada and colleagues published an article in the *Publications of the Astronomical Society of Japan* that showed the rapidly rotating white dwarf AE Aquarii was pulsating X-rays.

JUST HOW AR SCORPII ACQUIRED THE SUPERPOWERS OF A NEUTRON STAR IS A MYSTERY TO ASTROPHYSICISTS. WHITE DWARVES ARE NOT SUPPOSED TO BE ABLE TO DO THIS! ONLY NEUTRON STARS WERE THOUGHT TO BE ABLE TO POWER PULSARS. NOW WE KNOW DIFFERENT.

To change a textbook, it is great to have more than one exception to the rule. Which white dwarf ultimately lays claim to the crown of "first" pulsar heavyweight is less important than the fact that something as extraordinary as an Earth-sized diamond crystal can hold even more surprises for astronomers.

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

PHILOSOPHER'S CORNER

Street-fighting mien

Should scientists be getting political?

THE AMERICAN GEOPHYSICAL UNION'S annual meeting is usually a quiet affair. But not last December. Many of the attending scientists moved from the meeting rooms to the streets of San Francisco, to protest president-elect Donald Trump's plans to pull out of the Paris Climate Accords.

Likewise the start of the academic year in US science departments is a low-key affair. Professors chose their new graduate students and quietly teach winter- quarter classes. But not this year. Since January, scientists have been exchanging email petitions and planning a March for Science in Washington. A prominent climate scientist, Michal Mann, called for a "rebellion" against Trump's "assault" on climate science.

These are not ordinary times.

Climate scientists are not the only ones protesting. NASA astrophysicists are protesting planned cuts in the budget. Environmental researchers and civil engineers are protesting changes at the Environmental Protection Agency (EPA). Nobel prize winners are circulating a petition with thousands of signatories denouncing new travel restrictions.

In February, at the Annual Meeting of the American Academy for the Advancement of Science (AAAS), the talk in formal panels, seminar papers, over lunch and in every corridor was about Donald Trump. Senior scientists and policy makers spoke about "defending science", and shell-shocked Washington science policy veterans told stories of encounters with Trump supporters who denied global temperature change, or the need to regulate mercury in waterways.

In a nearby square, one could see what has become a familiar sight: hundreds of white-coated protesters holding signs like "Science trumps alternative facts" and "Didn't die because of an infection? Thank a scientist".

The protesters' fears are not unfounded. During the transition period, Trump staff sent a five-page memo to the EPA with 74 items that included questions about who attended the UN Climate Summit in Paris and who was involved in developing the social cost of carbon metrics. The man appointed to head the EPA is Scott Pruitt, who consistently sued the agency while Oklahoma's attorney general. Trump has also met with a prominent anti-vaccination activist and appointed a surgeon general who seems not to "believe" in human evolution.

In an interview with the BBC, the head of the AAAS, Rush Holt, explained why scientists are concerned.

"It is partly because of the previous statements of the president and his appointees on issues such as climate change and vaccination for children, which have not been in keeping with good science," he said. But mostly it had to do with the new administration's seemingly willful ignorance about science: "Very few appointments are filled by people who understand science; [there are] very few comments about the importance of science; there is no science adviser in the White House now and we don't know whether there will be one; and the silence is beginning to sound ominous."

One of those omens was realised in mid-February. Scientists woke up to a new reality with an executive order halting entry from seven largely Muslim countries. One by one, American university presidents had to defend their researchers in every field, and wonder if they could continue their work without the foreign students and post-docs so central to American science.

THERE IS A TIME WHEN NEUTRALITY IS NOT ENOUGH

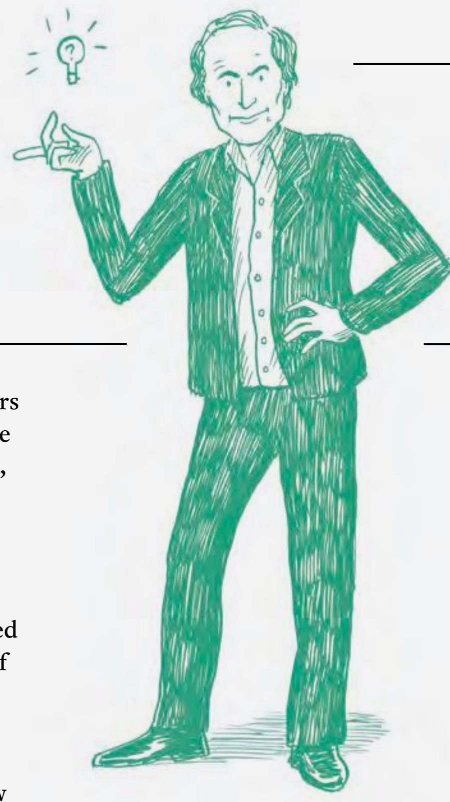
Since the Enlightenment, science has worked to position itself apart from the dictates of Church or State. Fact, causality, verification or falsifiability are supposed to be the only things that drive science to deliver a method by which we understand how the world works. That's why societies fund science.

But what if that essential bargain is threatened? What if "alternative facts" and ideological passions drive policy? Is it ethical for scientists to protest? Yes. For there is a time when neutrality is not enough, and that is when the basic premise of science as a search for verifiable truth is at stake.

So now to the streets to defend the great institution of American science.

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

INCURABLE ENGINEER



Very small time

Finally a nanotechnology that's worthy of the name

NANOTECHNOLOGY. When American engineer Eric Drexler coined this futuristic term in 1981, he had in mind molecule-sized machines that would do useful tasks. The idea was to copy nature's own machines – muscle proteins that exert force, for instance, or enzymes that carry out chemical reactions. But engineering at the nanometre scale is tough. We are talking about working with individual atoms. A silicon atom is 0.2 nanometres across. A muscle protein filament is as little as 7 nanometres in diameter.

For decades, we let human engineers off the hook, allowing a bevy of prosaic items from paints to plastics to claim the title of nanotechnology. To qualify, these products just had to involve particles smaller than 100 nanometres and display novel properties.

But finally, last year, a man-made machine claimed the title in the way Drexler imagined. It also made it into the top 10 list of *Science* magazine's breakthroughs of the year.

Delightfully, this nano machine made by Oxford Nanopore Technologies mimics nature to achieve the feat of reading the sequence of the letters of the DNA code, the chemical bases guanine, adenine, thymine and cytosine.

The machine is the size of a mobile phone and, unlike traditional sequencers which are desktop-sized and require the DNA to be pre-cut into short segments, it can handle DNA as it comes: double-stranded, long threads.

This "pocket sequencer" promises to make DNA sequencing cheaper and more accessible. It has already been used to identify the Ebola virus in a matter of hours and to read the sequence of soil microbes aboard the International Space Station.

Here's a nutshell description of how the sequencer works.

The machine is a "nanopore", a large single molecule pierced by a hollow channel a couple of nanometres in diameter. If you embed this nanopore in an ultrathin membrane bathed in an ionic solution and apply a small voltage, a tiny current will flow.

(As an aside, the reason I am so tickled by this achievement is that our brain cells also communicate via tiny currents flowing through the pores of proteins called ion channels; I spent the major part of my working career designing and manufacturing sensitive amplifiers to measure these currents.)

The simple idea behind the nanopore is that as a strand of DNA is threaded through, it partially blocks the current flow. Since the degree of blockage depends on the particular DNA letter, the fluctuations in the current pattern reflect the sequence of letters on the DNA strand as it slithers through the nanopore.

Sounds simple but, as always, the devil is in the detail.

The nanopore has two modules. The first grabs double-stranded DNA, cleaves away one of the strands, then ratchets the remaining single strand into and through the hole. It holds each base for a hundred microseconds or more before allowing it to proceed, thereby giving the detection system time to make its measurements.

The second component is the pore. Shaped like a thin hourglass, at its narrowest it is a mere 1.2 nanometres in diameter. This narrowing is the sensing region where the electrical resistance changes as each base squeezes through.

A complication is that neighbouring bases on the DNA strand can partially block the constriction. Accuracy is restored by reading the DNA strand multiple times.

Ingenious, but it took 25 years to master these devilish details. The implausible idea for nanopore sequencing was conceived in 1989 by David Deamer from the University of California at Santa Cruz; but it was way ahead of its time.

Years later I was delighted to learn that Deamer and his colleagues, in their early experiments to detect the resistance fluctuations, used a "patch clamp" amplifier made by my former company, Axon Instruments.

How does Oxford make the nanopores? It programs bacteria to do the work. Now scientists there and elsewhere are trying to develop next-generation nanopores that will be directly fabricated from silicon nitride or graphene molecules. If they succeed, that will truly be Eric Drexler's dream fulfilled.

GALLERY:
WORDS BY TIM WALLACE / CURATION BY ROBYN ADDERLY

EARTH RIDERS

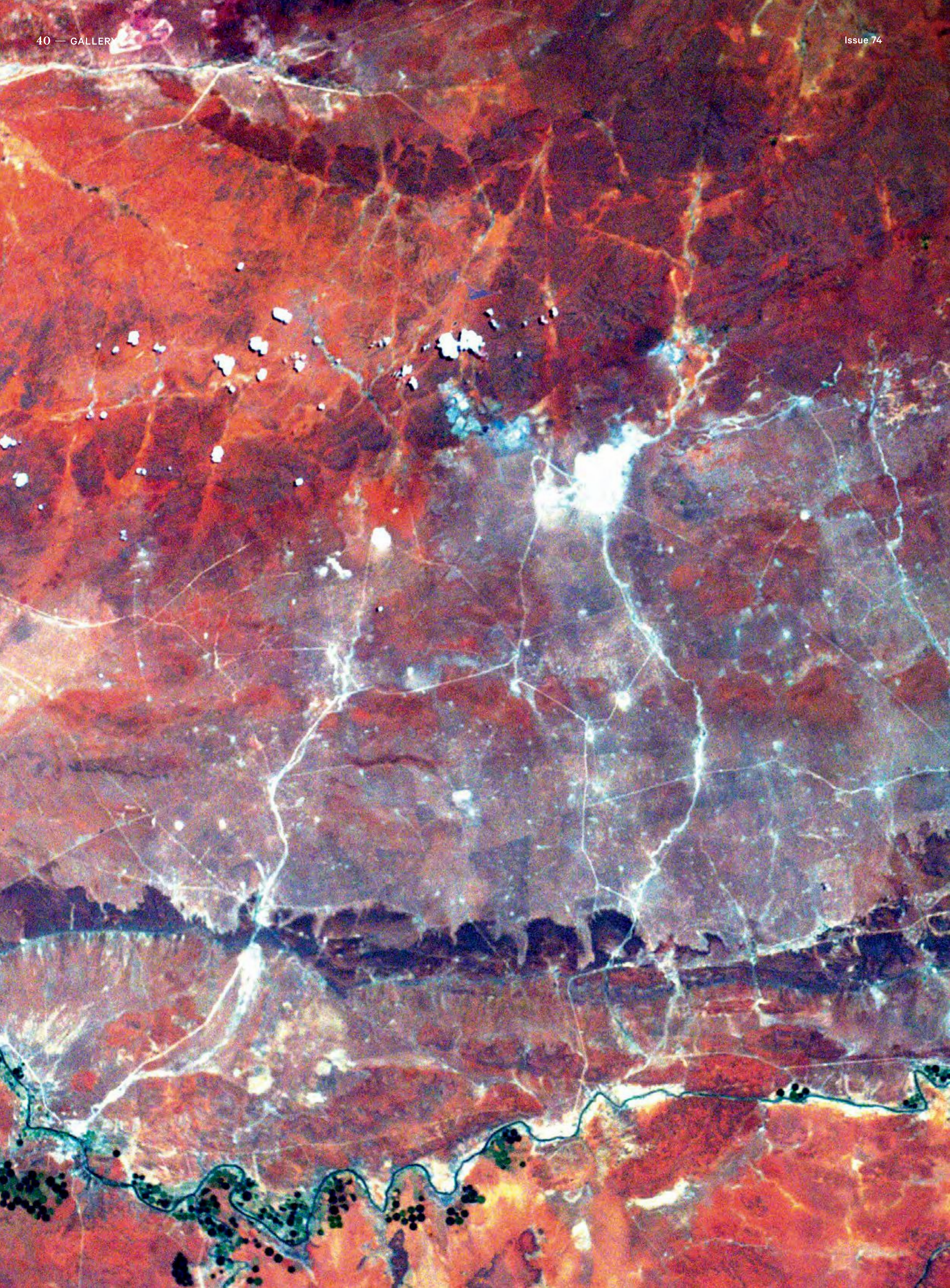
"THE EARTH IS ART, the photographer is only a witness." So said Yann Arthus-Bertrand, the French photojournalist famed for his creative career looking down on creation. But to be a witness akin to the world-renowned aerial snapper, documenting the planet from above historically meant having to part of a highly exclusive club, a membership as rarefied as the altitudes one needed to attain perspective. But no longer is the chance to turn landscapes into landscape art so limited; and no longer does it require commandeering a hot-air balloon, aeroplane or helicopter. Since 1996, a program sponsored by NASA has enabled school students around the world to remotely point and shoot a special camera on the International Space Station. The results are sometimes startlingly beautiful, less like Google Earth than a painter's canvas. Here are a few of the best, selected by art director Robyn Adderly from hundreds of images taken on recent missions. Pictured: Somalia, Africa 6.73° N, 47.30° E

CREDIT: SALLY RIDE EARTHKAM

COLOUR CODING

While the purpose of the imaging program is educational, the hauntingly vivid images that sometimes emerge demonstrate that art, like innovation, can be a creature of circumstance. In the case of EarthKam, the accidental artistry is amplified by occasional colour rendering befitting a Fauvist dream. The blues and yellows of this image might suggest the drama and dynamism of coastline shoals, for example, but in fact it's the middle of a dry desert. Here the earthy hues depict waves of wind-swept sand dunes, while the watery hues are also earth, an underlying tableau of clay and silt. Pictured: Libya, Africa 27.60° N, 11.72° E

CREDIT: SALLY RIDE EARTHKAM



STUDENT POWER

The Sally Ride EarthKAM program is unique in giving students direct control of an instrument on a working spacecraft. Four times each year the program provides a rare window of opportunity for students to request photographs of specific features or locations beneath the International Space Station's orbit. After the requests are processed and accepted by NASA's space centre in Houston, an onboard computer handles the picture-taking. Within hours of being taken, images are uploaded to the EarthKAM website and made publicly available. Now approaching 60 missions, the program has engaged more than 500,000 students from 78 countries. Pictured: South Africa 28.25° S, 23.66° E

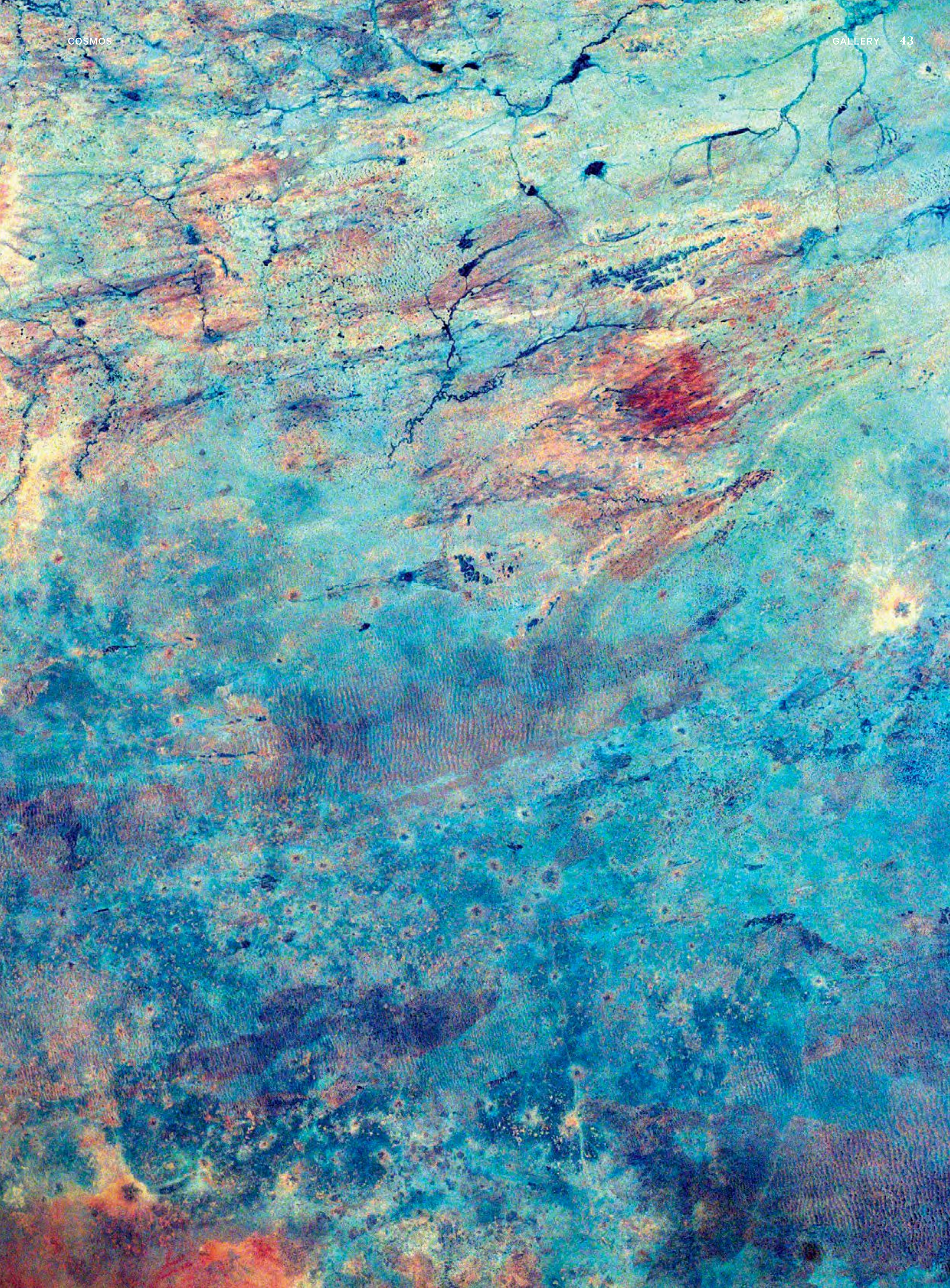
CREDIT: SALLY RIDE EARTHKAM

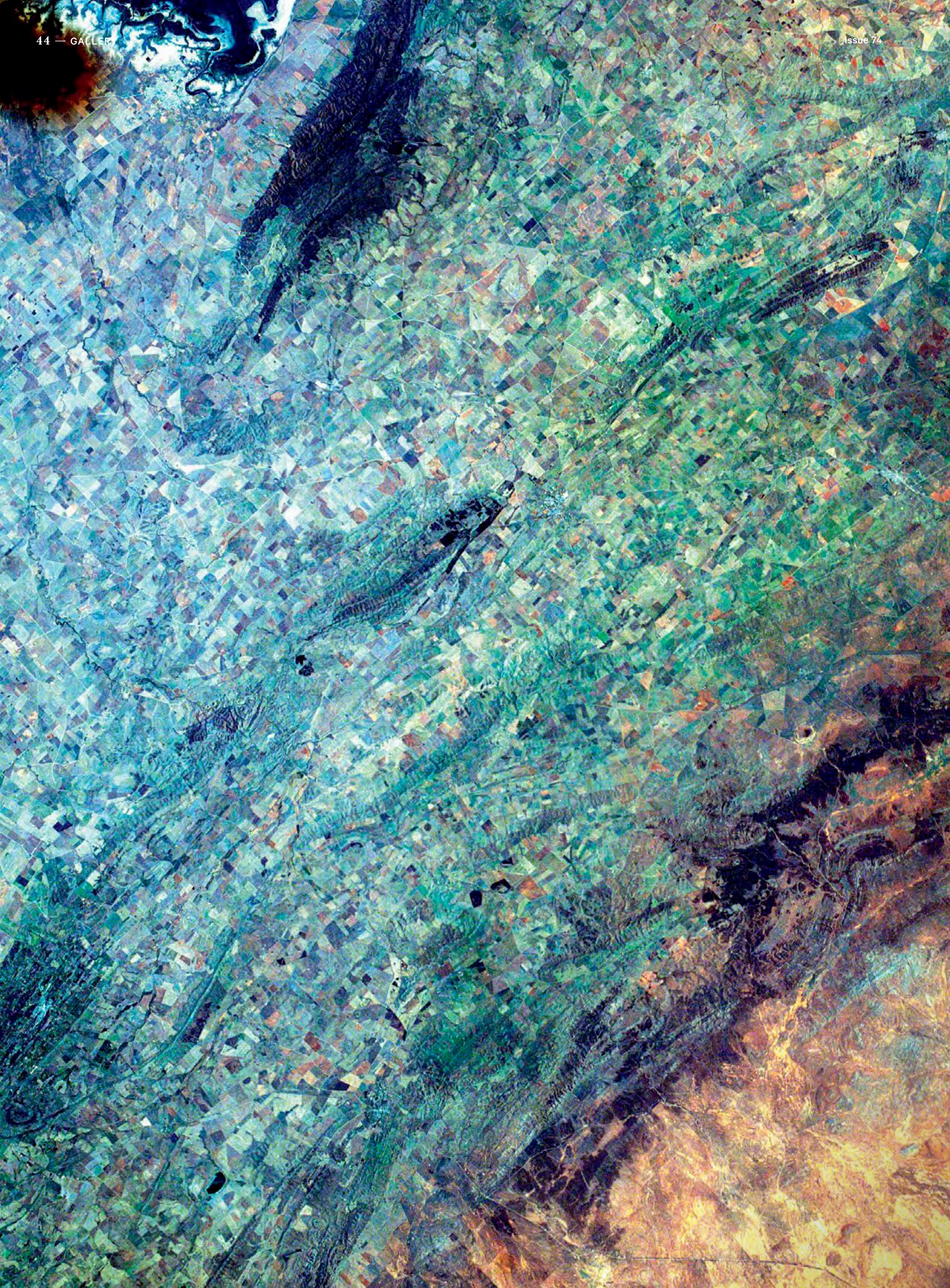
SHARING A VISION

The program (full name: the Sally Ride Earth Knowledge Acquired by Middle School Students program) is named after the first American woman in space. Sally Ride pioneered the educational inititiative (first called KidSat) in 1995 as a space shuttle astronaut. "She was amazed by the view of our beautiful blue planet wrapped in its thin blanket of air," explained colleague Tam O'Shaughnessy. "Sally wanted to share that view with young people all over the world." The program, which was renamed EarthKam in 1998 and shifted to the ISS in 2001, was finally named in honour of Ride in 2013, following her death of pancreatic cancer.

Pictured: Sudan, Africa 12.79° N, 28.13° E

CREDIT: SALLY RIDE EARTHKAM





BATTLE LINES

While students learn about space flight, orbital paths, mapping and weather by participating in the EarthKAM program, perhaps it is these snapshots that teach the greatest lesson. From space, differences between nations and groups are rarely discernable. But other fractures are starkly drawn. We see nature's organic forms subjugated to the geometric lines of human industry. The conquest is a graphic reminder. "This planet is not terra firma," as Mercury 7 astronaut Scott Carpenter once said. "It is a delicate flower and it must be cared for." Pictured: Australia 33.38° S, 138.90° E

CREDIT: SALLY RIDE EARTHKAM

01
With the fossil known as *Yi qi*, palaeontology has gone from the strange to the bizarre.

JURASSIC FLIGHT SCHOOL

Fossil discoveries in China are rewriting the history of flight. JOHN PICKRELL reports on a startling find.

SINCE 1996, nearly 50 new feathered dinosaur species have emerged from the fossil fields of China. Paleontologists thought they had a good idea of the diversity of these fluffy carnivores. But a recent finding left them scratching their heads.

THE SHANDONG TIANYU MUSEUM OF NATURE in Pingyi is the place to go if you want to experience China's dinosaurs in all their weird and wonderful glory. Five hundred kilometres south of Beijing, it's the largest museum of its kind in the world, with fossils of more than 1,000 complete dinosaurs, 2,300 early birds and plenty of creatures that bridge the boundary. Arranged in 28 halls in three nondescript-looking buildings, these spectacular displays merely hint at the treasures behind closed doors, where a backlog of new feathered dinosaur finds is stacked up waiting to be studied and named.

Species described from the collection here include *Tianyuraptor*, which resembles *Velociraptor*; *Tianyulong*, one of the first known feathered herbivorous dinosaurs; and the four-winged flying dinosaurs *Anchiornis* and *Xiaotingia*. Many museums have single specimens of dinosaur species in their collections; Shandong often has several hundred. "You don't need to do too much to dig up fossils in China," local palaeontologist Wang Xiaoli told a reporter from *The New York Times*. "When the wind blows, they reveal themselves."

Not much surprises the scientists and technicians who work on the geological riches that pass through these doors, but one fossil sold to the museum in 2007 had them stumped. "Over the past 20 years I have discovered many dinosaurs, so to a degree I am used to finding strange species," says Xu Xing, the world's most prolific living dinosaur hunter. Based at the Institute of Vertebrate Palaeontology and Palaeoanthropology in Beijing, Xu has been involved in the discovery and naming of approximately 60 dinosaur species, from the magpie-sized, four-winged flyer *Microraptor*, found in 2000, to the giant 9-metre-long fluffy tyrannosaur *Yutyrannus*, described in 2012. "But still," he says, "when I saw this particular discovery I was shocked."

Just when palaeontologists though they'd seen it all, this weird little fossil would reveal a bizarre experiment in the evolution of flight in dinosaurs – a process that also gave rise to modern birds.

To understand why it was so unusual, we must look back to 1996, to the very first discovery of a feathered dinosaur.

IN THE EARLY 1990S, nobody could have predicted the incredible flurry of dinosaur discovery that was about to begin in China. With the rebuilding of academic institutions after the cultural revolution, and foreign-trained Chinese palaeontologists returning home to prospect, China's Cretaceous- and Jurassic-era rocks began to give up their riches. Something like 160 species of dinosaur have been described across China since 1990, and the rate of new discoveries may not have peaked.

It wasn't just a matter of numbers; the remarkable preservation of fossils from north-eastern China (particularly the provinces of Liaoning and Hebei) was unique too. One of the things recorded in exquisite detail was feathers – the defining characteristic of birds. Most experts had come to accept that birds were the descendants of so-called theropod carnivorous dinosaurs (such as *Velociraptor*) based on the similarity of their skeletons, bones filled with air pockets, wishbones and many other features besides.

But while the fossils of archaic birds such as *Archaeopteryx* (which flew with feathered wings but also had teeth and a long bony tail) had been found as early as 1861, few thought we would ever find actual dinosaur fossils with feathers. That's why palaeontologists were astounded when, in 1996, a fluffy 1.5-metre-long dinosaur called *Sinosauropteryx* was found in Liaoning, near the border with North Korea. The region preserves a Pompeii-like world of dinosaurs in fine-grained sediments, including volcanic ash. *Sinosauropteryx's* feathers were not flight-worthy, however. They were a short, downy fuzz visible on the head, back and tail of this vividly preserved animal.

Since that finding, we now know of about 50 species of dinosaur for which there is direct evidence of feathers. Some have halos of fluff or beautiful fans of flight feathers delicately traced into their remarkable fossils; others have a distinctive pygostyle tailbone that would have been an attachment point for feathers; still others have bumps along their forearms – "quill knobs", where feathers attach to ligaments in the wings of modern birds. Most of these species come from the Chinese provinces of Liaoning, Inner Mongolia and Hebei, but a handful are from the nations of Mongolia, Burma, Madagascar, Germany, Canada and Russia.

Together these fossils show that most theropod dinosaurs all over the world had feathers.

Mongolia, for example, likely used great fans of tail feathers for mating displays. Only much later in the evolutionary process did feathers begin to be used for flight, such as in the four-winged, pigeon-sized dinosaur, *Microraptor*, found in 2000.

Another four-winged flyer, the eagle-sized *Changyuraptor* was discovered in 2014, and there are likely others yet to be found. The wings on the hind limbs and forelimbs of these animals helped them glide between the trees of China's Jurassic and Cretaceous forests. It is unlikely they were capable of full powered-flight, as they lacked the keeled sternum to which large flight muscles are anchored in today's birds.

The four-winged model was one early experiment in flight within the group of animals from which birds evolved. Many early birds would have had large feathers on their hind limbs and feet too, as some chickens do today.

WE NOW KNOW OF ABOUT 50 SPECIES OF DINOSAUR FOR WHICH THERE IS DIRECT EVIDENCE OF FEATHERS.

05

Feathered find: the *Sinosauropteryx* fossil, discovered in Liaoning province, shows the dinosaur was covered in downy fuzz. A remarkable fossil sequence now shows the evolution of dinosaurs to birds.

While more than 90% of fossil sites worldwide preserve only bones, Liaoning in particular preserves feathers and soft tissues. These unlikely fossils have given us a tiny window into a world we had no idea existed. We now have a remarkable evolutionary sequence of fossils from dinosaurs to birds. It shows how feathers evolved from very simple filamentous structures through to complex, branched flight feathers, and also how flight itself might have developed.

Sinosauropteryx's downy fuzz was probably used for insulation. In later models of dinosaurs, feathers also began to be used for display. The massive *Gigantoraptor*, an 8-metre-long, parrot-beaked omnivore found in the Gobi Desert of Inner

Apart from these small dinosaurs, palaeontologists were also surprised to discover that much larger carnivores also had feathers. A number of feathered tyrannosaur species were found in China including *Dilong* in 2004, and the much larger *Yutyrannus* in 2012. This shaggy 9-metre-long creature was much nearer in size to *T. rex*, making it plausible that the tyrant king itself had feathers.

Then there's *Zhenyuanlong*, a 2-metre-long dromaeosaur related to *Velociraptor*, described as a "fluffy, feathered poodle from Hell". Found in 2015 in the 125-million-year-old deposits of the Yixian Formation in Liaoning, it has the largest feathered wings yet found on a dinosaur.

THEIR FEATHERS, KNOWN AS 'DINO FUZZ', ARE MORE LIKE THE DOWN ON A CHICK.

Weird dinosaurs indeed, yet none of them were as perplexing as the specimen that Xu first examined in detail in 2009. At first it was just an overall impression. But it would soon become clear this dinosaur was sporting features that surely didn't belong in the same animal.

MANY OF THE TREASURES that arrive at the Shandong museum have been dug up by farmers who supplement their meagre income by excavating dinosaur remains and selling them on to dealers and institutions. In theory, it has been illegal to buy fossils collected by such "amateurs" since 2008. But better that these priceless fossils are available for science, the palaeontologists argue, than lost to the living rooms of wealthy private collectors.

The majority of feathered dinosaur fossils have come from Liaoning, but some – such as the enigmatic specimen – are from the neighbouring province of Hebei. This is a relatively new locality for fossil hunters, dated to the mid-to-late Jurassic, 160–165 million years ago. "Fossils in northern Hebei are not as rich as Liaoning, but often they are well preserved; in some cases, feathers and soft tissues are even better preserved," says Xu.

The new specimen was found by farmer Wang Jianrong, who dug it from a fossil quarry near the village of Mutoudeng in Qinglong County. Here Hebei's small mountains, deep valleys and rolling foothills are pocked with pits dug by fossicking farmers. Wang may not have realised he had found something important, as by the time the specimen arrived at the Shandong museum it was broken into several pieces and parts were missing.

Xu first saw the strange new specimen in 2009, shortly after it arrived at the museum. It was broken and partially covered with rock. He could tell it was a feathered dinosaur but, running his hands over it, he decided there was definitely something strange about it. In 2013 he sent his technician, Ding Xiaoqing, to the Shandong museum and asked her to clean the overlying rock away.

SEVERAL MONTHS OF WORK later, Xu could see from the distinctive skull shape and the hand that it was a scansoriopterygid ("climbing wings") dinosaur. This feathered group includes the species *Epidexipteryx* and *Epidendrosaurus* (previously called *Scansoriopteryx*), which have forward-slanting teeth and weird fingers. Discovered in 2002 in Liaoning, *Epidendrosaurus* was thought to have been a sparrow-sized climber and tree-dweller, with an elongated third finger. Its purpose? Possibly to skewer insects hidden inside tree hollows, much as the aye-aye lemur of Madagascar does today.

The slightly larger, pigeon-sized *Epidexipteryx*, found in Inner Mongolia in 2008, was weirder still. Like Epidendrosaurus, it was covered in downy fuzz but had four long, ribbon-like feathers emerging from its tail. Its third finger and putative skewer may have been half as long again as its entire body.

As with other scansoriopterygids, the feathers of the new creature were simple, short and brush-like, and would have covered its whole body; scansoriopterygids lacked the large vaned feathers with complex structure that are found on modern birds and many theropod dinosaurs. Their feathers, known as "dino fuzz", are more like the down on a chick – made of fluffy filaments with no central vane or complex branching structure found in what we typically think of as a feather.

03

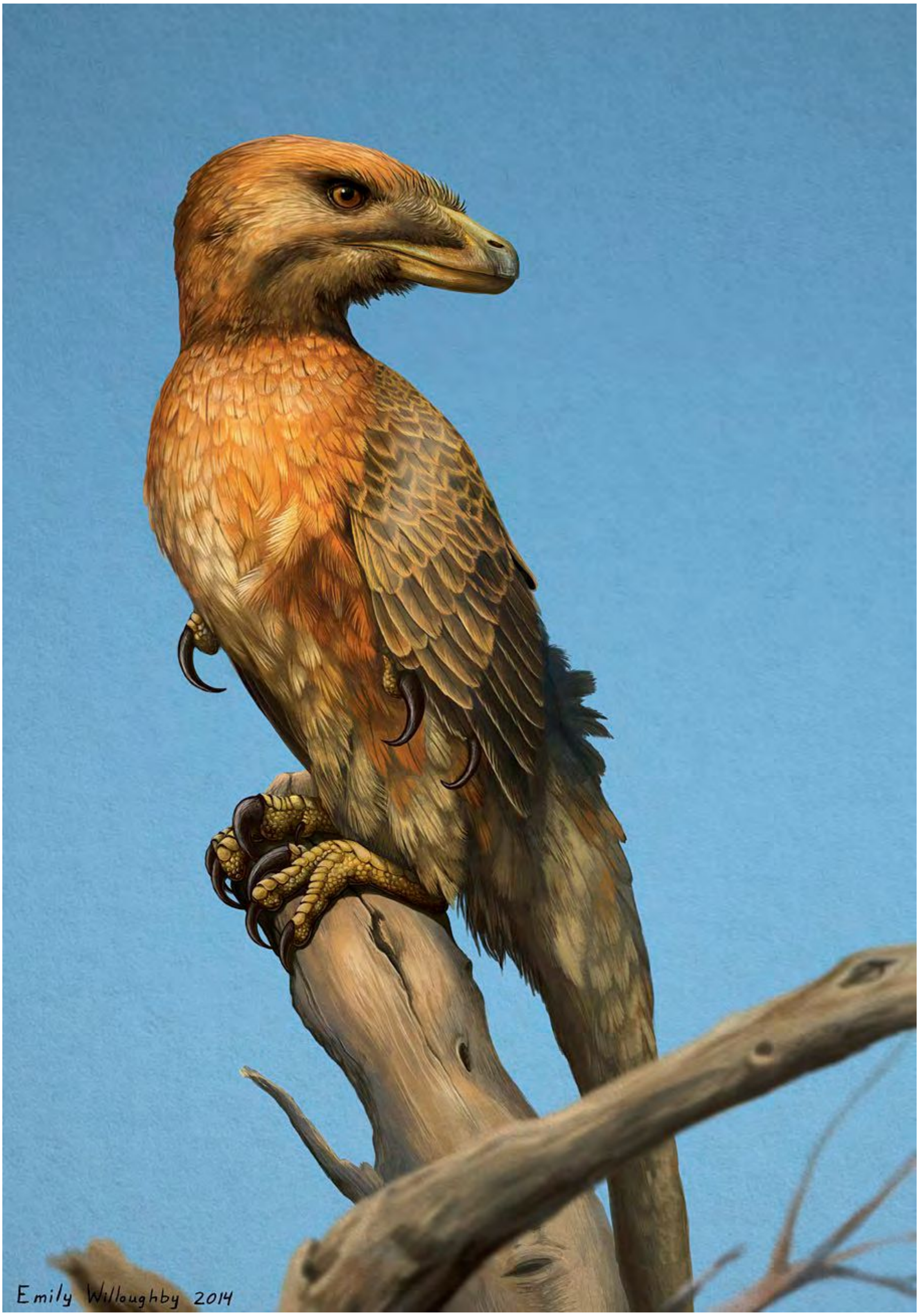
That was then: the theropod Deinonychus as once depicted in the *Encyclopaedia Britannica*.

More of these fuzzy feathers were preserved on another piece of the fossil, surrounding part of a hind limb and foot: an analysis with an electron microscope revealed the presence here of melanosomes – tiny packages of pigment responsible for feather colour in living birds.

Furthermore, as Ding slowly removed the matrix of rock encasing the fossil, the experts noticed two rod-like structures near the wrist that were like nothing they had ever seen before. "This confused us for quite a long time," Xu says. "It was apparently part of the skeletal system, but something you never see in other dinosaurs."

Xu's colleague Corwin Sullivan first saw the fossil in early 2014 when he, Xu and American palaeontologist Jingmai O'Connor were visiting the Shandong museum. "What really puzzled us

04



This is now: a modern interpretation of the theropod Deinonychus by palaeo artist Emily Willoughby, taking into account knowledge gained from recent fossil discoveries.

A CLOSER LOOK

FEATHERED DINOSAURS

Recent discoveries in China have revealed that dinosaurs, large and small, veggie and meat eaters, had feathers.

YI QI
'Strange wing'

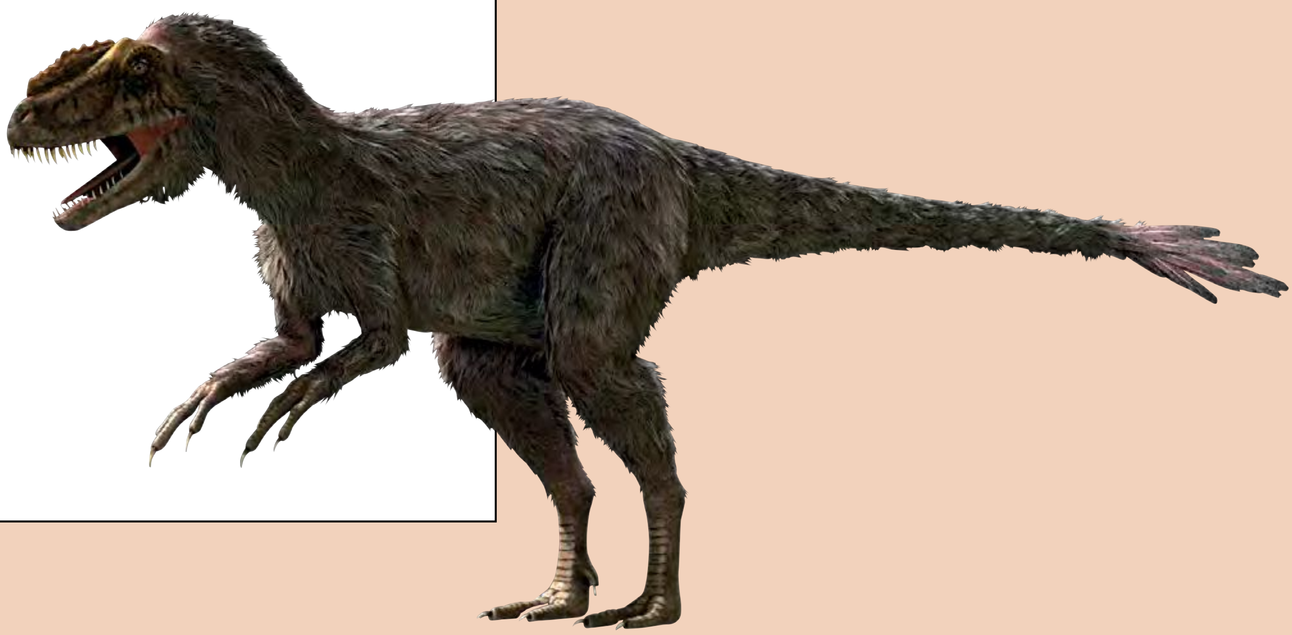
SIZE: 25 cm long
FEATURE: It reveals the bizarre experimentation in flight as feathered dinosaurs took to the sky.
TIME: Mid-late Jurassic – 165-160 million years ago

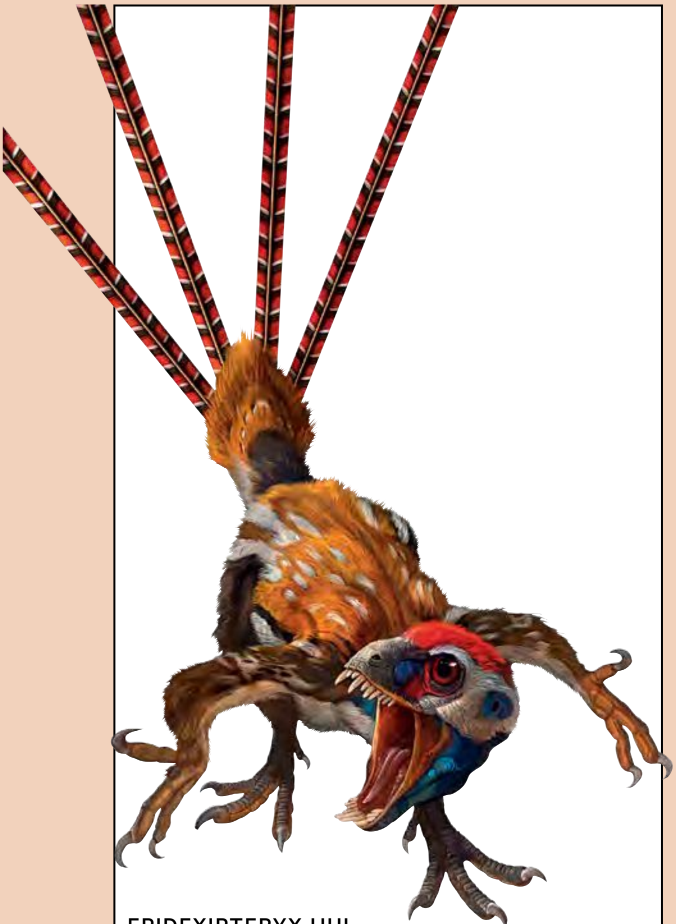
CREDIT: EMILY WILLOUGHBY

YUTYRANNUS HUALI
'Beautiful feathered tyrant'

SIZE: 9 m long
FEATURE: Yutyrannus showed that even large carnivorous dinosaurs had fluffy feathers.
TIME: Early Cretaceous – 145-100 million years ago

CREDIT: MATT DRUMMOND / HIVE STUDIOS





EPIDEXIPTERYX HUI
'displayed wing'

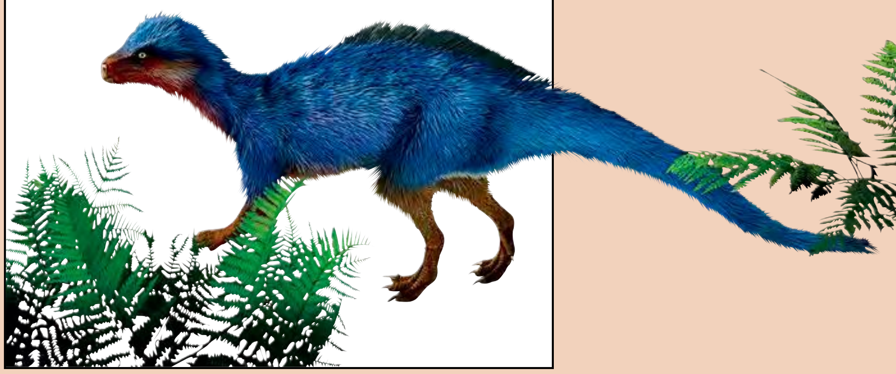
SIZE: 25 cm long
FEATURE: The pigeon-sized dinosaur had an extemely long third finger – now thought to be for attaching a membranous wing, as seen with *Yi qi*. Its tail sported four ribbon-like feathers.
TIME: Mid-to-late Jurassic – 170-150 million years ago

CREDIT: LIDA XING / ZHAO CHUANG

TIANYULONG CONFUCIUSI
Named in honour of Tianyu museum and the Chinese philosopher Confucius

SIZE: 70 cm long
FEATURE: One of the first-known feathered herbivorous dinosaurs.
TIME: Early Cretaceous – 145-100 million years ago

CREDIT: LIDA XING / YUJIANG HAN



XIAOTINGIA ZHENGI
Named in honour of Zheng Xiaoting founder of Tianyu museum

SIZE: 30 cm long
FEATURE: Four-winged flyer
TIME: Late Jurassic – 160-145 million years ago

CREDIT: LIDA XING / YUJIANG HAN

were these structures extending from both wrists that looked very much like bones on the slab, but of course theropods aren't supposed to have bones in this position," he recalls. "I remember standing around with Xu, Jingmai and Zheng trying to work out whether these were ligaments or some other kind of soft tissue, but we couldn't come up with anything that really made sense." (Later humorous suggestions included that they might have been used as giant chopsticks.)

CRUCIALLY, THE EXPERTS KNEW IT HAD NOT BEEN GLUED TOGETHER BY A HOAXER.

05

Skeleton clue: theropods weren't supposed to have wrist bones in these positions.

Sullivan happened to be working on a book with a section on gliding and flying animals; a photo of a flying squirrel grabbed his attention. It showed the animal's "styliform elements" – rods of cartilage that protrude from the wrists of some gliding mammals. These rods allow them to hold out their patagia, membranes of skin that extend from their wrists to their ankles, allowing them to fly.

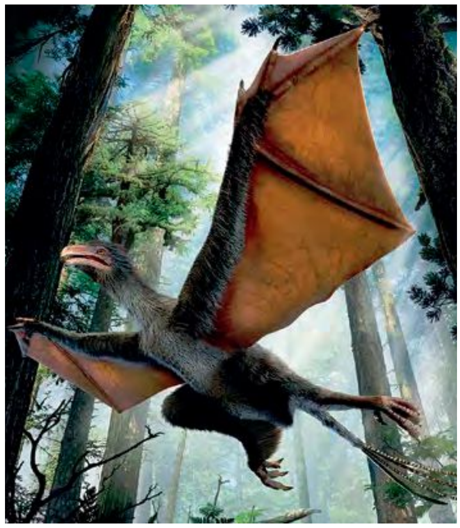
"When I read that thing about flying squirrels, the fossil just flashed into my mind," Sullivan says. "The idea was hugely exciting … but I reined myself in, thinking there were probably a dozen reasons this couldn't be the same structure." As he began to research it in more detail, however, he realised he was on to something.

Modern birds do in fact have a small skin flap in front of the elbow called a "propatagium", which forms part of the wing, but is covered by the much larger flight feathers. "You can imagine that if this propatagium was also present in theropod dinosaurs that are the ancestors of birds, then what's going on in the scansoriopterygids is that it has expanded to form a wing membrane," Xu says.

"Finally, we noticed there were patches of membrane preserved near the styliform elements… We suddenly realised this was a really bizarre dinosaur with kind of pterosaur- or bat-like wings. We all got so excited, and we just couldn't believe that this had happened… Wings in my mind always had beautiful, big flight feathers. These are the major components of dinosaur wings. Here we had something totally different."

Xu realised that what he had on his hands was the Jurassic equivalent of a platypus, the Australian oddity that stumped 18th century British naturalists, who at first considered the stuffed specimen they received a fake. This new dinosaur had a feathered body but wings made of skin flaps, resembling those of pterosaurs – distant cousins of dinosaurs that evolved independently.

06



Refreshingly weird: palaeontologists will be thinking about *Yi qi* for a long time to come, says Daniel Ksepka of Bruce Museum in Connecticut.

Working with colleagues including Sullivan, O'Connor, Zheng and Xing Lida, based at the China University of Geosciences, Xu began to amass the evidence needed to back up their extraordinary find. Just as for 18th century naturalists, fake specimens have been a big problem in China. In 1999, for instance National Geographic heralded the discovery of Archaeoraptor, a "missing link" between dinosaurs and birds; it turned out to be a skillfully glued-together composite of bird and dinosaur fossils. Xu's expert eye is rarely fooled, but he realised a bat-winged dinosaur was so improbable other palaeontologists might have doubts.

Before publishing in *Nature* in May 2015, the team did a variety of analyses to prove, for example, that the fossilised styliform element had a chemical composition suggesting it had originally been made of bone or cartilage. Crucially, the experts knew it had not been glued together by a hoaxer – Xu's own technician had prepared the fossil out of the rock at the Shandong Museum. "I am 100% sure this is not a faked fossil," Xu says. "Sometimes I am not so certain if a fossil is real, or I think something may be wrong with it, but in this case I am quite certain."

Furthermore, the researchers were able to pin down Wang, the original discoverer and visit the specific region within the quarry from which he'd extracted the specimen, to determine the geological layer and age. The team called the species *Yi qi* (pronounced "ee-chee") which means "strange wing" in Mandarin.

The announcement of the species was greeted with a mixture of bemusement and palpable excitement by a palaeontological community that had become somewhat desensitised to the feathered dinosaur riches pouring from China.

In an accompanying commentary, also published in *Nature*, palaeontologist Kevin Padian noted that in the two decades since Chinese finds had cemented notions about the dinosaurian origin of birds, "the picture of the evolution of feathers and flight has become richer and more complicated" with the discovery, "seemingly on a monthly basis", of other feathered dinosaurs: "But things have just gone from the strange to the bizarre."

Daniel Ksepka, from the Bruce Museum in Connecticut, similarly described the discovery as "refreshingly weird", adding that "palaeontologists will be thinking about *Yi qi* for a long time".

IT'S PROBABLE THAT GLIDING membranes were present in all the scansoriopterygid dinosaurs. This explains their puzzlingly long fingers: they were not skewers for picking insects out of trees but struts for membranous wings. "I tend to believe that *Epidexipteryx* and *Epidendrosaurus* both have wings like *Yi*," says Xu. "All the members of this group probably have styliform elements and membranes attached. You need fossils to support this, but if you ask me I believe it's possible."

It's not clear what kind of flight mechanism these "bat" dinosaurs employed, but they may have used a mixture of gliding and flapping. Xu's team attempted, without much luck, to make structural models based on the fossil, to test them aerodynamically. Now they are creating three-dimensional computer models instead. The experts also reappraised the handful of other scansoriopterygid fossils in light of what they know about *Yi*, but haven't yet found direct evidence of the styliform element or membranous wings.

"Given that the scansoriopterygids are so interesting and so bizarre, we want to do more work on this group," Xu says. He plans to search for fossils in several localities in Inner Mongolia and Hebei.

In 2016, Xu told me, his team carried out a study of the melanosomes on a few parts of the fossil. "I will say *Yi qi* probably had a green or brown colour. It's a guess, but the probability is high because the melanosome [structures] appear similar to modern birds with green or brown feathers." If proven correct, this is the first time that green has been detected in a feathered dinosaur fossil.

The really big question is why this group evolved a second method of dinosaur flight when many closely related theropod lineages had species with very large flight feathers.

"Why evolve a completely different flight mechanism and body plan?' asks Xu. "This is really bizarre and, so far, I don't have a good answer." He believes that whenever big evolutionary transitions take place – such as that from terrestrial dinosaurs to flying birds –strange experiments take place to fill the new niche.

Some of those experiments may well be recorded in the rocks of Hebei and Liaoning. "*Yi qi* was totally unexpected. We couldn't believe it. If you know dinosaurs very well and the transition well, then you'd never expect there would be a dinosaur with bat-like or pterosaur-like wings instead of feathered wings. Discoveries like this will continue to emerge and demonstrate how complex the transition to birds was', Xu says. "I would not be surprised if we find even more bizarre species in the future." ◉

JOHN PICKRELL is a science author, writer and editor of *Australian Geographic* magazine.

CREDIT
Edited excerpt from *Weird Dinosaurs: The Strange new fossils challenging everything we thought we knew* by John Pickrell, New South books.

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05 Nature
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PUTTING THE BITE ON MALARIA

In Papua New Guinea the war on malaria hangs in the balance. Danger lies in the final stretch, JO CHANDLER reports.

→

VANGUARD FIGHTER: Dr Leanne Robinson, head of vector-borne-disease research at the PNG Institute of Medical Research.

01

NIGHT LANDS WITH A THUD in the tropics, sounding another round of inevitable hostilities. In the fast-gathering gloom of equatorial malaria country, humanity's most dangerous adversary is on the move.

THE LOWLANDS of Papua New Guinea's north coast have been a flashpoint in the shattering contest of mosquito versus human throughout history. Here people don't so much die from malaria as endure it, morbidity outstripping mortality. Debilitating sickness reverberates through genetics, culture, prosperity and aspiration.

Only in the past few years have locals dared to hope it might not be ever thus, offering their blood and that of their children to the research scientists who come to this front line in their quest to find a vaccine to prevent infection, or better drugs to treat the casualties.

There is good reason for hope. Fighting malaria has been a global health success story. Since 2000, malaria incidence has fallen by 37% in populations at risk. Fatalities have dived by 60%. This means more than 6 million lives have been saved – most of them African children.

In PNG, control measures – in particular the rollout of long-lasting, insecticide-treated bed nets – have resulted in the prevalence of malaria declining by more than 80% across the country since 2009. Cases reported at four sentinel sites have dropped from 205 to 48 per 1,000, surpassing all expectations.

Encouraged by this success, PNG – in common with many other countries – has ramped up its ambitions from controlling malaria to eliminating it. It's an exciting time, but one tempered by the risks of overconfidence and complacency. Because we've been here before.

A global eradication campaign beginning in the 1950s, mainly using insecticides, had malaria eliminated in some locations and on the run in many more by the 1970s. But then the disease bounced back. Now, as the world again pursues what it hopes will be the defining end-game against the disease, the lessons of the past weigh heavily.

The greatest lesson of all is that the fight against malaria cannot be won by a shock and awe campaign but through a comprehensive hearts-and-minds campaign, aligned with dogged jungle warfare.

At the vanguard of the battle are the field teams of the Papua New Guinea Institute of Medical Research (PNGIMR). They trawl the lowlands of Madang and Sepik provinces for the morsels of intelligence required to further advance the assault on malaria, working alongside locals, enlisting vials, swabs, needles, slides and the stories and observations of communities. The teams are defining a textbook model of the grassroots research required in the long march to eradication.

"No corner of our understanding of malaria today is untouched by research findings from Papua New Guinea," said John Reeder, a former director of PNGIMR who now leads the Word Health Organisation's special program for research and training on tropical diseases, at the time of the institute's 40th anniversary last year: "While some other parts of the world were subjected to 'commando research', the PNGIMR program was built on the solid foundation of community participation."

LEANNE ROBINSON'S regular morning begins on the fractured roads of downtown Madang, a sweltering gridlock of battered buses and trucks piled with people and cargo. The port town was once said to be the prettiest in the Pacific, and there are still glimpses of that place. War, neglect, industry and exploding population have dulled its charms, but not its potential as a strategic hub for desperately needed trade, research and investment.

Driving from Madang to the laboratories of the PNGIMR about 10 km south takes Robinson into a more postcard tropical idyll, though tangled lush forest and past palm-thatched hamlets. She has driven this route most working days for the past eight years. Navigating around chickens, children, potholes and the odd creek crossing, she deftly works the gears of her 4WD. Locals wave her along. Many know her by sight; those who don't, know where she's from. One way or another they are all touched by the programs she oversees. Robinson has been head of the institute's Vector Borne Disease Unit since 2013. Infections carried by mosquitoes are her business, and this stretch of country is mozzie paradise.

Malaria is particularly and powerfully entrenched in the communities here on PNG's north coast and through the surrounding lowlands, where it has afflicted and shaped generations throughout history, a story written into their DNA.

This represents the highest malarial burden in the Western Pacific region, and among the highest burdens outside Africa. But the fixes applied in Africa won't always work in PNG, which hosts a different suite of mosquito species and parasites.

Not all mosquitoes transmit malaria. The culprits are certain species of the genus *Anopheles*, the unwitting air transport service enlisted by a diabolical biological passenger, *Plasmodium*. The parasite slips into the bloodstream when a pregnant female mosquito takes her meal.

There are four main types of human malaria. By far the most notorious and deadliest is *Plasmodium falciparum*, the biggest killer globally and the main

02

There will be blood: the feeding habits of pregnant female *Anopheles* mosquitos are responsible for millions of malaria case each year.

'NO CORNER OF OUR UNDER-STANDING OF MALARIA IS UNTOUCHED BY RESEARCH FINDINGS FROM PAPUA NEW GUINEA.'

Despite the gains of the past 15 years, malaria continues to take a heavy toll throughout PNG. Nearly 95% of the population lives in areas where malaria is a high risk, with more than 1 million presumed and confirmed cases in 2013 (the most recent year for which figures are available from the Asia Pacific Malaria Elimination Network). Countless more go undiagnosed and untreated.

strain in sub-Saharan Africa. By contrast, PNG has the world's highest prevalence of *P. vivax*, which is difficult to control because it lingers in the body and relapses. PNG is also host to low undercurrents of *P.ovale* (also relapsing) and *P. malariae*.

Beating malaria in PNG therefore requires a bespoke campaign of tools and tactics. Identifying, trialing and tracking effective countermeasures has been the preoccupation of scientists and researchers at the PNGIMR throughout its 40-year history.

The institute's work, which is funded by the PNG and Australian governments as well as grants from a wide collection of international NGOs and institutions, helps inform a national strategy that has made encouraging progress across the country. Intensive control efforts have slashed the number of annual deaths from about 20,000 in 2000 to about 300 today.

Rates of sickness, however, remain high, and it's common for the same person to be infected multiple times. They suffer terrible headache, nausea, shaking chills, raging fever, fatigue, body ache. The toll on children's health and education, and on households when parents get sick, is shattering. The debilitating disease is a major health and economic burden on the country.

THE TOLL ON CHILDREN'S HEALTH AND EDUCATION, AND ON FAMILIES WHEN PARENTS GET SICK, IS SHATTERING.

heat but functional, jammed to the sagging rafters with equipment, personnel and archives, the facilities are stoic testimony to the resolve of the researchers who have worked here since the lab was built in 1977.

Over those years they have had some remarkable achievements. They include conducting, in 1985, one of the first field trials of insecticide-treated mosquito nets, now a critical tool in the global antimalarial arsenal. At one point they even came tantalisingly close to realising the dream of a vaccine, progressing to field trials of a therapy that ultimately proved unsuccessful. An effective vaccine for the dominant strain of malaria in this part of the world (*P. vivax*) has so far eluded everyone. The most promising vaccine to date, RTS,S, now undergoing testing in pilots in Africa, targets *P. falciparum*, so it doesn't work against the

03

Leanne Robinson and members of the PNGIMR team in Houdini village near Madang. The program's success is built on a solid foundation of community participation, says former director John Reeder.

Maddening questions remain about the local malarial parasites' persistence and idiosyncrasies. What is it about the particular strains here that makes it more likely for children to get sick than die? How can the cycle of infection and re-infection be broken? These and other enigmas are the questions preoccupying Robinson and her team.

ROBINSON PULLS UP in the shade near a constellation of weary shacks that house the PNGIMR laboratories. Mouldering in the tropical

parasite most widespread in the Asia Pacific.

Robinson and her colleagues continue in the tradition of a long line of scientists who have come to this coast determined to make some contribution to beating the disease. It was the scourge of the German colonialists. In 1899, they imported their celebrated countryman Robert Koch, the scientist who unveiled the tuberculosis bacterium some years earlier, to try to find some solution to malaria. Despite two years' work, it defeated him.

In 1977, another storied scientist arrived in

Madang. Australian researcher Michael Alpers had already spent years working in remote areas of the country, playing a central part in cracking the baffling case of killer "kuru" disease (*Cosmos* #68, April/May 2016), helping discover prions and a whole new ball game of infectious disease.

Taking up his position as director of the fledgling PNGIMR, Alpers was convinced the time was ripe for a concerted effort to develop a vaccine against malaria. He set to work immediately to make Madang the permanent field headquarters of the research mission, recruiting specialists, scrounging funds, and negotiating to set up shop in a cluster of disused buildings at a bush hospital in the nearby village of Yagaum.

Alpers' researchers also went on the hunt for other strategies and interventions that might curtail – even quash – spread of the disease. By then experience had taught them about the resilience of their foe. Almost a decade had passed since massive insecticide spraying campaigns using DDT – the weapon of choice in the first war on malaria, the Global Malaria Eradication Program (GMEP, 1955-1969) – had rolled out across PNG and the rest of the world.

Despite being successful in many locations internationally, for a complex mess of reasons the program was abandoned: it couldn't work as a lone strategy in less developed nations; funding fell short; complacency about other control measures grew; mosquitos developed resistance; environmental safety concerns brewed.

Malaria bounced back with a vengeance in many countries – including PNG, where an elimination campaign had reached about 70% of the population by the early 1970s.

The moral of the story? There can be no weakening of the effort against malaria. As the World Health Organisation's director general, Margaret Chan, warned in 2015 at the launch of a joint WHO-UNICEF report on the success of antimalarial programs since 2000: "With a disease like malaria you can never tread water. You either surge ahead or you sink."

That year Papua New Guinea signed on to efforts to eliminate malaria from the Asia Pacific by 2030. "It is a big shift in the mindset of a country, and the decision makers, that elimination is even on the agenda," Robinson says. But the welcome ambition is not without its own hazards: "The risk of committing to such an ambitious goal is the potential that attention is diverted away from the need to maintain control, and that is the worst thing that could possibly happen, because it will backslide and we will be back to square one."

Complicating the campaign, and adding to its urgency, is concern around increasing resistance to artemisinin, a powerfully effective component of many treatment drugs. It has already been confirmed in five countries in South East Asia, and there is a real risk that strains of disease resistant to most available antimalarial medicines will soon emerge elsewhere in the region.

The challenge for Robinson and her colleagues now is to generate more insights and tools to stay one step ahead of the wily, masterful survivor, *Plasmodium*, which has so successfully exploited humans and mosquitoes to its advantage throughout history.

"KNOW THE ENEMY, *and know yourself*" – this oft-quoted rule of war reflects the core of the research efforts in the PNGIMR laboratories and its far-flung field sites.

The strain of malaria which looms most dangerously in PNG, *P. vivax*, has too often been overlooked and underestimated in malaria research efforts because it's less deadly than *P. falciparum*. But debilitating sickness has a shattering and enduring impact on individuals and communities when its victims can't work or go to school or care for their families.

The powerful trick of *vivax* and the other local player, *ovale*, is their ability to lurk, dormant, in the liver of human hosts. Over the ages these parasites have ensconced themselves as liver-stage hypnozoites deep in the collective body of the populations of north coast PNG, carried about and nurtured by often healthy, unwitting men, women and children. The enemy is within.

Sometimes the hypnozoites rouse to inflict relapsing illness on their carriers. This is the malaria tale familiar to so many travellers and soldiers who have returned from the tropics to find themselves mysteriously floored by bouts of illness for years afterwards.

Often the hypnozoites lurk entirely under the radar. Individuals hosting them rarely if ever experience any of the classic symptoms of malaria. The hypnozoite does not show itself on any presently available diagnostic blood test. Even when awakened the infection in the blood can sometimes also lie low, produce few if any symptoms and be difficult to detect by standard methods.

But, explains Robinson, "if you screen people with something more sensitive, you often find they come up positive, and potentially have the parasite stage that is transmissible back to the mosquito".

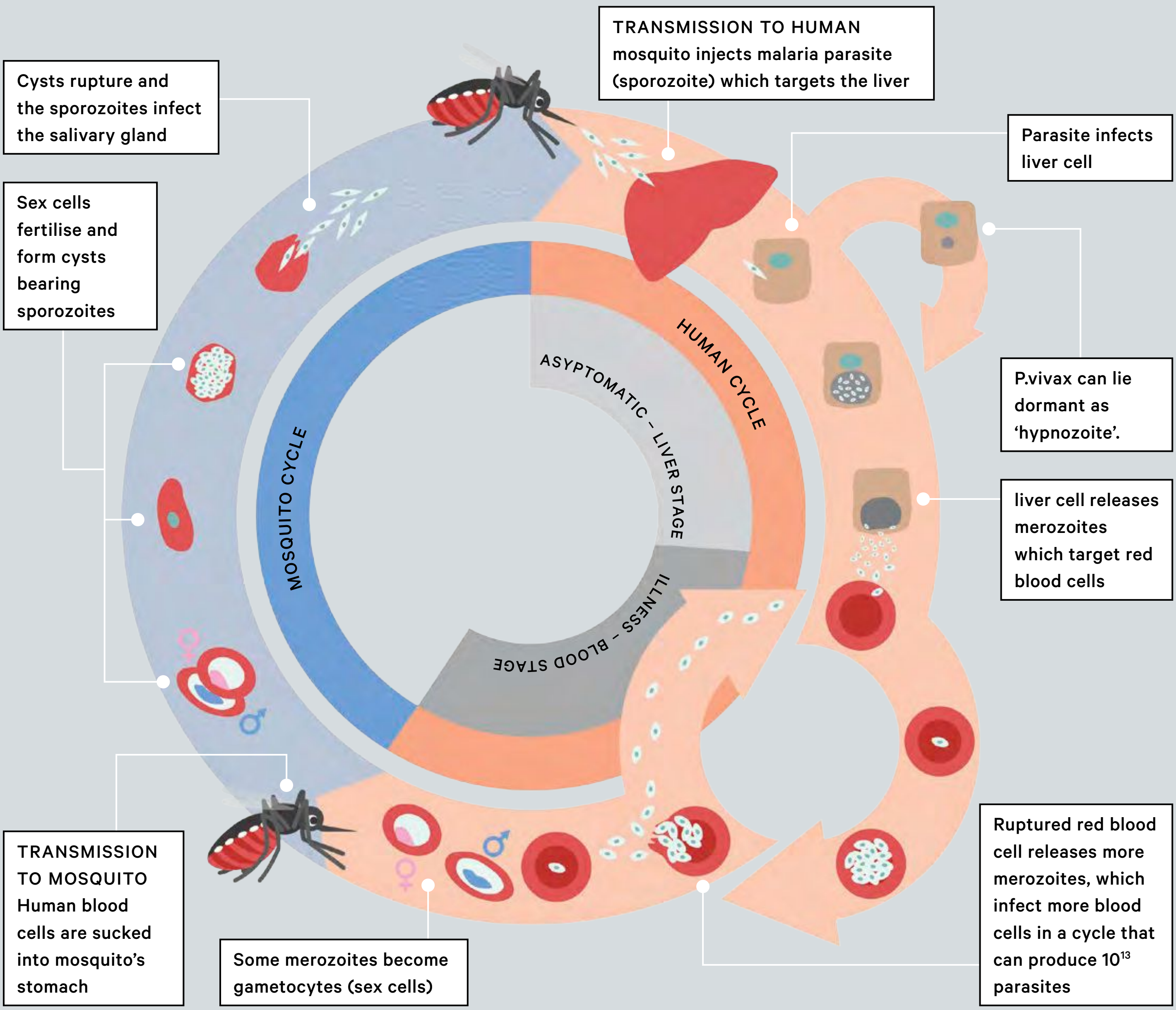
A CLOSER LOOK

THE MALARIA LIFECYCLE

Once inside a human host, the *Plasmodium* parasite rides the blood stream into the liver, then pushes its way into a liver cell. It digs in and multiplies, copying its DNA over and over. A single infected liver cell can host thousands of newly hatched parasites modified to target red blood cells.

After the parasite enters a blood cell, it continues to multiply while hiding out from the body's immune system. Eventually the infected cell bursts, and more parasites are unleashed into the blood stream.

It's about now that the human host might begin to feel sick. Without treatment, depending on the strain of the parasite, and the host's health, age and level of acquired immunity, she or he may suffer anything from mild fever to overwhelming sickness to blood loss, convulsions, brain damage, coma and death. Pregnant women and children under age five are the most vulnerable.



If an uninfected mosquito feeds on a *Plasmodium*-infected human, the parasite might seize the opportunity to climb aboard the mosquito. When the now-infected mosquito next takes a meal of human blood, injecting saliva down into its meal to stop it clotting, the parasite slides in as well.

The system makes for a kind of parasitic magic pudding. The blood running in the veins of human populations in endemic malaria country serves as a replenishing reservoir for the parasite. "Tackling this," Robinson says, "is a major challenge."

Robinson was lead investigator of a landmark 2015 study that revealed four out of five cases of *P. vivax* malaria infections, and at least three out of every five *P. ovale* cases in PNG children, come from relapses rather than fresh bites. The study provided a critical insight into the dynamics of the disease, and what it would take to get on top of it. Interrupting the transmission cycle, the researchers concluded, requires mass treatment campaigns combining blood and liver stage treatments. Whatever measures might be taken to eliminate or control the parasite's spread in the outside world – bed nets, insecticide spraying – would be undermined so long as the parasite could revive itself from the liver stage.

The capacity to roll out treatments that can knock the parasite out of the liver is hampered by limitations around available drugs. Right now the only drug licensed to clear the hypnozoite liver stage is primaquine. But for individuals who lack a gene that is important for normal red blood cell function, primaquine can be toxic, so all patients need to be carefully screened and monitored

Finding ways to overcome these obstacles is just one of a broad sweep of investigations underway in the PNGIMR laboratories, drawing on work across a range of communities and field sites, many of them enlisting cohorts of hundreds, sometimes thousands, of local people.

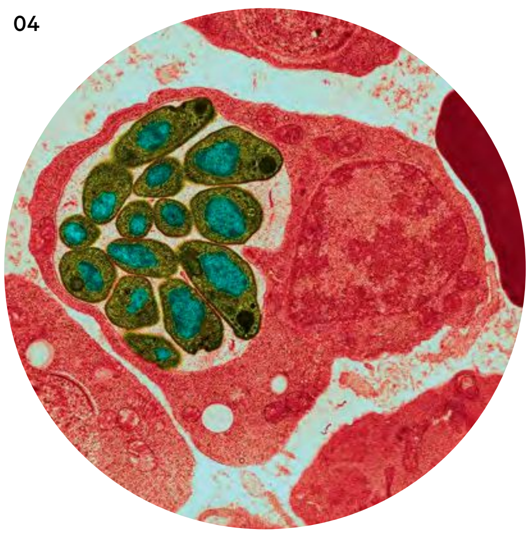
"For me, understanding malaria, and ways that we might possibly intervene against malaria, is all about the people," Robinson says. "Working closely with communities to identify who is infected, who is most at risk and how that is changing. Understanding the dynamic interplay between host, parasite and vector, so that we know what interventions will be effective and have a sustained impact."

ONE OF THE COMMUNITIES where Robinson, her institute colleagues and their international partners have been engaged for the past decade, collecting intelligence and blood samples and rolling out trials, is the old mission settlement of Mugil, about an hour's rough driving north from Madang up the coast of the Bismarck Sea. She parks her 4WD under the trees at the busy health centre, where about two dozen people – many heavily pregnant women, or women with young babies – wait their turn to see a nurse. Robinson chats easily, mother to mother, in a mix of English and *Tok Pisin*.

It's something of a treat these days for Robinson to get out of the office but she plainly revels in field work, connecting easily and warmly with locals. Seduced into global health during a stint volunteering in Ghana, she first came to PNG a decade ago as a 27-year-old, doing fieldwork for her PhD in malaria immunology at Melbourne's Walter and Eliza Hall Institute (WEHI). She lived for months at a stretch in one of PNGIMR's field outposts at Maprik, in East Sepik Province (north-west of Madang), famous for its wild rivers, crocodiles, carvings, culture, and off-the-chart malaria rates.

A LANDMARK 2015 STUDY REVEALED FOUR IN FIVE CASES IN PNG CHILDREN COME FROM RELAPSES RATHER THAN FRESH BITES.

04



Under the microscope: malaria parasites multiplying inside a red blood cell.

Her interest was in studying the natural immune responses in children living in endemic malarial zones, and her research drew on samples and data collected by PNGIMR teams.

Having fallen a bit in love with PNG, she leapt at the opportunity in 2009 to work at the institute full-time – initially on secondment from WEHI, and these days working in affiliation with the Burnet Institute, also based in Melbourne. When she and her husband made the move to Madang, they planned to stay for two years, but they stayed for eight years and two babies of their own.

Though the Mugil facilities are tired, they are better resourced and staffed than many others in PNG. In a tiny room tucked under a wide veranda, Sr Mary Salib examines a miserable-looking seven-year-old boy brought to the clinic by his mother because he has "*skin i hat*"– fever. Although based at the health centre and pitching in on general duties, Salib is also on PNGIMR's payroll, attending to any patients suspected of having malaria.

She pricks the boy's finger and squeezes a drop of blood onto a white dipstick. A few minutes later a rapid diagnostic test, which has revolutionised malaria treatment in recent years, comes up positive for *P. vivax* malaria.

colleagues can begin to untangle questions around children's immunity as well as the activity of the various parasite species in PNG – which ones are active in which locations and what sicknesses in addition to malaria are they causing.

Nationwide, there has been a progressive decline in the prevalence of both *P. falciparum* and *P. vivax*, Robinson says, but the story varies between different parts of the country, and is dynamic. Inland, transmission has declined and stayed low, with bed nets having made a big impact on reducing cases. But in coastal areas and lowlands – like the Madang province – the suspicion is that rates have popped back up a little bit.

'WE NEED TO CONSIDER THAT IN THE NEXT 10 YEARS THE VULNERABLE AGE GROUP MIGHT SHIFT UPWARDS."–

05

In the field: Sr Mary Salib attends to patients suspected of having malaria at a health centre in Mugil. Close co-operation with field outposts is crucial to the PNGIMR's work in monitoring the disease.

Salib explains to the boy's mother he will be given artemether-lumefantrine tablets and primaquine (PNG's first-line standard treatment for uncomplicated malaria) and should begin to feel much better within a week or so. Sickness, though, might linger for a month, its severity compounded by common factors like sepsis, bacterial meningitis and, most significantly, malnutrition.

Salib also works through a consent protocol with the boy's mother to enrol him in one of the ongoing studies being conducted at Mugil that range from routine surveillance to long-haul tracking of hundreds of children.

With this information, Robinson and her

Whether this is indeed happening and, if so, whether these are new infections or coming out of the hypnozoite "reservoir", is soon to be the subject of a major investigation by Robinson and colleague Moses Laman, who has a central role in a suite of international studies now underway.

Laman, a paediatrician turned researcher, is himself a survivor of severe malaria he contracted as a child growing up on the Sepik River. His research tries to unpick some of the intriguing genetic factors at play in malaria scenarios in PNG. There is a lot of evidence in the literature that mortality in Melanesian children with severe malaria is lower. Laman's work investigates why, when they get the disease, they don't die like African children.

One of the key projects at the Mugil centre investigates the potential "kick in the tail" of successfully preventing malaria in children aged under five – historically the cohort most likely to die. The current hypothesis is that as exposure to the malaria parasites becomes less frequent, children won't develop strong protective immune responses when they are very young. Which means they may become sick as older children or adolescents.

"So we need to consider that in the next 10 years the vulnerable age group might shift upwards," Robinson says, "and what impact this will have in terms of transmission and control."

TO DEFEAT MALARIA requires capturing not just human data, but the enemy. To that end, the PNGIMR deploys some creative and sometimes crude, albeit effective, strategies.

An example is the "human landing catch". Valiant teams of researchers are sent into villages at dusk. They bare their ankles, tantalising the mosquitos. When the insects land, the trick is to suck them up in lengths of plastic and imprison them in vials before they take their meal.

Another technique is to hoist plastic barriers up on stilts to catch passing mosquito traffic. This provides the institute's entomology laboratory with specimens that have already sated their thirst for blood. That blood meal is analysed, yielding insight into which creatures, human or pig or otherwise, are preferred by different species.

The surveyors also compose data sheets of mosquito behavior. There is evidence that some species are evolving countermeasures to bed nets. Denied access to warm, sleeping bodies, they change strategy. Late-night biters strike earlier; indoor biters feed outdoors. This gift for adaptation – the secret of the *Anopheles* mosquito's superlative evolutionary performance – will have profound implications for control measures into the future.

Overseeing this cornucopia of programs makes for a richly rewarding scientific life, Robinson says. While some research is long haul, other programs can have immediate translation and impact on the ground. For instance, earlier IMR work investigating and demonstrating the efficacy of new antimalarial drugs underwrote the shift to artemether-lumefantrine as an effective first-line treatment. And trials of new prevention regimes in pregnancy and infancy substantially improved the health of mothers and babies involved, reinforcing policy on intermittent preventative treatment for malaria during pregnancy – that is, giving pregnant women a full course of antimalarial medicine at routine antenatal checkups, whether the woman has malaria or not.

Currently the institute is running a world-first trial of a novel drug regime for the control and elimination of another disease spread by mosquitoes, lymphatic filariasis. Commonly known as elephantiasis, this neglected tropical disease impairs the lymphatic system and leads to gross swelling, disability and stigma. This trial is set to change WHO policy and accelerate elimination of the disease worldwide.

Robinson is passionate about nurturing home-grown talent. "One of the most rewarding parts of being here this length of time is being able to see people go from being clinicians or science graduates straight out of university coming into research for the first time, learning how research is done, to getting a PhD, coming back as experienced and independent researchers," she enthuses.

"We are seeing the development of a cohort of Papua New Guineans in leadership positions in this institute, addressing the questions that are really important for PNG; and that is an incredibly satisfying difference to when I arrived in 2009."

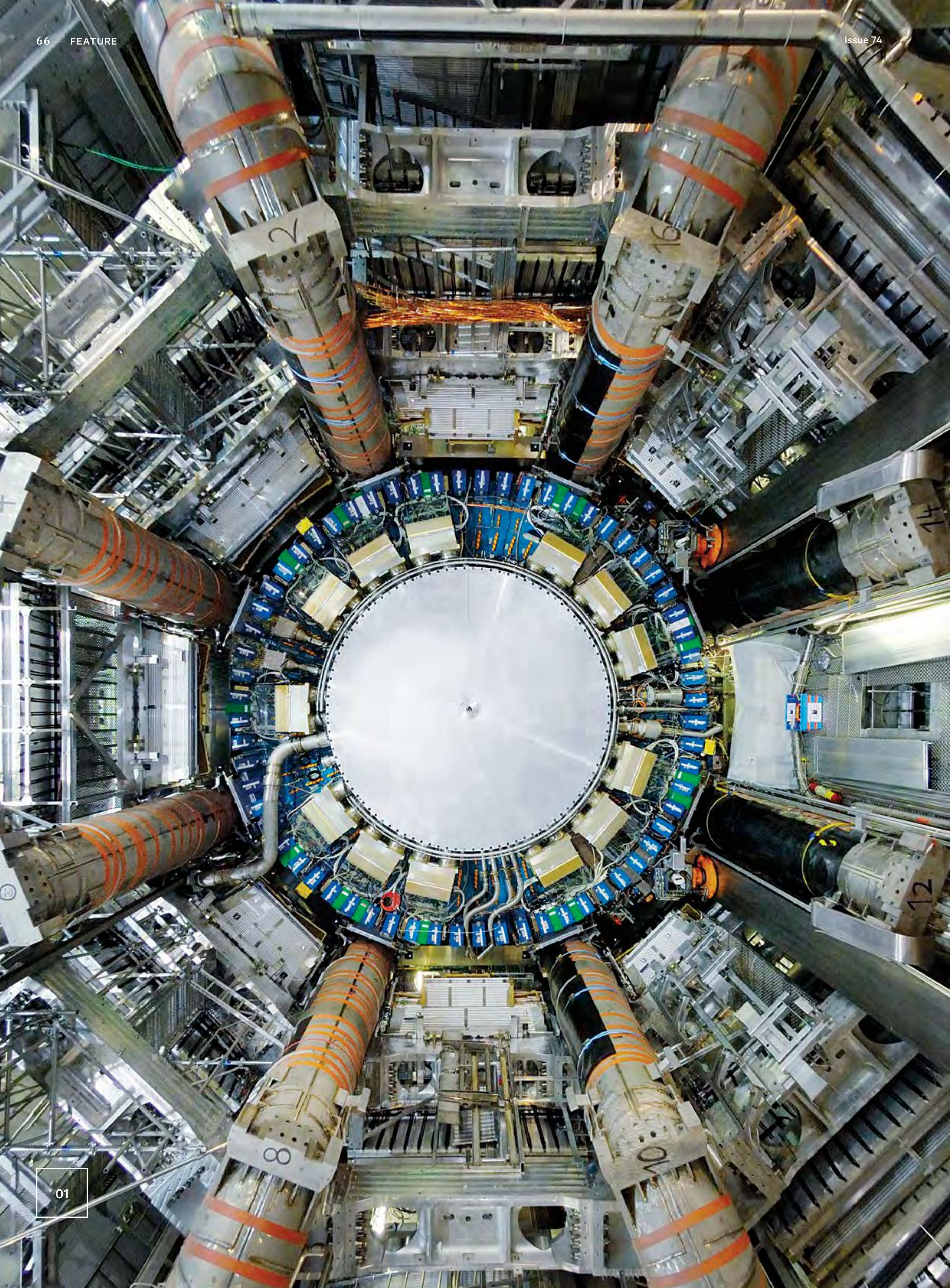
What PNG and its people have taught Robinson, she says, is immeasurable.

"When I came up here I was very focused on the research questions I was wanting to ask, the projects I was working on, and probably had a narrow and fairly naïve view of how that work fitted into the overall context of malaria in PNG, and even globally," she says.

She has also learnt how to communicate science and negotiate informed consent with teams operating in 70 languages and vastly differing cultural systems, to locate individuals in far-flung jungle villages, to reconcile the ritual demands of modern medicine and ancient superstitions and not run afoul of complex local politics. And, not least, how to pilot that 4WD across rivers, mountains, and broken roads.

JO CHANDLER is an award-winning freelance journalist and author.

IMAGES
01 Mayeta Clark
02 Hugh Sturrock / Wellcome Images
03 Mayeta Clark
04 Omikron / Getty Images
05 Mayeta Clark



01

THE NEXT WONDER OF THE WORLD

Even bigger colliders will be need to unravel the mysteries of particle physics. CATHAL O'CONNELL looks at what's on the drawing board.

THE LARGE HADRON COLLIDER is a wonder of the modern world, our version of the great pyramid at Giza, but built by 10,000 scientists and engineers.

It's a giant ring of superconducting magnets, 27 kilometres around, running 100 metres beneath the surface of France and Switzerland. Physicists use it to rev protons up to 99.999999% the speed of light before smashing them together to reveal the building blocks of the universe.

Simply building the LHC was a monumental achievement – it has the largest refrigeration system on the planet and its magnets are coiled with enough superconducting wire to stretch to the Sun and back five times.

And it works. In 2012, physicists used it to discover the Higgs boson, the last unverified part of the standard model of particle physics, with a special place in the family of fundamental particles because it gives the others their mass. Its identification has been hailed as one of the great scientific breakthroughs in human history.

But the biggest machine ever built is not big enough. The LHC's operator, the Geneva-based European Organisation for Nuclear Research (CERN), still sees a long working life ahead of the collider, with about another 15 years of groundbreaking research to come. Yet physicists know that some of the biggest challenges in particle physics lie just outside its reach.

There are two "big questions" the LHC's successor will try to answer, says Geoff Taylor, a particle physicist at the University of Melbourne who leads Australia's research contribution to the LHC: "What are the details of the Higgs? And what is the dark matter particle – or particles?"

Finding the Higgs boson was, in the words of distinguished British physicist Peter Knight, "the physics version of the discovery of DNA"; and, like the discovery DNA or any other great breakthroughs in science, it provoked more questions than it provided answers.

At just 130 times the mass of the proton, the Higgs was a lot lighter than many physicists expected. Why? We've so far only found one Higgs particle, yet some theories predict at least four others – do they exist? Does the Higgs mechanism, which gives mass to most subatomic particles, work just as the standard model says it should? What exactly can the Higgs decay into? The LHC can't answer these questions because it can't produce Higgs bosons in great enough numbers or in conditions clean enough to observe clearly.

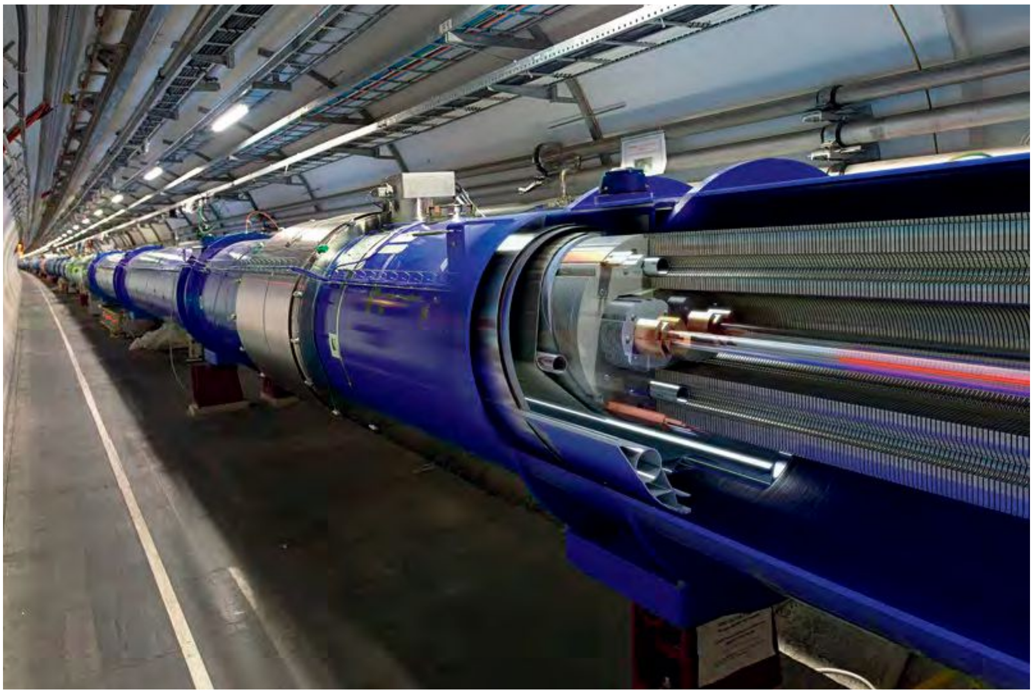
In order to do that, we need a new collider, a so-called "Higgs factory" calibrated to produce the boson en masse.

Alas, despite some titillating signals, no more new particles have yet been found. To uncover these particles, if they exist, will need much more energetic collisions than the LHC can ever muster.

Already, the wheels are in motion to set up the LHC's successors. Three gargantuan projects are on the cards: one in Japan, one in China and one in Europe. Each would, in turn, become the largest experiment ever devised.

PROTON COLLIDERS LIKE THE LHC ARE THE SLEDGE-HAMMERS OF PARTICLE PHYSICS – USED TO BREAK NEW GROUND.

02



Proton colliders are the sledgehammers of particle physics; electron colliders are more precise.

The new field of Higgs physics could tie up many of the loose ends in the standard model of particle physics, but the ultimate prize would be to go beyond the standard model itself, and thereby solve one of the great mysteries in all physics.

From the seemingly off-kilter dance of galaxies, we know the universe is made of more than what meets the eye – that about 80% of the material in the universe. is "dark matter".

Many physicists think dark matter must be made of a new kind of particle, or perhaps whole families of new particles. It was hoped the LHC might produce them in collisions – perhaps in the form of so-called "superpartners" of the common electrons and quarks we're made of.

As British theoretical physicist Peter Higgs has said, the boson that bears his name is "not the most interesting thing that the LHC is looking for".

INTERNATIONAL LINEAR COLLIDER, JAPAN —

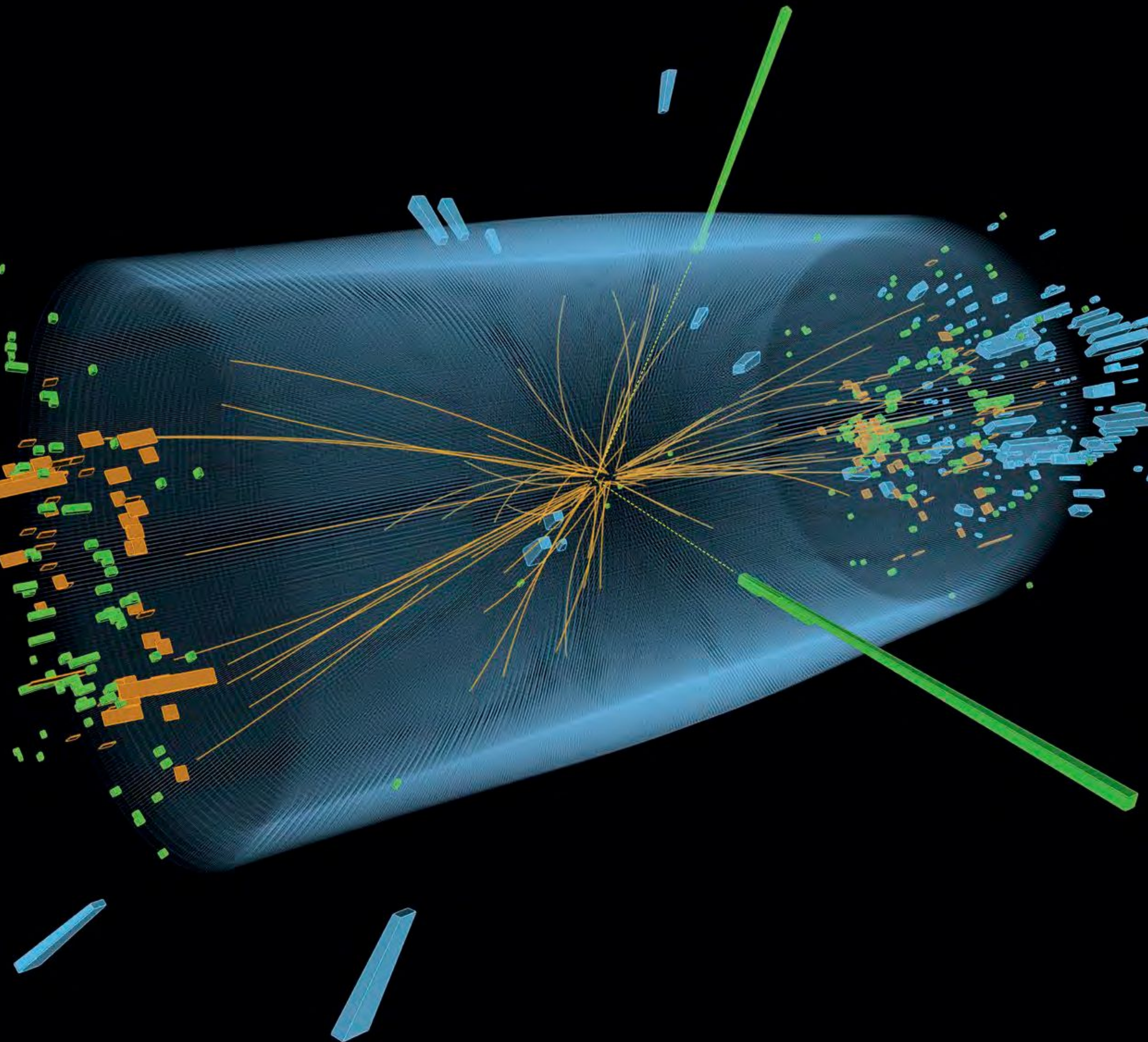
The first, or at least easiest, cab off the rank is the International Linear Collider (ILC) destined for Japan, says Taylor.

Imagine a gun barrel 15.5 kilometres long. Imagine a second barrel, pointing down that of the first. Now imagine firing two bullets at each other at almost the speed of light and photographing the collision. That's the ILC in a nutshell.

The ILC is an electron-positron collider, so each "bullet" is actually a bunch of 20 billion electrons or positrons.

On the face of it, the ILC's collision energy of 500 gigaelectronvolts seems puny compared to the LHCs 13 teraelectronvolts. But it's a totally different animal.

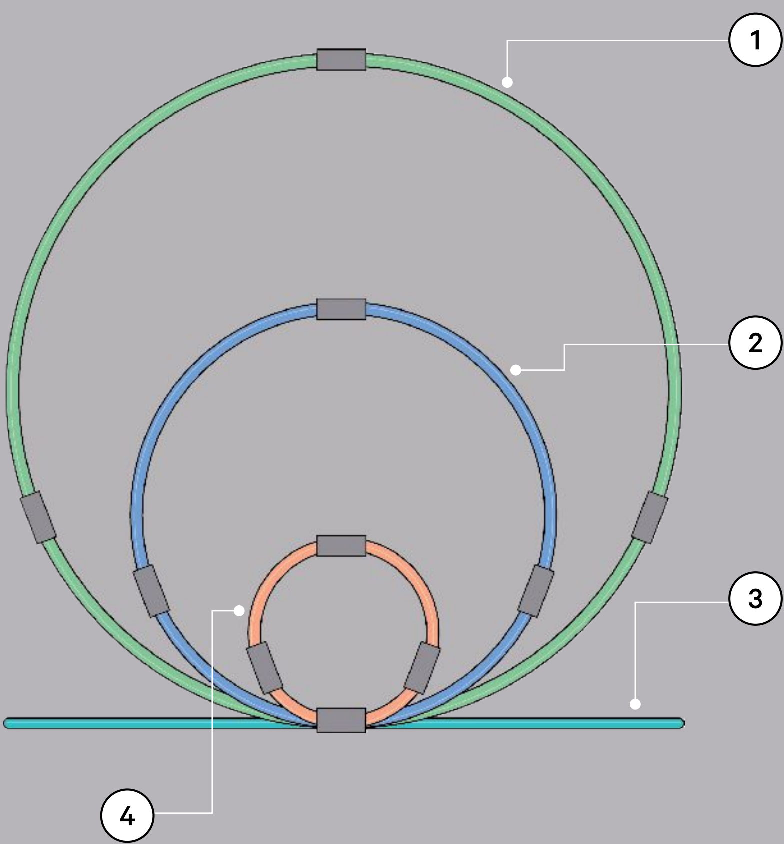
Proton colliders like the LHC are the sledgehammers of particle physics – used to



03
The LHC was instrumental in establishing Higgs physics but can't produce enough bosons.

A CLOSER LOOK

FUTURE COLLIDERS



1 FUTURE CIRCULAR COLLIDER (FCC) CERN, Switzerland
Circumference: 90-70 km

2 CIRCULAR ELECTRON POSITRON COLLIDER (CEPC), China
Circumference: 70-50 km

3 INTERNATIONAL LINEAR COLLIDER (ILC), Japan
Length: 31 km

4 LARGE HADRON COLLIDER (LHC) CERN, Switzerland
Circumference: 27 km

break new ground. Electron collidersare akin to a precision instrument to dissect a specific particle.

Proton smashers can reach much higher energies but also produce an unholy mess. Protons are little bags of other particles: subatomic quarks and the gluons that stick them together. Each collision at the LHC produces millions of particles. It's a huge job to tease out the telltale signature of a particular type, such as the Higgs.

Electrons and positrons, on the other hand, are fundamental, having no internal parts. As antimatter partners, they annihilate each other when they collide, creating a clean burst of pure energy. At the right collision speed, this pure energy is converted to Higgs bosons without the mess of extra particles produced by a proton collision.

With an electron collider, therefore, physicists can fine-tune the collision energy to produce just one kind of particle a bit like tuning a radio to a particular station. Set the dial at 250 gigaelectronvolts, and the ILC produces Higgs bosons in abundance, and not much else. Tune a bit higher, to 375 gigaelectronvolts, and the collision can produce Higgs particles along with a top quark. This would be a chance to see the Higgs get physical with nature's heaviest known particle.

The main advantage a linear collider has over a circular one is that it's much easier to accelerate electrons (or positrons) in a straight line than in a circle. Particles running in a circle shed lots of extra energy as gamma rays, which puts the brakes on.

After two decades of design work, the ILC is ready to be built, Taylor says. All that is needed is for the relevant parties to cough up the dough for construction – about US$10 billion (though some estimates go far higher).

The current agreement says the host country should pay half, but Japan is trying to renegotiate this with its partners in the US and Europe. The Japanese government is also being cautious in other respects, commissioning studies on how the massive project will affect life in the region. All this means we don't have an ETA on the project yet.

Besides the ILC, another linear collider on the horizon is the Compact Linear Collider (CLIC). It would use a more advanced design to hit energies of three teraelectronvolts or even higher along a similar length to the ILC; but it's only in a very early design stage.

CIRCULAR ELECTRON POSITRON COLLIDER, CHINA —

Another option is the Circular Electron Positron Collider (CEPC), set for Qinhuangdao, a port city in the northern province of Hebei in China.

It would be a giant ring at least twice the size of the LHC. A few possible sizes are on the table: 54, 70 and 88 kilometres – the latter in part because eights are auspicious in Chinese numerology.

CEPC would start out as a Higgs factory, just like the ILC, smashing electrons and positrons at up to 250 gigaelectronvolts. The long-term goal is to upgrade the same tunnel to host a new facility called the Super Proton-Proton Collider (SPPC). It's in this capacity that the collider would really shine, with the potential to reach energies in the order of 70 to 100 teraelectronvolts, boldly whizzing physics into unexplored territory.

Particle colliders are tools for turning energy into mass. It's that piece of magic contained in Albert Einstein's famous equation: $E = mc^2$.

Slam two particles together at speed, and you can convert that kinetic energy into a spray of new particles. The higher the collision energy, the heavier the particles you can create. With proton-proton colliders, Taylor says, "you just bang them as hard as you can and see what comes out".

The Chinese plans are not as far along as the ILC, though the team is working to finish its design by 2020. China does have a reputation for striving ahead with massive infrastructure projects, which does give the project some chance of jumping to the front of the pack as the world's top atom smasher. Construction could feasibly start as early as 2021, with the first collisions set for 2028 – so long as the project remains in favour with the powers that be.

Not everyone is enthusiastic. China's most famous particle physicist, Nobel laureate Chen Ning Yang, has criticised the plan as too expensive for a country with such pressing societal needs. The first electron-positron stage carries a US$6 billion price tag. China would be expected to fork out at least half this. The SPPC upgrade, scheduled for 2042, would bring the cost to about US$20 billion.

In support of the collider, the director of China's Institute of High Energy Physics, Yifang Wang, has argued its construction would boost China's development, make the nation a world leader in high-energy physics and attract important intellectual capital.

FUTURE CIRCULAR COLLIDER, FRANCE / SWITZERLAND —

CERN is not resting on its laurels. It's working out plans to supersede the LHC. The Future Circular Collider (FCC) is the biggest plan on the table, with a circumference of 90 to 100 kilometres and a whopping 100-teraelectron volt collision energy.

Ultimately the FCC project would result in a proton-proton monster collider. But before reaching that end, it could also spend some time as an electron-positron collider (another possible Higgs factory) and an electron-proton collider (which would be great for studying the quark-gluon interactions that hold a proton together).

CERN scientists are working out the details of each option and plan to deliver a design report by 2018, with construction earmarked some time in the mid-2030s.

FEAR OF FAILURE —

There is some overlap in the capabilities of these three projects, and Taylor doubts they'll all be built. But as to which, he can only speculate: "Perhaps one of the circular colliders, plus the ILC, because then we'd get two different sorts of machines."

In making these decisions, governments and physics communities are wary of overshooting, and repeating the mistakes of the past.

In the 1980s, the US started to build the Superconducting Super Collider in Texas. Its ring circumference of 87.1 kilometres would have dwarfed the LHC. About US$2 billion was spent before the project was canned in 1993 due to rising costs. That failure cemented a shift in the centre of particle physics from the US to Europe. Could that centre shift further east? Only time will tell.

For now, the LHC will remain King Collider at least another decade. Whatever knocks it off its perch will spectacularly take the crown of the next wonder of the modern world.

WITH PROTON COLLIDERS 'YOU JUST BANG THEM AS HARD AS YOU CAN AND SEE WHAT COMES OUT.'

CATHAL O'CONNELL is a science writer, with a background in physics, based in Melbourne.

IMAGES
01 ATLAS Experiment / CERN / Claudia Marcelloni
02 CERN / Daniel Dominguez
03 CERN / Thomas McCauley / Lucas Taylor

01
Where there's smoke:
Costa Rica's Turrialba volcano
has observers on edge.

PREDICTING FIRE WITH BRIMSTONE

The tricky science of forecasting volcanic eruptions can mean the difference between natural disaster and human catastrophe. KATE RAVILIOUS reports.

PERCHED ON THE EDGE OF a crater up high on the slopes of Costa Rica's Turrialba volcano, an instrument is sniffing the volcano's bad breath. If the gaseous mix changes, it's likely to be the signal the volcano is set to erupt.

Maarten de Moor, from Costa Rica's Volcanic and Seismic Observatory, is monitoring the signals closely. In recent months there have been troubling minor eruptions. In January a state of emergency was declared for a few days, postponing international flights.

Volcano watchers like de Moor know all too well that their job can mean the difference between life and death. Nearby Colombia is a tragic reminder. On one November day in 1985, just after 3pm, Nevado del Ruiz erupted without warning. Within minutes, four deadly rivers of clay, ice and molten rock raced down its flanks, destroying towns and villages. More than 23,000 people died. While there had been mini-eruptions and earthquakes prior to the blast, scientists were unable to convince the community of the risk in time.

The decades since the Colombian tragedy have seen major improvements to the science of eruption forecasting. Early warning systems enabled 75,000 people to evacuate prior to the massive explosion of the Mount Pinatubo on the Philippine island of Luzon in 1991. More than 70,000 people were moved out of harm's way before Indonesia's Mount Merapi erupted in in 2010. But forecasting is not infallible. In 2014, Mount Ontake in Japan erupted unexpectedly, killing 57 people.

OUR PLANET HOSTS an estimated 1,550 active volcanoes. Most signal their vitality with just an occasional rumble, approximately 20 are non-stop fumers that don't erupt, and about 50 explode each year. A handful of these are big enough to cause problems.

To forecast big blasts, scientists measure fumes emanating from within the volcano. When magma starts to move upwards, carbon dioxide, being less soluble, bubbles out first. It's followed by a belch of sulfur dioxide as the magma nears the surface. So an increase in the ratio of carbon dioxide to sulfur dioxide can provide an early warning that the magma is rising.

For decades, the only way volcano researchers could measure these gases involved walking up the slopes towards the crater, or swooping past in an aircraft – both risky activities, especially once an eruption was underway and researchers wanted to see how gas composition changed during the event.

Being a volcanologist has become somewhat less risky since 2005. Two international groups – the Network for Observation of Volcanic and Atmospheric Change (NOVAC) and the Deep Carbon Observatory – have been developing instruments to monitor the target gases remotely and continuously. Both use portable low-cost spectrometers that analyse gas concentrations based on how sunlight is absorbed as it passes through the volcanic plume. Another type of meter measures changing levels of sulfur dioxide and can be installed kilometres downwind of active vents or on aircraft and satellites, allowing continuous monitoring. At present, some 35 volcanoes around the world are watched this way.

TURRIALBA'S LESSONS CANNOT NECESSARILY BE APPLIED TO OTHER VOLCANOES.

EARLY IN 2014, de Moor installed gas sensors on the lips of Turrialba's three craters. Since then he and his colleagues have observed sharp increases in the carbon-sulfur ratio in the months prior to small eruptions. "It is a really promising result," he says, "and a huge step forward for eruption forecasting."

Nevertheless de Moor is worried by the similarities he is seeing to the last large eruption on Turrialba, in 1864: "The ash deposits suggest that it started with small eruptions, like those we are seeing now." Those little disturbances, he says, gave way to an enormous "Strombolian" outburst (a reference to the hyperactive volcano on the island of Stromboli off the coast of Sicily).

Such an eruption from Turrialba, just 50 kilometres from the outskirts of Costa Rica's capital San Jose, would devastate the surrounding terrain, potentially killing thousands and crippling the nation's economy. In March de Moor installed more sensitive instruments on the volcano, to ensure even the smallest murmurings are detected.

Turrialba's lessons, however, cannot necessarily be directly applied to other volcanoes. Take the rising ratio of carbon dioxide to sulfur dioxide. Turrialba's menacing neighbour, Poás, produced the opposite signal prior to small eruptions.

The reason for this lies with the acidic lake that fills the Poás crater. Its waters normally absorb sulfur dioxide while allowing carbon dioxide to bubble through; that creates a permanently high carbon-to-sulfur ratio in the gas cloud plume. But in the days prior to an eruption, the lake's ability to absorb sulfur dioxide reached saturation point. Unable to be absorbed by the lake, the excess gas bubbled out. As a result, the carbon/sulfur ratio fell prior to an eruption.

Deciphering the signal from Poás was a milestone, de Moor says, since many of the world's most unpredictable and explosive volcanoes – including Nevado del Ruiz and Mount Ontake – have crater lakes. The findings from the Costa Rican volcanoes, he says, underscore "there is no one size fits all" eruption signal.

02

Spectrometers analysing gas emissions now keep tabs on 35 volcanoes around the world.

THE KEY TO SUCCESSFUL prediction is to combine different techniques. Besides the established methods of gas and seismic monitoring, new satellite imaging techniques can reveal whether a volcano is actually swelling with magma. Volcanologist James Hickey at the University of Exeter in Britain is taking this approach to generate a computer model of what is happening underneath Sakurajima, an active volcano on the Japanese island of Kyushu.

Sakurajima's last major eruption took place in 1914, killing 58 people and causing a massive flood in the nearby seaside city of Kagoshima. Its magma chambers have been refilling since, causing minor eruptions virtually every day.

Hickey's model incorporates the area's topography and underlying rock types, along with very precise GPS measurements of surface movement, to gauge just how fast the magma is replenishing. The results, published in *Scientific Reports* in September 2016, indicate the tank needs roughly 130 years to fill.

"In other words," Hickey says, "enough magma

03

A study in opposites: the Poás volcano produces gas signals the reverse of its neighbour, Turrialba.

might be stored in the next 30 years for an eruption of the same scale as one in 1914."

That finding prompted the Kagoshima City Office to review its evacuation plans. Hickey is developing similar models for volcanoes in Ecuador and the Lesser Antilles in the Caribbean.

But even with all the high-tech advances, people in the poorest parts of the world are still at risk. Despite the efforts of NOVAC, right now there are still too few experts to analyse every volcano's halitosis and generate the models that reveal what is going on deep underground.

"We hope to interest more people in coming to do this kind of work," de Moor says.

In many countries where people live in the shadow of active volcanoes, there is barely any monitoring at all. According to a 2015 United Nations report, Indonesia and the Philippines top the list of populations most at threat.

At least in Colombia, 30 years after the devastation, villagers living under the menacing shadow of Nevado de Ruiz are placing their hopes in science. Continuous gas-monitoring instruments were installed in the volcano's vent last year and scientists are schooling themselves in how to read warning signs.

No doubt they are keeping a watchful eye on the lessons from Turrialba.

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

IMAGES
01 Ezequiel Becerra / AFP / Getty Images
02 NOVAK
03 Javier Fernández Sánchez / Getty Images

01
Planet Nine is believed to be Neptune-sized, orbiting the Sun once every 16,000 years.

PLANET 9 FROM OUTER SPACE

Astronomers are confident they are on the cusp of locating a giant, lurking at the fringes of the Solar System. RICHARD A. LOVETT reports.

GENERATIONS OF SCHOOLCHILDREN were taught the Solar System contains nine planets. Perhaps they weren't misled after all. Pluto may have been banished from the planetary pantheon but astronomers are now almost certain the system really does have a ninth planet hiding in its outer reaches; and this one's a giant.

With the same mounting excitement that attended the search for Pluto a century ago, 10 astronomical teams are training giant telescopes on the likely orbit of Planet Nine. The planet is believed to be Neptune-sized, circling the Sun in a highly elliptical orbit 200 to 1,200 times more distant than that of the Earth (Pluto's orbit, by comparison, is never more than 49 times more distant). A full revolution around the Sun is estimated to take about 16,000 years.

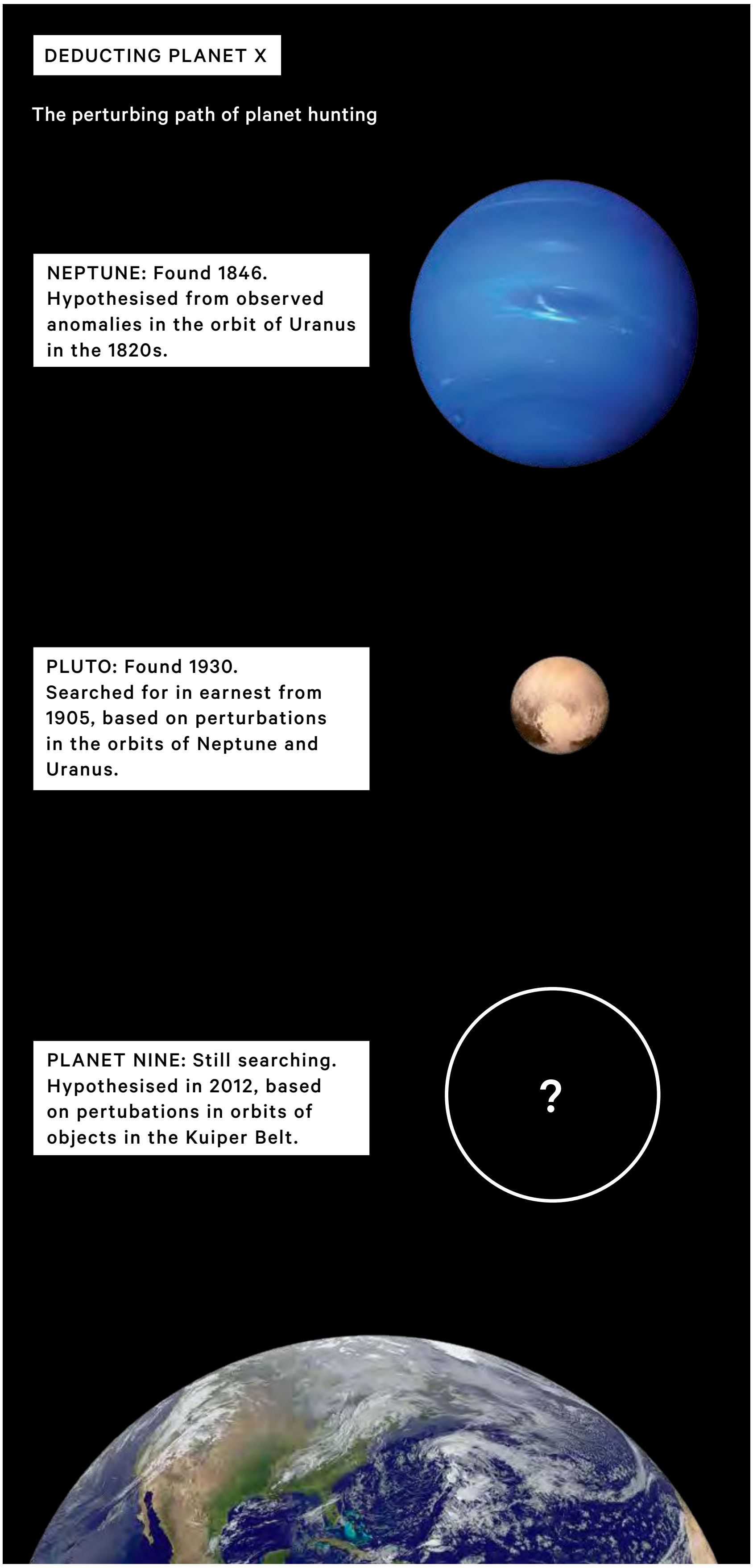
Unless the models are totally wrong, somebody is going to find it soon. Meanwhile speculation about the possible origin of Planet Nine is running rife. One of the most intriguing theories is that the Sun roped it in as a stray from interstellar space.

Arguments for the existence of Planet Nine hark back to the same logic that was used to deduce the existence of Neptune and Pluto. It was the skewed orbit of Uranus that suggested the tug of an unseen outer planet that proved to be Neptune. Oddities in Neptune's orbit then helped lead astronomers to Pluto. Now the skewed orbits of objects in the Kuiper Belt (where Pluto resides) suggest the influence of a gigantic outer planet.

Rodney Gomes of the National Observatory of Brazil first made this argument at the 2012 meeting of the American Astronomical Society's Division on Dynamical Astronomy. He had observed half a dozen distant objects in the Kuiper Belt with orbits that appeared perturbed by something very big in the dim recesses of the outer Solar System.

Gomes' peers thought his presentation was interesting but not yet planet-shifting. I was the only journalist in the room at the time, and had trouble finding science editors interested in the story. It would take another year or two, after other researchers began reporting the discovery of more orbital oddities, before the astronomical community really began to get excited.

One of those who got excited was Mike Brown at the California Institute of Technology. Brown is



known as "the man who killed Pluto" because of his team's discovery of Eris – the distant mini-world, only slightly smaller than Pluto, that showed the Kuiper Belt was potentially home to many such bodies. This led astronomers to lift the bar on what qualifies as a "planet", bumping Pluto off the list.

In a paper published in July 2016, Brown and colleagues declared in favour of the likely existence of Planet Nine, arguing it would solve a 150-year-old mystery of the Solar System: why it is that the orbits of the known planets all fall within a single plane, give or take a degree, while the spin axis of the Sun is tilted six degrees away from that plane.

According to all that is known about solar system formation, if the Sun and the planets arose from the same primordial disc then their rotations should be aligned. The existence of a large, distant planet with a tilted orbit whose gravitational tug has tilted the orbits of the other planets would explain the perplexing misalignment.

Studies like these, Brown says, have narrowed the hunt for Planet Nine to a portion of space small enough to be "pretty sure" the elusive body will be found within the year.

WHICH BRINGS US BACK to the question of how something that big wound up so far away. Theories vary. One idea is that the planet began its life much closer to the Sun, before being flung out into the far reaches of the Solar System billions of years ago.

Today's models of Solar System formation are no longer premised on the belief that planets stayed put once they were formed. Instead the models begin with thousands of small objects circling the Sun in an orderly disc. As time passes, these proto-planets start colliding. Some collisions result in mergers that form planets; on other occasions, close encounters fling proto-planets into interstellar space. It is also possible for planets' orbits to shift while remaining in the Solar System.

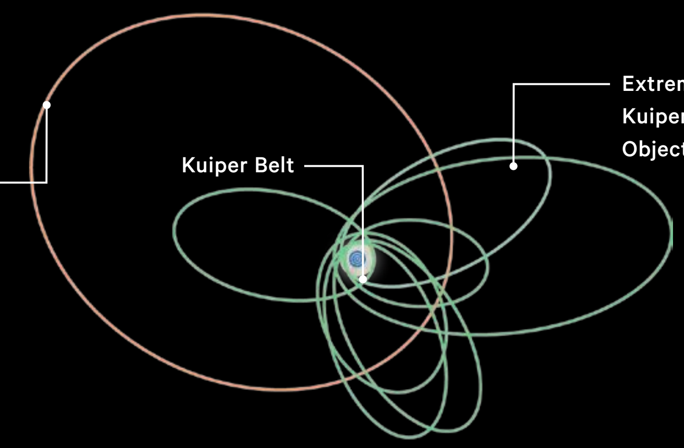
One increasingly accepted model for the formation of the Solar System, called the Nice model (because it was first proposed in Nice, France), suggests the system's four known giant planets – Jupiter, Saturn, Uranus and Neptune – formed closer to the Sun than their locations now, then migrated outward – possibly with Neptune and Uranus exchanging positions in the process.

The Nice model works even better if the Solar System originally had five giant planets rather than four, says Alessandro Morbidelli of Observatoire de la Cote d'Azur in Nice. Planet Nine might be that fifth planet.

Another theory is that Planet Nine is a "rogue

KEEPING ITS DISTANCE

Out there: Planet Nine's orbit, even at its closest to the Sun, lies far beyond most Kuiper Belt objects.



planet", booted out of some other solar system and somehow captured by ours.

Evidence for the existence of such rogues comes not only from computer models but from a 2011 study by a Japan astronomical team that identified Jupiter-sized planets floating in interstellar space, spotted by the way their gravity bent the light from distant stars. Such planets might be as common as stars – and if Jupiter-sized rogues exist, there are almost certainly many smaller-sized ones.

Another solar system is not the only possible source of such a rogue. In a paper presented at a January 2017 meeting of the American Astronomical Society, Eden Girma of Harvard University described how stars passing too close to the giant black hole at the centre of our galaxy can be "spaghettified" into long streamers of matter. These streamers can then recondense into planet-sized "spitballs" that are flung out from the galactic centre at speeds of 1,000 to 10,000 km per second.

According to Girma's models, these spitballs would be too big and fast to be captured by the Sun. While that means a spitball is not a likely explanation for the origin of Planet Nine, her findings nonetheless bolster the idea the galaxy might be teeming with rogue worlds, cruising the darkness of interstellar space.

At the same meeting, James Vesper of New Mexico State University presented modelling of a slower-moving stray planet passing through the Solar System. In 156 simulations of rogues of various sizes, about 60% were simply sling-shotted into interstellar space. In some cases, however, it was possible for the rogue to be captured in a far-flung orbit. "Is Planet Nine a captured rogue?" Vesper asks. "It's plausible."

Once Planet Nine is found, its origin may become more clear, Brown says: "My hope is that something about it will make the answer obvious, though I will admit it is not obvious what that something is. Chemical composition? Isotopic differences? A big sign that says where it came from?"

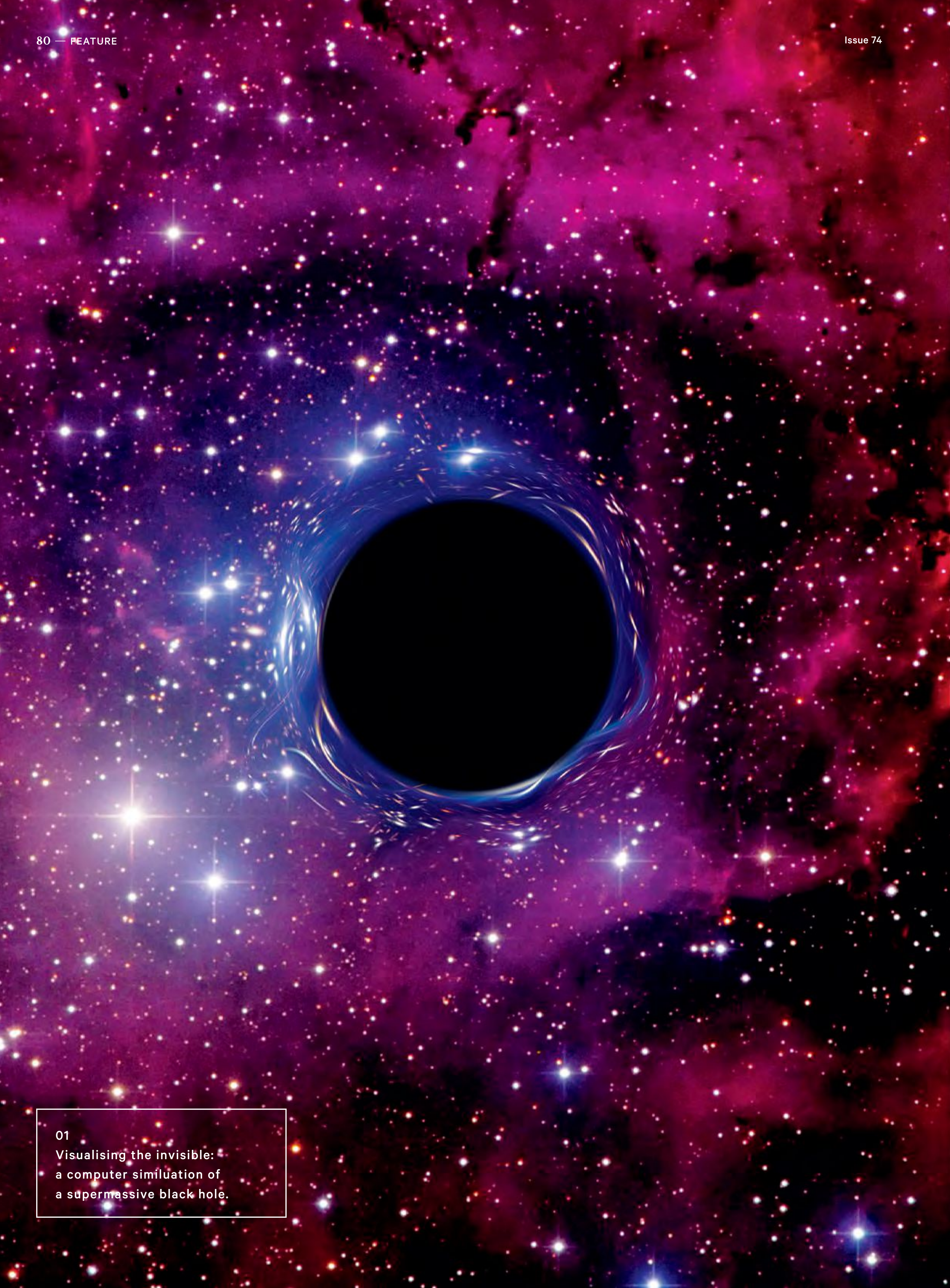
One part of the answer, Morbidelli says, may lie with the planet's mass. "The ejection process during planet dynamics always ejects the lighter planets and keeps the heavier ones," he says. "It would be unrealistic to think a [larger-than] Neptune planet was ejected, if Uranus and Neptune stayed behind." In other words, if Planet Nine is bigger than Uranus and Neptune, it is probably a captured rogue.

"The future will tell," says Morbidelli. Right now, it seems the future is close. It took decades for speculations about another planet influencing the orbit of Uranus to end with the discovery of Pluto in 1930. This time around, the search for the new ninth planet should take just years; and once found, Planet Nine will be here to stay. The only truly unknown is what we will call it.

'IF PLANET NINE IS BIGGER THAN URANUS AND NEPTUNE, IT IS PROBABLY A CAPTURED ROGUE'

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

IMAGES
01 NASA / ESA / STScI



01
Visualising the invisible: a computer simiuation of a supermassive black hole.

WHEN GIANTS WARPED THE UNIVERSE

The discovery that massive black holes existed billions of years earlier than thought possible is forcing a major rethink about galactic origins. GRAHAM PHILLIPS reports.

THEY GOBBLE STARS, bend space, warp time and may even provide gateways to other universes. Black holes fire the imagination of scientists and science-fiction aficionados alike.

But at least one thing about them wasn't all that mind-bending: we've long understood black holes to be the end point in the life of a big star, when it runs out of fuel and collapses on itself.

However, in recent times astronomers have been confronted with a paradox: gigantic black holes that existed when the universe was less than a billion years old. Since average-sized black holes take many billions of years to form, astrophysicists have been scratching their heads to figure out how these monsters could have arisen so early.

It now seems that rather than being the end game in the evolution of stars and galaxies, supermassive black holes were around at their beginnings and played a major role in shaping them.

IT WAS THE LITTLE KNOWN English clergyman and scientist John Michell who, in 1783, first articulated the idea of "dark stars" whose gravity was so great they would prevent light from escaping them. The concept was astonishingly prescient even if parts of his theory – particularly those based on Newton's idea that light particles had mass – were flawed.

The first accurate description of black holes came in 1916 from German physicist and astronomer Karl Schwarzschild. Schwarzschild was serving in the German Army at the time, despite already being over 40 years of age. After seeing action on both the western and eastern fronts, Schwarzschild was sent home due to a serious auto-immune skin disease, pemphigus. It was late 1915 and Einstein's theory of General Relativity had just been published. Inspired, Schwarzschild lost no time writing a paper that predicted the existence of black holes; it was published just months before he succumbed to his disease in May 1916.

According to Einstein's theory, the force of gravity was the result of a mass distorting the fabric of space-time. In the same way that a bowling ball dimples the fabric of a trampoline, a star's mass dimpled the space-time fabric of its system, keeping planets circling around it. The theory was underpinned by equations laying out the interaction of energy, mass, space and time. Schwarzschild's achievement was to apply Einstein's equations to a simplified scenario: a perfectly spherical star. One of the things that jumped out of his mathematical musings was an object with such a strong gravitational pull that not even light could escape it.

While Schwarzschild's idea made sense in the theoretical realm of mathematics, most physicists did not expect to find an exemplar in the real universe. By the 1960s, however, expectations were changing. Astronomers discovered the existence of extremely dense objects known as neutron stars. Detected by their unusual pulsing of electromagnetic radiation, they were the dense corpses of large stars that had exhausted their fuel. Without the force of the burning fuel pushing against their own gravity, they collapsed, compressing their matter until only the pressure of neutron against neutron halted the crush.

> 'BLACK HOLES ARE NOT VACUUM CLEANERS IT'S VERY DIFFICULT FOR ONE TO SWALLOW LOTS OF STUFF.'

Neutron stars got astrophysicists thinking back to Schwarzschild's idea. What happens when really big suns with even stronger gravity cave in? All the matter would be squeezed down to a point with an extraordinarily strong gravitational field. Sometime in the 1960s, physicists coined the term "black hole", and the hunt for something more than just a mathematical artefact was on.

The first evidence that black holes weren't just theoretical came in 1964, when a rocket decked with sensitive instruments was shot into sub-orbital space. It detected suspicious X-rays emanating from the constellation of Cygnus (the swan). The X-ray source became known as Cygnus X-1. By the early 1970s most astronomers inferred the X-rays were radiated by super-heated matter being sucked into the gravitational field of the black hole.

It would take decades more, however, before the first conclusive evidence that black holes exist and obey Einstein's equations of general relativity. This came in September 2015 with the detection of gravitational waves by the Laser Interferometer Gravitational-Wave Observatory (LIGO) in the United States. These ripples in the fabric of space-time had been generated by two black holes colliding 1.3 billion years ago. Theorists had predicted that if such a titanic event occurred somewhere in our galaxy, the reverberations should be measurable on Earth. LIGO's detection of gravitational waves thus also confirmed the existence of black holes.

YET EVEN AS THE EVIDENCE that black holes truly exist has firmed up, our understanding of how they arise seems to be crumbling.

The cracks in the theory grew gradually as astronomers accumulated evidence for the existence of a very different kind of black hole. While most black holes have a mass that is equivalent to 10-100 times that of our Sun, these monsters were equivalent to a million or a billion solar masses. With typical prosaicness, astronomers dubbed them supermassive black holes. Unlike smaller black holes, they also resided at the centres of galaxies.

Most surprising of all, far-reaching telescopes like the European Southern Observatory's Very Large Telescope detected them in extremely distant galaxies. Because of the extreme length of time it takes for their light to reach Earth, they provide snapshots of the universe in its infancy.

02

Star power: Avi Loeb's direct-collapse theory explains the presence of supermassive black holes at the beginning of galaxies.

"A billion years after the big bang you have black holes that are as massive as the biggest black holes we find around us today," says Avi Loeb, an astrophysicist at Harvard University. That simply doesn't make sense according to the accepted understanding that black holes come only at the end of a star's life. "It's sort of like going to the delivery room in a hospital and finding giant babies."

Were these monster babies the result of many black holes colliding? Or did they arise from a moderately sized black hole that ballooned by feeding on gas and other stars?

Neither of these scenarios sit well with astrophysicists. "Getting from even a hundred solar masses up to several billion solar masses in less than a billion years is quite challenging," says Mitch

Begelman, an astrophysicist from the University of Colorado. “Black holes are not vacuum cleaners. That’s a popular misconception. It’s very difficult to get a black hole to swallow lots of stuff [in a short period of time] .”

Loeb, who has been captivated by supermassive black holes since he got into astrophysics, thinks he might have a solution to the mystery: in 1994, he came up with the idea that a different kind of process gave birth to black holes in the early universe.

In the modern universe, black holes take billions of years to form. Their star (which must be greater than 10 solar masses to muster the required gravitational force) must first burn through its fuel, then explode as a supernova before it collapses.

But while the biggest stars today reach the size of 300 solar masses, the early universe might have blazed with stars equivalent to a million solar mases. Such a super star, according to Loeb’s calculations, would burn so feverishly it would use up its fuel in just a million years. Then it would collapse directly into a black hole a million times the mass of the Sun – what Loeb calls “a direct collapse black hole”.

According to Loeb, the reason super stars were formed only in the embryonic universe, is because back then stars were made of simpler stuff: “The gas was pristine. It came from the big bang and had only hydrogen and helium,” he explains. Lacking heavier elements to radiate heat, the clouds stayed relatively warm. That allowed them to grow without fragmenting, forming super stars. By contrast, in today’s universe star dust contains heavy atoms like carbon, silicon and oxygen – forged in the nuclear furnaces of the first generation of stars and blown throughout the cosmos when those stars exploded. As result, modern-day dust clouds can cool to extremely low temperatures and fragment, mostly forming stars about the size of the Sun.

IF LOEB IS RIGHT, early super stars gave rise to the direct collapsers, which gave rise to supermassive black holes. These monsters have had an enormous influence on how the universe evolved.

They shaped galaxies in two ways. First, they gobbled up clouds and stars in their immediate vicinity. Second, like some cosmic air blower, they beamed out jets of energy that propelled dust and gas out of their galaxy. “Within tens of millions of years the black holes can remove the gas from the host galaxy,” Loeb says.

By cleaning the galaxy of the raw material for star creation and growth, the black holes have capped the size of galaxies. If not for the supermassive black hole at the centre of the Milky Way, Loeb estimates, our galaxy could have grown a thousand times bigger than it is today. That would be some night sky to look up at.

03

Without the black hole at its centre, the Milky Way might be a thousand times bigger.

“The growth of black holes seems to be a crucial element in galaxy formation,” Begelman agrees. “Galaxies would look very different if there weren’t these black holes.”

Of course, the absolute proof that direct collapse black holes exist will come when one is observed. In the past year astronomers have seen some tantalising clues. One is a galaxy known as CR7, which hosts a source of light much brighter than its stars – perhaps the radiation caused by a black hole sucking in gas. “You see evidence for a galaxy that has mainly hydrogen and helium,” Loeb says. “That could potentially be the birthplace of a direct collapse black hole.”

GRAHAM PHILLIPS is a science journalist with a PhD in astrophysics.

IMAGES
01 Gmutlu / Getty Images
02 Jemal Countess / Stringer / Getty Images
03 NASA / CXC / MIT / F.K.Baganoff et al.

ASK THE QUANTUM ORACLE

AI looks in to the future to predict and fix failures before they happen. CATHAL O'CONNELL explains.

01

IMAGINE PREDICTING your car will break down and being able to replace the faulty part before it becomes a problem. Now Australian physicists have found a way to do this – albeit on a quantum scale.

LED BY MICHAEL BIERCUK at the University of Sydney, they enlisted machine learning to "foresee" the future failure of a quantum bit, or qubit, and make the corrections needed to stop it happening.

Quantum computing is a potentially world-changing technology with the potential to do in minutes what now take computers thousands of years. But achieving practical, large-scale quantum technologies still seems a long way off.

One of the major challenges is maintaining qubits in the delicate, zen-like state of superposition they need to do their business.

Any tiny nudge from the environment – such as the jiggly atom next door – knocks the qubit off balance.

So physicists go to great lengths to stabilise qubits, cooling them to more than 200 degrees below zero to reduce atomic jiggling. Still, superposition typically lasts but a tiny fraction of a second, and this cuts quantum number-crunching time short.

Biercuk and his colleagues have found a new way of stabilising qubits against noise in the environment. As they reported in *Nature Communications*, it works by predicting how a qubit will behave and act pre-emptively. In a quantum computer, the technique could make qubits twice as stable as before.

02

The breakthrough comes from tweaking a qubit made a single ion of ytterbium.

The team used control theory and machine learning (a kind of artificial intelligence) to estimate how the future of a qubit would play out.

Control theory is the branch of engineering that deals with feedback systems, such as the thermostat keeping your room temperature constant. The thermostat reacts to changes in the environment, initiating warm or cool air to pump into the room.

Meanwhile, new machine learning algorithms look at how the system behaved in the past and use

03
Qubits hold great processing potential but are too delicate to be useful yet. This may change, thanks to artificial intelligence.

04

Learning from machines: 'The quantum future is looking better all the time,' Michael Biercuk says.

THE MORE TIME THE ALGORITHM WATCHED THE QUBIT, THE MORE ACCURATE PREDICTIONS BECAME.

this information to predict how it will react to future events.

First, Biercuk's team made a qubit by trapping a single ion of ytterbium in a beam of laser light. To train their algorithm, they simulated noise, tweaking the light to disturb the atom in a controlled way. Their algorithm monitored how the qubit responded to these tweaks and made a prediction for how it would behave in future.

Next, they let events play out for the qubit to check their algorithm's accuracy. The longer the algorithm watched the qubit, the more accurate its predictions became.

Finally, the team used the predictions to help the system self-correct. The qubit was twice as stable with the algorithm as without it.

While similar machine-learning algorithms have been used in other advanced feedback systems, such as those used to stabilise the interferometer that detected gravitational waves last year, this is their first use in a quantum technology.

Because the technique is software based, it could be easily adapted by other quantum technology efforts around the world. To help, the team is making the computer code available to other scientists.

"The quantum future is looking better all the time," Biercuk says.

CATHAL O'CONNELL is a science writer, with a background in physics, based in Melbourne.

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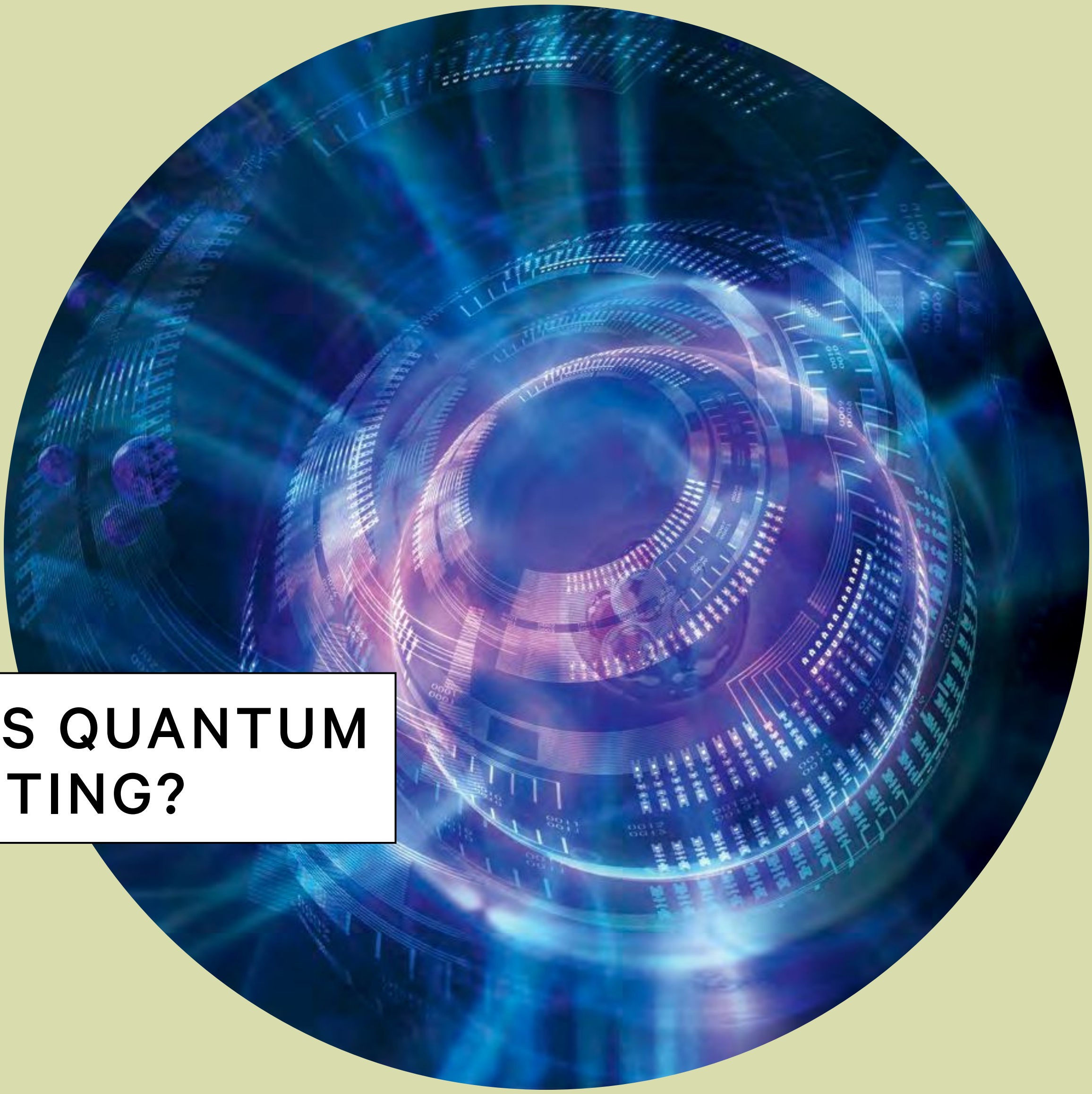
WHAT IS QUANTUM COMPUTING?



Quantum computing has the potential to massively increase computing power.

CREDIT: HARALD RITSCH / GETTY IMAGES

REGULAR COMPUTERS operate according to strict rules of logic. But tiny quantum objects – such as electrons, or photons of light – can break those rules.

Quantum computing is the idea that we can use this quantum rule-breaking to process information in a new way—one that's totally different from how regular computers work. This makes them, in some cases, exponentially faster than any regular computer.

For example, one quantum computer could easily crack the codes that keep internet banking secure.

SO, LIKE A SUPERCOMPUTER? —

Not exactly. A quantum computer is not just a "faster" computer. There are a few specific tasks – such as factoring very large numbers – which a quantum computer would be amazing at. (This is where the codebreaking comes in – see below.) But for most jobs, a quantum computer would be little better than a regular computer.

SO WHAT COULD A QUANTUM COMPUTER BE USED FOR? —

They will probably be most useful for government agencies, research and development companies and universities in solving problems that current computers struggle with.

The first practical idea, proposed by the physicist Richard Feynman in 1981, was to use a quantum computer to simulate quantum mechanics. This would impact chemistry and biology. Chemists, for example, could accurately model drug interactions and biologists could study all the possible ways proteins can fold and interact with one another.

While quantum computers were once an academic curiosity, interest exploded in 1994 when the American mathematician Peter Shor found a way to use quantum computers to break codes.

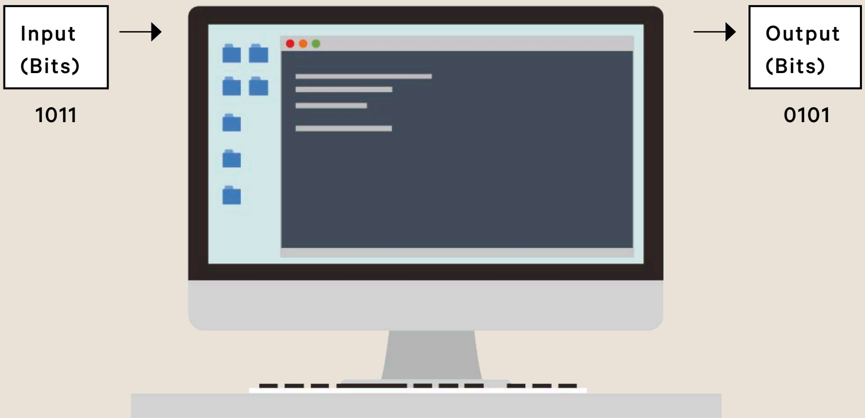
Currently, many online security systems run on the principle that it's next to impossible to take a very large number and figure out what its prime factors are. All a regular computer can do is try every possibility one after another – a task that could take billions of years. Using Shor's algorithm, a quantum computer could perform the task in a few hours.

Quantum computers could also be fantastic at recognising patterns in data – useful for machine learning problems, such as being able to identify different objects in an image. They could be great at building

MAKING THE QUANTUM LEAP

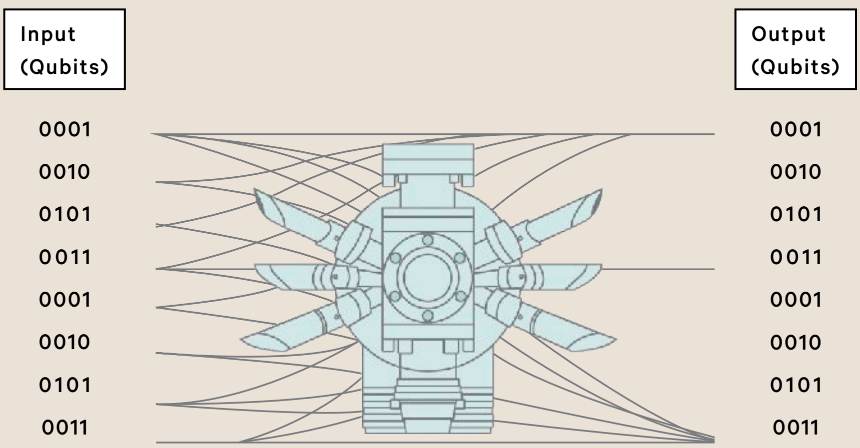
STANDARD COMPUTER

Classical computers can only try one calculation at a time. One input gives one output. That's because the information is coded in 'bits' which can only sit in one state at a time: either a '0' or '1'.



QUANTUM COMPUTER

A quantum computer would be built from 'qubits' – which can be '0', '1' or a mixture of both simultaneously. These mixed qubit states allow the quantum computer to run many inputs, billions perhaps, or trillions, at the same time. This makes quantum computers way faster than regular computers, at least for tasks like codebreaking.



models to predict the future, such as in long-term weather forecasting.

But ultimately the uses of quantum computing are unpredictable. Consider that in 1943 the president of IBM, Thomas Watson, said: "I think there is a world market for maybe five computers." Now there are as many as five a household.

If precedent is any guide, we've yet to imagine what the uses of quantum computers will be.

HOW DOES QUANTUM COMPUTING WORK? —

Regular computers are based on "bits" – imagine them as little switches pointing to either a 1 or a 0.

Quantum computing relies on quantum bits, or "qubits", which can also represent a 0 or a 1. The crazy thing is, qubits can also achieve a mixed state, called a "superposition" where they are both 1 and 0 at the same time. This ambiguity – the ability to both "be" and "not be" – is key to the power of quantum computing.

HOW DOES SUPERPOSITION HELP? —

The difference between regular computers and quantum computers boils down to how they approach a problem.

A regular computer tries to solve a problem the same way you might try to escape a maze – by trying every possible corridor, turning back at dead ends, until you eventually find the way out. Superposition allows the quantum computer to try all the paths at once – in essence, finding the shortcut.

Two bits in your computer can be in four possible states (00, 01, 10, or 11), but only one of them at any time. This limits the computer to processing one input at a time (like trying one corridor in the maze).

In a quantum computer, two qubits can also represent the exact same four states (00, 01, 10, or 11). The difference is, because of superposition, the qubits can represent all four at the same time. That's a bit like having four regular computers running side-by-side.

If you add more bits to a regular computer, it can still only deal with one state at a time. But as you add qubits, the power of your quantum computer grows exponentially. For the mathematically inclined, we can say that if you have "n" qubits, you can simultaneously represent 2n states.)

It's like that old fable about an ancient Indian, called Sessa, who invented the game of chess. The king was delighted with the game and asked Sessa to name his reward. Sessa humbly requested a single chessboard with one grain of wheat on the first square, two on the second, four on the third and so on. The king agreed at once, not realising he'd promised away more wheat than existed on Earth. That's the power exponential growth.

Just like each square doubled Sessa's wheat, each additional qubit doubles the processing power. Three qubits gives you 23, which is eight states at the same time; four qubits give you 24, which is 16. And 64 qubits? They give you 264, which is 18,446,744,073,709,600,000 possibilities! That's about one million terabytes worth.

While 64 regular bits can also represent this huge number (264) of states, it can only represent one one at a time. To cycle through all these combinations, at two billion per second (which is a typical speed for a modern PC), would take about 400 years.

All this means quantum computers could tackle problems that are "practically impossible" for classical computers.

But to get that exponential speed-up, the fate of all the qubits has to be linked together in a process called quantum entanglement. This weird phenomenon, which Einstein called "spooky action at a distance", can connect quantum particles even if they are at opposite ends of the universe.

WHAT MAKES A QUBIT? —

To make a qubit, you need an object that can attain a state of quantum superposition between two states.

An atomic nucleus is one kind of qubit.

Like placing angels on the head of a pin: the challenge with qubit computing is placing and addressing a single atom.

CREDITS: MASSIMO BREGA / GETTY IMAGES

The direction of its magnetic moment (it's "spin") can point in different directions, say up or down with respect to a magnetic field.

The challenge is in placing and then addressing that single atom.

A team led by Michelle Simmons at the University of New South Wales has made atomic qubits by placing a single phosphorus atom at a known position inside a silicon crystal.

Another idea is to strip an electron off the atom and turn it into an ion. Then you can use electromagnetic fields to suspend the ion in free space, firing lasers at it to change its state. This makes for a "trapped ion" quantum computer like one being developed at MIT.

A current in a loop of superconducting metal can also be in a superposition (between clockwise and anticlockwise), a bit like a treadmill running forwards and backwards at the same time. Canadian company D-WAVE bases its quantum computing technology on these so-called flux qubits. Its customers include Lockheed Martin, NASA and Google.

A photon of light can be in superposition in the direction it's waving. Some groups, such as at the University of Bristol, have been assembling quantum circuits by sending photons around a maze of optical fibres and mirrors.

HOW DO YOU CREATE THE SUPERPOSITION? —

Have you ever tried to balance a coin on its edge? That's what programming a qubit is like. It involves doing something to a qubit so that, in a sense, it ends up "balanced" between states.

In the case of the atomic nucleus, this might be through zapping it with an electric or magnetic field, leaving it with an equal probability of spinning one way or the other.

SO HOW DO YOU READ INFORMATION FROM THE QUBITS? —

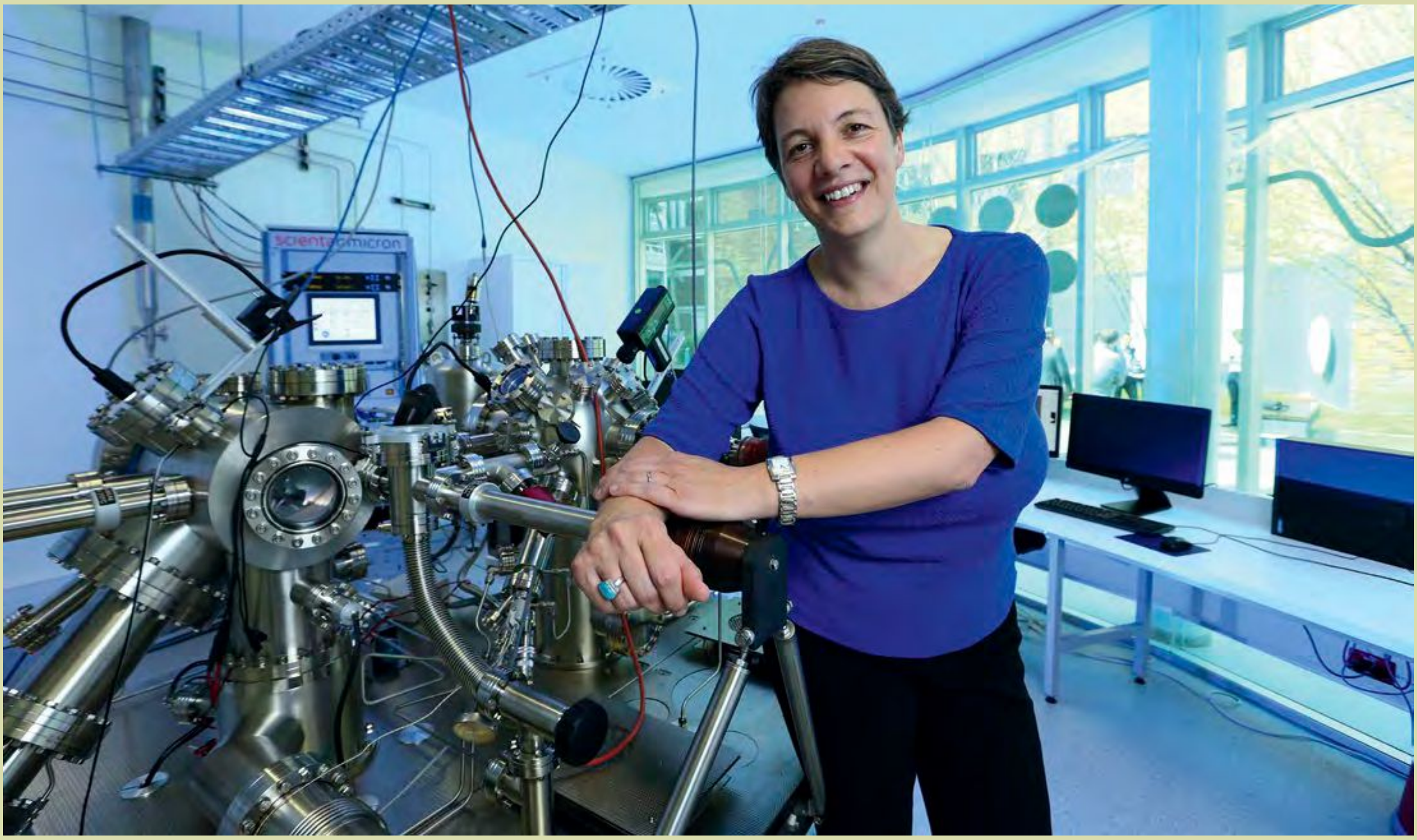
There's an aura of the mystical about what goes on during a quantum computation. The more way-out physicists describe the qubits as engaging in a sort-of quantum séance with parallel worlds to divine the answer.

But it's not magic, it's just quantum mechanics.

Say you've got your new 64-qubit quantum computer up and running for its first computation. You place all 64 qubits in superposition, just like 64 coins all balanced on edge. Together, they hold 264 possible states in limbo. You know one of these states represents the right answer. But which one?

The problem is that reading the qubits causes the superposition to collapse – like banging your fist on the table with all those balanced coins.

Here's where a quantum algorithm like Shor's comes in handy. It loads the qubits to make them more likely to fall on the correct side, and give us the right answer.



Michelle Simmons, at the University of NSW, has made qubits using a single phosophorus atom. CREDIT: BRITTA CAMPION / NEWSPIX

I STILL DON'T GET IT. HOW DO THE QUBITS FACTOR THE NUMBER? WHERE'S THE REST OF THE COMPUTATION? —

We'll admit we're skimping on the details here. For more detailed information try: http://michaelnielsen.org/blog/quantum-computing-for-the-determined/

One take-home message is that a quantum computer is not entirely "quantum" – it still needs a bunch of electronics to do most of the basic work.

HAVE ANY QUANTUM COMPUTERS BEEN BUILT YET? —

Probably not. The work is very much at the research stage, and scientists tend to rave about the assembly of a handful of qubits. In June 2016, for example, *Nature* magazine celebrated a nine qubits computer developed by Google researchers.

Way out ahead of the pack is D-Wave, which claims to have built a large-scale quantum computer with up to 1,024 superconducting loops as qubits. The system seems to do a good job at optimisation problems, such as scheduling airline routes to maximise profit from a limited fleet. Most physicists are sceptical that D-Wave has built a true quantum computer, however.

WHAT'S STOPPING US? WHY IS IT SO DIFFICULT TO BUILD A QUANTUM COMPUTER? —

Although we know in theory what a quantum computer could look like, there are challenges at every level, from assembling qubits to reading and writing information on them, to shuttling information back and forth without it disappearing in a puff of uncertainty.

A qubit is the ultimate diva. While a Hollywood starlet might demand a gigantic dressing room and a bath full of rose petals, a qubit demands perfect isolation and a thermostat set at one-hundredth of a degree above absolute zero. The slightest vibration from a nearby atom can cause a qubit to throw a quantum tantrum, and lose its superposition.

The overriding difficulty is how to maintain the delicate states of superposition and entanglement long enough to run a calculation – the so-called coherence time.

The truth is we don't know how long it will take to build the quantum diva's dressing room, or if it's even possible. Despite this daunting challenge, the race to build the first practical quantum computer has become one of the grand scientific challenges of our time – involving thousands of physicists and engineers at dozens of research institutes scattered around the globe.

— CATHAL O'CONNELL

PEOPLE, CULTURE
& REVIEWS

SPECTRUM

ZEITGEIST

After the astronauts, cometh the archaeologists

In the rush to explore space, the tools we use risk being forgotten. Archaeologist Alice Gorman aims to prevent that happening, reports ANTHEA BATSAKIS. →

01

ZEITGEIST

After the astronauts, cometh the archaeologists

→ The far reaches of space exploration don't usually gel with the annals of archaeology – but for Alice Gorman, it's a match made in heaven.

The 52-year-old space archaeologist at Flinders University in Adelaide, South Australia, is living her childhood dream, assessing the cultural and heritage values of spacecraft, landing sites and crash-landed debris to decide which should be preserved, and which consigned to the junk pile.

"Every now and then I have to pinch myself," Gorman says. Space conferences are usually filled with engineers and mathematicians who handle the technical intricacies of nuts-and-bolts research, she explains, so the cultural significance of space travel is often overlooked.

Much like excavating ancient sites to understand past human behaviour, space archaeology looks at aeronautical artefacts with fresh eyes and places them in the context of our past, present and future.

Her favourite example of modern archaeology, she says, is cable ties. Cable ties! They are items quickly discarded – and then rescued by Gorman to add to her collection – that show the trajectory of different kinds of technology since World War II.

Gorman grew up on a farm in the Riverina area of southern New South Wales, far from big city lights. The constant presence of a big, wide night sky gave her a passion for astrophysics.

But getting there was not a quick journey, nor an easy one. While Gorman was at school in the 1970s and 1980s, women were typically prodded towards humanitarian rather than technical fields.

The pressure was never overt but enough to smother her astronomical ambitions. "You got the really strong impression that, if you weren't brilliant as a girl in maths or physics, you were edged towards more literary fields," she recalls. "If you were just average at those things as a boy, it wasn't seen to be an impediment to continuing."

After graduating, therefore, she moved into her other academic love, archaeology, and quickly became recognised as an expert in stone tools. The work – largely at Australian indigenous heritage sites – was fascinating, but didn't stop her studying astrophysics in her downtime.

In 2002, this brought her to examine the cultural value of a rocket launch site at the Royal Australian Air Force's Woomera Test Range in the South Australian desert. In 2007, the 122,000 km^2 site was bestowed the status of Historic Aerospace Site by the American Institute of Aeronautics and Astronautics.

Not long after Gorman became the first woman ever elected to the board of the Space Industry Association of Australia. These days she sits on its advisory council.

So while women still comprise a minority in space research, she says "it's possible, just by perseverance, to be taken seriously".

Now she is taking part in the first archaeological study of human habitation in space, based on the International Space Station and spearheaded by her colleague Justin Walsh from Chapman University in California.

Their research came about after NASA put a call out for astronauts from a range of backgrounds – but explicitly excluded archaeologists and anthropologists from the mix.

WHY DON'T THEY WANT ARCHAEOLOGISTS? WE'RE USED TO WORKING IN REMOTE LOCATIONS AND IN DIFFICULT CONDITIONS IN THE FIELD. WOULDN'T THAT BE QUITE USEFUL IN SPACE?

"Why don't they want archaeologists?" she asks. "We're used to working in remote locations and in difficult conditions in the field. Wouldn't that be quite useful in space?"

Although there have been physiological and psychological studies on long-haul missions, she says, no research has delved into how people interact with objects in a space environment over time, and how these technological artefacts might carry social meanings.

The ISS study, then, is partly aimed at proving to NASA that archaeologists are, indeed, valuable high above the atmosphere.

Gorman says the approach to space travel has so far been similar to that of 19th Century colonisation – excluding or not giving a voice to entire groups of people.These include not only to women and experts in maverick fields but also local communities affected by space programs, such as indigenous Australians. "Space technology doesn't exist in isolation, but often against a backdrop of colonisation and indigenous alienation from their country," she says.

Our ability to survive in space would be "radically advanced" if we brought in fresh perspectives from a greater diversity of people, she argues. Imagine the rich ideas indigenous communities could bring to the space age, for instance.

"People have this idea that space travel is part of a long evolutionary process and use the past to support current

02

Alice Gorman at Flinders University beneath the "Chandelier", made from the recycled parts of electron microscopes and other decommissioned scientific hardware from university laboratories.

power imbalances," she says. "But the archaeologist knows the past is incredibly diverse."

Shaping how we will explore space down the track also keeps Gorman busy. Now that human footprints will soon imprint the dirt on Mars, contemplating space colonies is no longer restricted to the realm of science fiction.

Gorman says life in space – including potential industrial practices such as asteroid mining –might need different social and political structures to those we're familiar with in Western civilisations. Nuclear families, for instance, are a fairly recent construct that might not work in an isolated colony.

"Are we going to put those social structures into space without considering them?" she muses. "Without an anthropologist or archaeologist, nobody asks those questions. If we settle the rest of the solar system, we shouldn't replicate, uncritically, the social structure we have here and now."

So what would space exploration or settlements look like in an ideal universe?

Gorman believes in the old space treaties from the 1960s – such as the Outer Space Treaty formulated in 1967 and signed by 20 UN member states – that promote the idea space is the common heritage of humanity and access should be open to all, with everyone deriving benefits. "I don't see why we have to let go of the dream," she says.

She explains that while these ideas may seem a bit utopian, if we don't keep talking about those principles, "they'll drop like a cable tie in the dirt and people will forget that's how we started out in space".

ANTHEA BATSAKIS is a writer based in Melbourne, Australia.

IMAGES
01 NASA
02 Elizabeth Weeks

SNAPSHOT

Home is where the heat is

THE DANAKIL DEPRESSION in northern Ethiopa is one of the most inhospitable habitats on Earth. A geological depression at the juncture of three tectonic plates, about 125 metres below sea level, it provides a surreal vista of volcanic rock, lava flows, salt-encrusted plains and sulfur lakes. The climate is unremittingly brutal; it rarely rains and is considered the hottest spot on the planet, the temperature averaging 34°C. Yet even here life manages to survive. In the sulfur springs and lakes, micro-organisms called extremophiles find a home – in the process turning their toxic habitats into colourful attractions. The area is also rich in evidence of past life, with more than 200 palaeontological and archaeological sites identified so far. These have provided a trove of information about the origins of our species, including human remains more than a million years old.

IMAGE
Carl Court / Getty Images

FIELDNOTES

Science's war on art fraud

Technology helps us see what lies beneath.
ANDREW MASTERSON reports.

IN 2016 A TEAM OF scientists led by David Thurrowgood of the National Gallery of Victoria took a painting by French impressionist Edgar Degas to the Australian Synchrotron in order to solve a long-standing mystery.

Art experts had previously noted that the artwork, *Portrait de Femme* (1876-1880) had been painted directly over a previous composition. Faint traces of the earlier work were visible but the piece was otherwise completely obscured – probably as the artist intended.

Thurrowgood and the team at the Synchrotron, in the Melbourne suburb of Clayton, used high-definition X-ray fluorescence (XRF) to penetrate the surface of the painting to reveal (upside down, as it were) the face of an entirely different sitter.

With false colour added to provide at least figurative flesh to the hidden portrait, the result was extraordinary – and a powerful demonstration of how cutting edge science and technology have an increasingly valuable role to play in revealing the secrets of art.

Nowhere is this more the case than in the murky but highly profitable area of forgery. The global art market turns over something north of US$60 billion a year, and some experts estimate that as much as 50% of the works traded are forged.

Now, however, new techniques are being developed in laboratories around the world that look set to make the forgers' lives much more difficult.

GUMSHOE DETECTION

In 2010, German painter Wolfgang Beltracchi was unmasked as one of the most successful art forgers of the modern era, reaping millions of euros through creating near-perfect artworks, mainly in the styles of 20th century masters.

His output included works ostensibly by the great Cubist painter Georges Braque (1882-1963). Should anyone today attempt to repeat that dishonest little trick – and someone, inevitably, will – he or she will find attempts to pass off a moody Braque very, very much more difficult.

In 2016, Clara Granzotto and Kenneth Sutherland from the Art Institute of Chicago developed a new imaging technique to investigate the media used by the French artist in creating a painting titled *Ajax* (1949-54). The work was owned by the institute and catalogued as "oil on paper" but the researchers had a hunch the description was inaccurate.

The pair developed a method of analysing minute particles taken from the edges of the work. Called matrix assisted laser desorption ionisation time-of-flight mass spectrometry (MALDI-TOF MS), the technique uses lasers to ionise large molecules, such as carbohydrates.

When the results were in, Granzotto and Sutherland found the paint mixture contained two separate types of acacia gum. Known in art circles as gum arabic, the substance was a common addition to watercolour paints during the period. This indicated that Braque had used watercolour as well as oil paints to make the piece.

MALDI spectrometry is today used mainly to provide detailed information for conservators and restorers. Should a previously unknown Braque from the same period suddenly come onto the market, however, it's London to a brick any decent dealer will be giving the gumshoe detectives a call.

LOOKS DECEIVE NO MORE

Many methods used to determine the authenticity of paintings – scanning electron microscopy, for instance – necessarily destroy part of the artwork itself.

Perhaps the best known non-destructive investigative method is optical coherence tomography, a medical imaging system that uses near-infrared light and is employed often by ophthamologists to get three-dimensional, highly detailed images of the retina.

In the art world it is extremely useful for providing in-depth data on elements such as the composition and layering of paint. Its main drawback, however, is that it images only very small areas, so using it to map a large canvas is both time-consuming and expensive.

Recognising this problem, a team of computer scientists and art historians from the Pusan National University in South Korea set about designing an alternative. Led by Seonhee Hwang, the group developed a method that combined fibre optics reflectance spectroscopy with a laser-based topographic analysis. The system is able to scan an entire artwork, measuring the colour characteristics of the whole piece. At the same time, a laser-based map of the thousands minuscule ridges created by the artist's brushstrokes and fingerprints is also produced.

To test the accuracy of their new technique, Hwang

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Penetrating insights: high-tech methods such as X-ray fluorescence are revolutionising art conservation and authentication.

and colleagues commissioned expert painters to create forgeries of paintings by well-known Korean artists. The system was then used on the originals and the fakes. Writing in *PLOS ONE* in February this year, the researchers reported that the reflectance spectroscopy identified the forgery in 76% of cases, while the laser topography was successful every time.

IT'S IN THE DNA

Once upon a time an artist's signature – down there, in the corner of the painting – was just about all the verification anyone needed to be sure an artwork was genuine. If you had the provenance as well – the documented history of the work's sales and owners – no more proof was needed.

Such innocent days are long gone. Signatures and records of sale can both be forged; and even the experts, from time to time, are fooled.

Is there, then, a foolproof way to establish that a work is genuine? For new paintings, the answer is yes, and it involves synthetic DNA. A technique developed at the Global Centre for Innovation at the State University of New York involves inserting a tiny amount of specially created genetic code into still-wet paint – establishing a permanent, updatable record a little like a microchip inside a pet cat.

The system was developed at the behest of a company called the ARIS Title Insurance Corporation, which specialises in insuring fine art. Although still in its infancy, the company intends to log the DNA – each piece unique and created to order – into a database, which will also contain provenance information. To verify the authenticity of a tagged work, all any dealer will have to do is run a proprietary scanner over the canvas.

The DNA bonds with the media used to make the artwork, so it is impossible to remove it, let alone copy the work. The system – dubbed the i2M Standard – is now being trialled, with a full-scale rollout expected soon.

DOING YOUR BLOCK

If master forgers often get away with creating fake oil paintings, imagine what they can get away with digitally made art, a medium that can be copied any number of times without the slightest change occurring.

Everyone knows digital art is endlessly reproducible, but over the past few years artists who work specifically in digital media have started to attract big prices for their creations. Since then, two questions have become urgent: how do the artists protect their originals; and how can buyers be sure they are getting the genuine article?

The answer is a blockchain – the same type of recording technology now commonplace in the world of online currencies such as Bitcoin.

A blockchain is a growing database of individual transaction records (known as blocks). Each transaction produces a timestamp and a link to the previous one – creating a verifiable and (theoretically, at least) forger-proof provenance.

Several companies in the art world are already offering blockchain verification services to artists keen to maintain control over their creations.

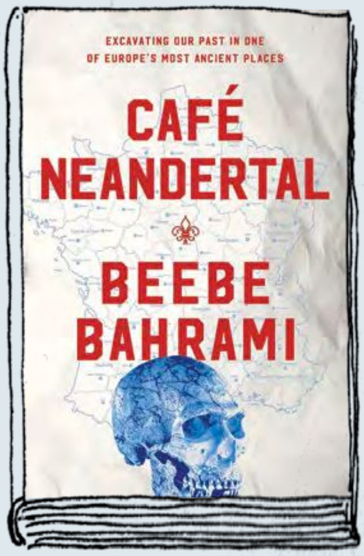
In the world of digital art this is quickly emerging as a critical course. In a field where 10 people can display artworks that to all intents and purposes are exactly the same, there has to be some way to verify who has the "real" – and hence really valuable – one.

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

IMAGES
01 David Thurrowgood

REVIEWS

Culture and our complex cousins



NON-FICTION
Café Neandertal:
Tracking One of Prehistory's Biggest Mysteries in One of France's Most Ancient Places
by BEEBE BAHRAMI

Counterpoint (2017)
RRP $26.00

THE RELATIONSHIP WITH our distant Neanderthal cousins is complex – part origin story, part romance, both larded with an unhealthy dollop of Rousseau's Noble Savage. We admire them and relate to their plight, but there is also disdain. "Neanderthal" remains a term of abuse, synonymous with slow wits and a lack of sophistication, no matter how much evidence we might find of the real Neanderthals' advanced tool use and the survival skills we have lost, if we ever we held them.

Then there is the small matter of their extinction. They must have been inferior to modern humans if we survived and they didn't, right? But, as one scientist in *Café Neandertal* points out, Neanderthals lived for more than 250,000 years, whereas we *Homo sapiens* have only managed 160,000 so far.

But that hasn't stopped our growing fascination, driven in large measure by geneticist Svante Pääbo, whose lifelong obsession with ancient DNA has helped to write pages of paleo history that seemed lost forever. With the discovery that there is a little bit of them in all of us has come insights into our own human origins.

It doesn't matter that most of what we think we know about what it means to be Neanderthal is almost certainly wrong – and, some believe, might not be possible to ever get right. "We think with the *Homo sapiens* mind," Bahrami quotes one archaeologist as saying. "We can't possibly know the Neandertal reality."

Yet it is precisely the search for that reality which lies at the heart of this beautifully crafted book.

While Bahrami gives an excellent account of the pioneering DNA sequencing of Pääbo and others, it is the story of the extraordinary work of palaeoanthropologists – struggling to bring the Neanderthals to life, to recreate how they lived, loved and died – that clearly captures her imagination.

Mind you, it was with an inward groan that I read from the blurb: "*Café Neandertal* is also a detective story, investigating one of the biggest mysteries of prehistory and archaeology." The detective story trope is too often the cliché juste publicists grope for to describe any straightforward piece of scientific enquiry. But as it turns out, it is entirely justified with *Café Neandertal*, which indeed picks up the many pieces of the puzzle, carefully examines them and painstakingly places them in context.

In many ways it is a most unusual science book. Bahrami is a wonderful writer who brings many of the attributes of the novel to a clear and compelling narrative that encapsulates a snapshot of the state of current knowledge about Neanderthals.

Peopled with a vast cast of fascinating characters, from village locals to querulous scientists, it brings to life the excitement of unearthing the past and describes the "new, more enlightened era in studies of human evolution" that is dawning.

Bahrami is an anthropologist by training and throughout this book those roots show. Brought up in the American school of cultural anthropology, as a student she was encouraged to undergo psychotherapy before going out into the field. The thinking was that unless one's own biases were uncovered and known, any reading of another cultural system was bound to become tainted by mirroring the psyche of the researcher – a problem she notes is rampant in the field of palaeoanthropology.

> THE DETECTIVE STORY TROPE IS TOO OFTEN THE CLICHE PUBLICISTS USE TO DESCRIBE ANY PIECE OF SCIENTIFIC ENQUIRY. BUT AS IT TURNS OUT, HERE IT IS ENTIRELY JUSTIFIED.

Given the incomplete picture of the deep past that we have at any given time, she notes, archaeology is as much art as science. This almost inevitably leads to emotion creeping in. "Thinking that Neandertals buried their dead," archaeologist Dennis Sandgathe is quoted as saying, "makes them more human, more like us, so we like this idea."

The book begins and ends in the southwest of France in the beautiful and ancient Périgord region, which itself plays a starring role. Bahrami draws the book's title from the near-universal fascination for prehistory among those who live within reach of the Dordogne River, an area with the richest concentration of early hominid sites in the world. Locals, she found, whether born there or, like her, migrants to the region, feel a deep spiritual connection to its prehistory, "a profound connection to life, land, and spirit for all who came later". That sense of place is what led to her realisation "we all existed in a special place, one I called Café Neandertal".

The book follows the main dig at the La Ferrassie site in the Vézère valley from 2010 to 2014, and the subsequent lab work through the summer of 2015.

It is not the first time La Ferrassie – the motherlode of Neanderthal sites in Europe – has been excavated. Nor will it be the last. As Bahrami explains, archaeology is a multi-generational process, in which one generation of archaeologists will close a dig with the hope the next have better techniques and tools to winkle out a more accurate picture of the long past.

And La Ferrassie holds many secrets. Of 30 or so nearly complete skeletons of Neanderthals found across the world, the site has yielded seven.

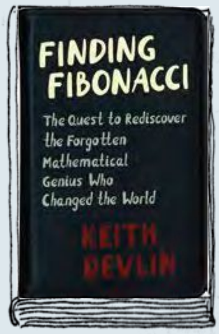
The latest mission was designed to reinvestigate the question of whether Neanderthals buried their dead – and whether they had at La Ferrassie, as earlier generations had conjectured. This was to be done by using improved state-of-the-art excavation techniques. There were also questions of tool creation and use, innovation and creativity, love and family to be addressed, along with, perhaps the most vexed problem of all, why did the Neanderthals disappear around 35,000 years ago?

While there are no definitive answers to any of these questions, and probably never will be, Bahrami helps us to understand the value of trying.

As one of the leading scientists explains to the author: "We need to remain humble, and know we will never know everything. We'll never unlock the entire mystery of human evolution." But that, he adds, is what makes it so exciting.

— BILL CONDIE

BRIEFLY NOTED

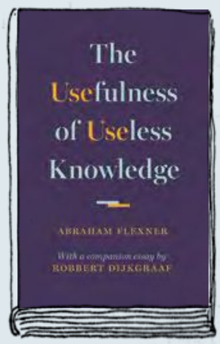


NON-FICTION

Finding Fibonacci: The Quest to Rediscover the Forgotten Mathematical Genius Who Changed the World
by KEITH DEVLIN

Princeton University Press (2017)
RRP $29.95

ONE MAN'S personal quest to understand Leonardo Bonacci, better known as Fibonacci, the 13th century mathematician known to many as the father of the modern maths. Devlin's search brings together travelogue, history and detective work. Most famous for the Fibonacci numbers – which he didn't invent – Fibonacci's greatest contribution was the 1202 "Book of Calculation" that introduced modern arithmetic to the Western world.



NON-FICTION

The Usefulness of Useless Knowledge
by ABRAHAM FLEXNER
With a companion essay by ROBBERT DIJKGRAAF

Princeton University Press (2017)
RRP $9.95

DO WE GET OUR best value from research by removing the shackles and letting our scientists dream big? That's what Abraham Flexner, founder of the Institute for Advanced Study in Princeton, argues in his elegant 1939 essay. We can't plan great inventions, or applications we might find for them. A welcome argument for passion and curiosty in these bottom-line obssessed times, updated with a companion essay by Dutch string theorist Robbert Dijkgraaf.

NON-FICTION

Cave Art
by BRUNO DAVID

Thames & Hudson (2017)
RRP $24.95

AUSTRALIAN ARCHAEOLOGIST Bruno David's comprehensive and fascinating book delves into some of humanity's earliest artistic endeavours. In a story spanning many millennia he explores the historical connections between people and places and attempts to untangle what the mysterious cave decoration can tell us about our anscestors from the oldest known art in Africa to the wealth of Ice Age Europe and beyond.

REVIEWS

Image is everything

EVENT

Nature's Best Photography: Windland Smith Rice International Awards

Smithsonian Museum, until September 2017

SNAPPING THE perfect picture is no easy task, particularly for nature photographers. These persistent artists must climb, crawl, camouflage and battle savage environmental conditions to capture life at its most telling.

Each year the annual Nature's Best Photography Windland Smith Rice International Awards rewards the most compelling examples of nature photography.

In 2016, the 21st year of the esteemed awards, more than 20,000 entries worldwide were submitted and judged on technical quality, originality and artistic merit. Now the winning entries, along with a selection of "highly honoured" images from other Nature's Best Photography competitions, are on display at the Smithsonian National Museum of Natural History in Washington DC. The free exhibition runs until September.

More than 80 photographs are included in the exhibition. The images range from stark close-ups, detailing every fluff, wrinkle and sheen, to portraits and immersive, panoramic landscapes. They are divided into various categories, focusing on themes such as Africa, the polar regions, oceans and birdlife.

Taking out the title of the Grand Prize Winner in 2016 was Swiss photographer Daisy Gilardini, who captured a family of polar bears playing in the snow in Canada. Gilardini is a full-time photographer and has travelled to the snow more than 60 times since 1997. For this shot, Gilardini lay flat on the frozen ground, fearing frostbite but staying resolute until she caught the perfect moment.

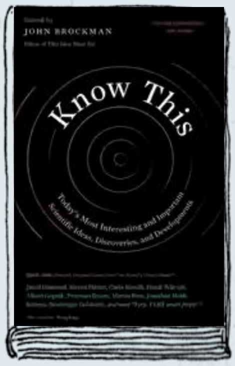
The annual prizes and exhibition, first launched in 1996, aim to deepen people's connection to the planet through photography.

Says Gilardini: "Science is the brain, while photography is the heart."

Images from the current and past Windland Smith Rice International Awards can be found at *naturalhistory.si.edu*

— ANTHEA BATSAKIS

IMAGE
Daisy Gilardini



NON-FICTION
**Know This:
Today's Most Interesting
and Important Scientific Ideas,
Discoveries, and Developments**
edited by JOHN BROCKMAN

HaperCollins (2017)
RRP $27.99

THE EDGE.org is the website of the Edge Foundation, which was launched in 1996 as the online version of "The Reality Club", an association of science and technology intellectuals who met from 1981 to 1996 to have their ideas challenged by others in the group.

The driving force of Edge is a Boston literary agent and author with a scientific bent, John Brockman. But it takes its name from the motto of the Reality Club, inspired by the late artist-philosopher James Lee Byars: "To arrive at the edge of the world's knowledge, seek out the most complex and sophisticated minds, put them in a room together, and have them ask each other the questions they are asking themselves."

Most years, Brockman comes out with an anthology of essays by the world's finest thinkers about a specific scientific theme – the aim being to examine it from as many angles as possible. Of course, it's also a lovely excuse to rummage around inside the minds of some of the best and brightest scholars around today and to reinforce Brockman's unapologetic faith in Enlightenment culture.

"The gifts of progress we have enjoyed are the result of institutions and norms that have been entrenched in the last two centurie: reason, science, technology, education, expertise, democracy, regulated markets and a moral commitment to human rights and human flourishing," he writes. While the world might fall short of a utopia, the norms and institutions of modernity "have put us on a good track.

The past few years has seen Brockman pose questions about hidden threats in *What Should We Be Worried About?* and scientific theories that are blocking progress in *This Idea Must Die* and *What to Think About Machines That Think*.

This year's poser – "What do you consider the most interesting recent scientific news?" – resulted in 197 responses displaying an exhilarating variety of topic and author speciality. Most of the contributors are scientists but there are also psychologists, economists, sociologists, linguists, artists, poets, musicians and philosophers.

The responses are organised by topic and cover global warming and climate change; dark matter, dark energy and quantum gravity; gene editing; what it will mean to be human in a world dominated by Big Data and artificial intelligence; and the mind-bending number of planets out there orbiting distant stars.

Contributors form a dazzling constellation in themselves, including Pulitzer Prize-winning author Jared Diamond on the best way to understand complex problems; *Seven Brief Lessons on Physics* author Carlo Rovelli on the mystery of black holes; Harvard psychologist Steven Pinker on the quantification of human progress; Harvard physicist Lisa Randall on the true measure of breakthrough discoveries; Nobel Prize-winning physicist Frank Wilczec on why the 21st century will be shaped by our mastery of the laws of matter, and music legend Peter Gabriel on tearing down the barriers between imagination and reality.

The short essays are conveniently bite-sized, making this a volume to keep by your side to dip into again and again – a great travel or nightstand companion or an *aide memoire* for further study.

— BILL CONDIE

TOP 5

Bestsellers

1

Hidden Figures
by MARGOT LEE SHETTERLY

HarperCollins (2016)
RRP$44.99

2

When Breath Becomes Air
by PAUL KALANITHI

Random House (2016)
RRP$14.95

3

The Lost City of the Monkey God
by DOUGLAS PRESTON

Grand Central (2017)
RRP$56.99

4

The Undoing Project
by MICHAEL LEWIS

Norton (2016)
RRP$45.00

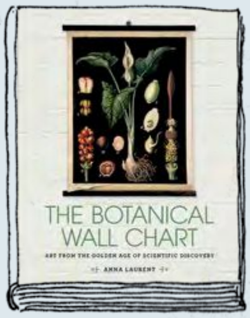
5

You Are the Universe
by DEEPAK CHOPRA AND MENAS KAFATOS

Harmony (2017)
RRP$32.99

— FROM THE NEW YORK TIMES SCIENCE BESTSELLER LIST

REVIEWS



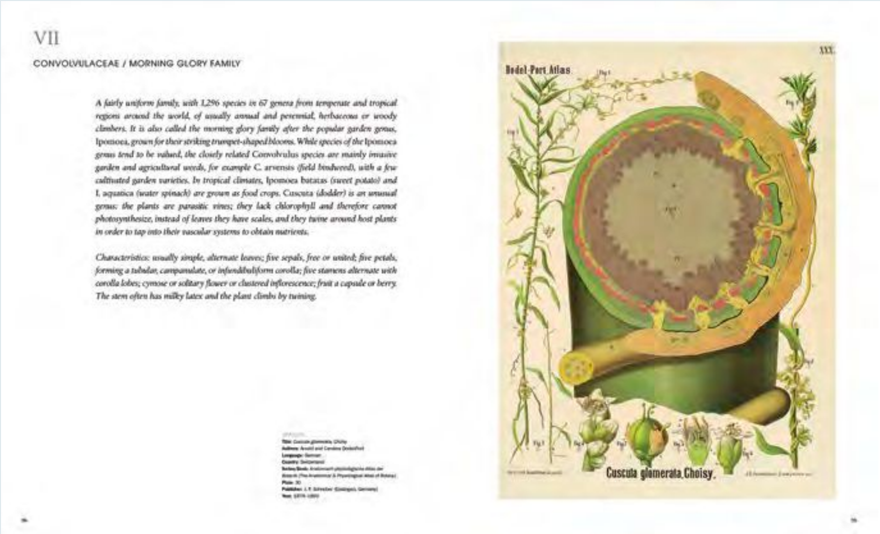
NON-FICTION

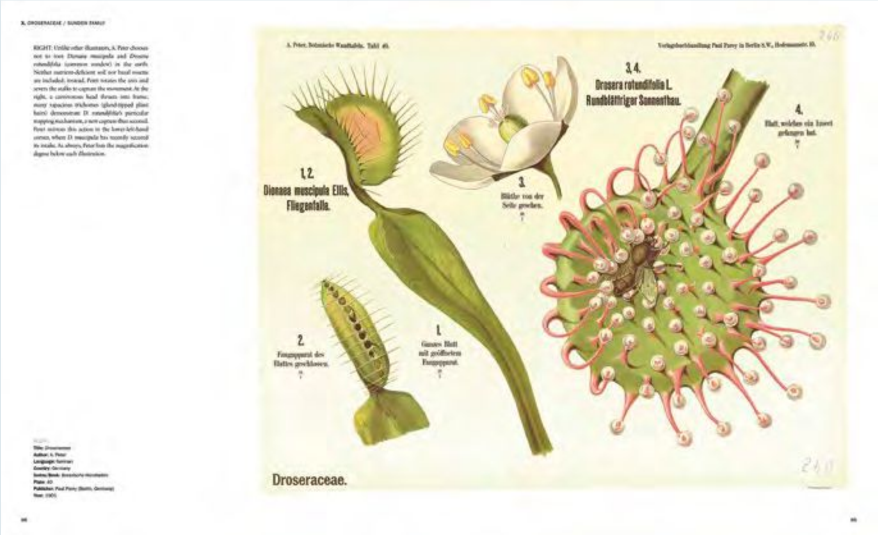
The Botanical Wall Chart: Art from the Golden Age of Science Discovery by ANNA LAURENT

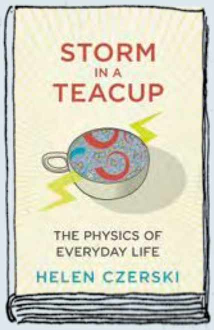
Ilex (2016)
RRP $49.99 Hardback

LONG BEFORE photography, scientists relied on drawings and paintings of specimens for their study. This led to an amazing convergence of art and science in the late 19th and early 20th centuries. Scientific – and specially botanical – illustrations and wall charts are enjoying a well-deserved resurgence in interest as both objet d'art and historical records. Writer and photographer Anna Laurent encapsulates this Renaissance-like convergence with a varied career that began studying biological anthropology and literature at Harvard, before becoming, first, a documentary filmmaker and then a botanist in Southern California. Since 2010 she has been a writer and producer for an ongoing documentary called *The Iraqi Seed Project*, about heirloom species and economic botany in the Fertile Crescent . This book is a tribute to her passion.

— BILL CONDIE







NON-FICTION
Storm In A Teacup: the physics of everyday life
By HELEN CZERSKI

Bantam Press (2017)
RRP $34.99

TO MAKE THE POINT that the forces that govern the universe also determine what goes on in your house can be a revealing strategy for pop science exploration or a banal statement of the obvious. The difference lies in the skill of the person making the point.

Helen Czerski is both a physicist and a BBC television presenter. The odds, then, suggest this book should be a winner. Sadly, this turns out not to be the case. Though certainly not without merit – and containing a host of fascinating facts and figures – the book is nevertheless weighed down by a curiously opaque style, and hampered by less than rigorous editing.

Storm In A Teacup contains nine chapters, each exploring a separate area of physics, including gas laws, gravity, viscosity, equilibrium, atoms and electromagnetism. The approach is the same for each: start with something small and familiar, illustrate the principle of physics at issue, and then broaden focus to encompass both subatomic and cosmological perspectives.

It's a serviceable enough approach, but its success depends crucially on conveying delight and enthusiasm in revealing the momentous forces that shape the banalities of day-to-day life.

Czerski does, no doubt, derive these little pleasures but she has a sometimes awkward way of showing it. Her chapter on equilibrium, for instance, opens by way of tomato ketchup and its tendency to be difficult to extract from the bottle in an orderly manner. It's a functional observation, but a depressingly hackneyed one, extended over three pages. Her intent is to make the point that timescales – rapid or slow movements – change the way solids and liquids behave; but at that length, ketchup just isn't that interesting.

Attention is sustained by hope (fainter at every sentence) the author might be about to plunge us into the fascinating world of non-Newtonian fluids, of which ketchup is a great example. But the subject never crops up. This is odd, given that when not on the telly Czerki's speciality is fluid dynamics and bubble formation.

The ketchup introduction does, however, eventually lead to this statement: "Time matters for coffee and pigeons and tall buildings, and the timescale that matters is different for each of them." This neatly epitomises Czerski's most noticeable stylistic trait, a tendency to stand just on the wrong side of the dividing line between illuminating and dull.

A little later in the same chapter, for instance, she discusses the idea of equilibrium, opening with the attention-grabbing statement that "Mid-afternoon teabreak is an essential part of my working day." This introduces a multi-page exploration of the fact that coffee sloshes in a cup if you try to walk with it, and that different sized cups produce different rates of slosh.

"A mostly full mug always sloshes the same number of times each second, however big the initial push was," she writes, roughly halfway through the section. "But that number depends on the mug, and the thing that matters most is the mug radius."

There are quite an array of passages in the book that require (with the best will in the world) an extra burst of concentration from the reader to combat the temptation to glance sideways at something shiny.

Occasionally, too, one can be forgiven for thinking that perhaps Czerski herself drifted off a wee bit during the writing. How else, for instance, can one explain a sentence, complete with disordered syntax, such as this: "Fossil fuels are made of up plants that built themselves using energy from the Sun, diverting that energy from its alternative outlet: gentle warmth, which is the equivalent of the bottom of the river when it comes to usefulness."

One might have expected an editor to suggest reframing the sentence such that its meaning was clear and its constituent parts in the correct order but, annoyingly, throughout the book the author has been poorly served in this regard.

Mostly the editing flaws are minor, but irritating in their number: the inclusion of both imperial and metric units in the first few pages, for instance, or a missing capital in a species binomial. Simple things.

More complex things, too, could have greatly assisted the text. In her chapter on atoms, for instance, Czerski uses minor variants of the phrase "we can't see the individual atoms" three times in four paragraphs. In the hands of a skilled writer, repetition can be used to great effect; in this case, you get the feeling, it was just that nobody re-read the section.

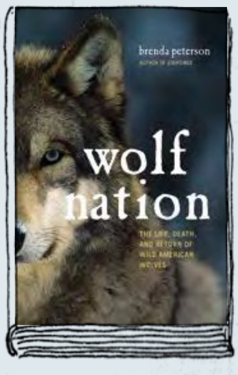
> THERE'S A TENDENCY TO STAND JUST ON THE WRONG SIDE OF THE DIVIDING LINE BETWEEN ILLUMINATING AND DULL.

A little later in the chapter, the author relates how while making a television documentary she experienced a monsoon in India. For a tantalising paragraph or two an interesting anecdote seems set to emerge, only to gradually morph into a description of how wet clothes do, or do not, dry.

In the end, the reader is left with little insight into the passions and excitements of the author – in contrast to the experience of reading other physics popularisers, such as Richard Feynman, or Brian Greene. What we do discover, though, is that Helen Czerski likes diving, although not from anything higher than five metres above the water, and is fascinated by ways to stop her swimming goggles fogging up. And that, like the book itself, is as enthralling as it gets.

— ANDREW MASTERSON

REVIEWS



NON-FICTION

Wolf Nation: The Life, Death, and Return of Wild American Wolves
by BRENDA PETERSON

Hachette - Merloyd Lawrence (2017)
RRP $36.85

ONE GROUP DID NOT rejoice at the return of the grey wolf to Yellowstone National Park in 1995 – the coyotes. The last wolves in Yellowstone had been killed in 1926 and without them the coyotes had become abundant. In a healthy ecosystem, wolves and coyotes compete – usually with the wolves simply running the coyotes off their territory. But, especially when the numbers are so high, wolves will kill and eat the smaller canines – easy prey. So it was in Yellowstone.

It was not the only dramatic change from the apex predator returning to its old hood. Many of those changes are counter-intuitive, with numbers of prey animals rising even as the wolves feed off them.

These days there are at least 98 wolves in 10 packs living primarily in Yellowstone. There are also three times as many elk in the park as in 1968. There was only one beaver colony in 1995 but now the park is home to at least nine. Throughout the ecosystem the effect of the return of the wolf is being felt, and in an overwhelmingly positive way.

When, for example, the elk population was a third of what it is today, willow stands along streams were rapidly dying out, browsed out of business by the foraging ruminants. Today, with wolves keeping the elk on the move, willows are in robust good health, and doing a good job shoring up river banks against erosion.

Usually the term “trophic top-down cascade” has negative connotations as ecologists describe the devastating flow-on effects of removing a top predator. In the case of Yellowstone the cascade is a positive, with the return of the apex predators having a beneficial effect on systems way beyond willows and beavers.

Despite such positive outcomes, easily demonstrated, there is still a long way to go. As renowned nature writer Brenda Peterson notes: “To return wolves to their native lands will take not just time but also a change in cultural values – an evolution in the American character.”

In 1872 when Yellowstone Park was created, the grey wolf population was already in decline across Montana, Wyoming and Idaho. The extermination gathered pace in the early years of the 20th century with government predator control programs. By the 1920s they were gone. For Peterson that was a loss, not just for the ecosystem but for the culture.

Wolf Nation takes a comprehensive look at the 300-year history of wild wolves in America and their complicated relations with humans living there.

To the early settlers, the wolf was an enemy to be treated like the wilderness itself – something to be subdued and excluded. Even today, while some enlightened farmers learn to live beside the animals, others want to return to the old ways of driving them to destruction.

THE CREATURES ARE THE MOST MISUNDERSTOOD OF ANIMALS, AND AMONG THE MOST MAJESTIC.

As Peterson notes, these creatures are the most misunderstood and maligned of animals while at the same time among the most majestic and mysterious of all our creatures. They are a paradox, says pioneering wolf biologist Douglas Smith – creatures of extraordinary strength, with an ability to thrive given half a chance, but also a reminder of how frail natural vitality can be when humans are determined to wipe it from the face of the Earth.

Peterson’s is a comprehensive look at these animals – their behaviour and biology, why they howl and how they hunt, how alpha females can lead a family pack, and how their presence has improved every ecology to which they have returned.

She tracks individual animals, such as the larger-than-life Yellowstone female 832F – also known as 06 Female, for the year of her birth – perhaps the most famous wolf in the world.

As matriarch of Yellowstone’s Lamar Valley Pack, 06 earned a reputation as an amazing hunter until she was shot dead one day in 2013, just 24 kilometres east of the park in Wyoming. Her obit appeared in *The New York Times* and her death became a focus of the clash between the competing beliefs of wildlife management, scientists and hunting advocates.

Many believed the animal was shot precisely to aggravate the wolves’ supporters. “They’ve been waiting 17 years in Wyoming to kill wolves,” said Laurie Lyman, a retired schoolteacher and one of the most dedicated wolf-watchers of Yellowstone, at the time. “They wanted to get those wolves because it hurts the people who watch them. They did it to stick it to us.”

For 06’s family it was a tragedy, too, Peterson notes: “After 06 was shot, her mate, 755M left his family... Animals mourn. We know that much from much-documented research about animal emotions and behaviour.” (In another surprising twist, 755M, against the odds, survived the loss of his mate and the hunting support she provided. One of 755’s daughters, wolf 926, became matriarch of her own Lamar Valley pack.)

But 06 did not die in vain. Whatever the hunter’s motives, the killing did much to fire up the determination of wolves’ supporters – and there are many, including those ranchers who have learned to live alongside the wolves.

There is much to play for. As Peterson concludes, “the wolf nation must thrive if we are to make the world wild and whole again”.

— BILL CONDIE

Back to Earth

FILM
Planet Earth II
BBC

Available through streaming services and DVD

IT'S EASY TO FEEL HELPLESS when we're so often confronted with news about devastated animal habitats. But *Planet Earth II* is a happy, though cautious, reminder of the wildlife that continues to thrive on our planet.

Narrated by David Attenborough, still vibrant at 90, *Planet Earth II* was released 10 years after the first Planet Earth series, and each hour-long episode takes its viewers to a different geographical location: islands, mountains, jungles, grasslands, deserts and cities.

In the intervening decade, technology has advanced, allowing closer, more dramatic footage. Open-mouthed viewers can watch, in perfect detail, lemurs criss-cross through trees, or bloodied drool drip from a Komodo dragon's mouth, for instance.

In fact, the quality of the footage is, at times, so astounding some viewers have alleged it to be computer generated, but no cheat shots were used. The final 15 minutes of every episode is a behind-the-scenes look at how the film crew battled the elements to capture the images.

The stunning results are shown against an evocative score composed by Hollywood legend Hans Zimmer, whose credits include the soundtracks for *Gladiator* and *Interstellar*.

The series explains that many animals can't adapt fast enough, and the show ends on a sobering, though hopeful, note. "Could it not be possible to build cities more in harmony with nature?" Attenborough asks.

Planet Earth II is worth a watch. Ultimately it shows how fragile the balance of life on the planet is, but does so without abandoning a refreshing sense of optimism.

— ANTHEA BATSAKIS

IMAGE
BBC / Ruth Peacey

GADGET

CAMERA
Brio webcam
LOGITECH

MOST LAPTOPS have cameras in-built, but prolific streamers and Skype enthusiasts might still consider the new Brio from Logitech, because it's the first ultra high definition webcam that streams in what is known as 4K HDR.

To translate: 4K refers to a picture quality with a resolution of 3840 pixels x 2160 lines, or 8.3 megapixels. HDR stands for *high dynamic range*, meaning it delivers greater depths of colour than standard television.

The film and TV industry has been relatively slow to adopt 4K, but video-sharing platforms such as YouTube have welcomed it since 2010.

The Brio features a 5-times digital zoom, multiple fields of view so you can focus on what's most important, and works in any lighting. It also comes with infrared facial recognition, meaning you can use it as your computer log-in system if you want.

The webcam is only compatible with recent model devices, so checking with your friendly neighbourhood geek is strongly recommended before shelling out for one.

— ANTHEA BATSAKIS

REVIEWS

NON-FICTION
Lotus Blue
by Cat Sparks

Talos (2017)
RRP $19.95

CAT SPARKS LIVES and breathes literary sci-fi. During an earlier incarnation as fiction editor for *Cosmos* she always showed a talent for the smart, savvy modern expression of the genre. *Lotus Blue* shows she has a talent for writing it, too.

Set in an environmentally degraded post-apocalyptic future that could become common enough across the planet the way we are going, her debut novel is unmistakably Australian.

The desert's encroachment on what habitable land remains, and the bandits that rule the wasteland of the interior, echo the "otherness" with which Australian writers have often viewed the outback, even in the good times. And these are definitely not those.

The landscape Sparks describes has a *Mad Max*-meets-*Dune* feel, with a bit of Tatooine thrown into its dysfunctional, desolate towns (weaponised lantana as a sort of biological razor wire is an inspired touch).

But the setting is a backdrop for a wonderfully inventive story centred around Star and her sister Nene, nomadic orphans travelling in a caravan through the treacherous desert where the pair face many terrors, including the Templars – genetically and mechanically enhanced human/cyborg troops – and the Tankers – war machines running amok on corrupted programs.

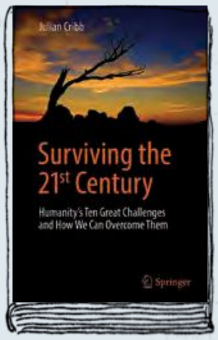
But there is a much greater danger lying in the desert – Lotus Blue, an ancient and malevolent machine, now awakening. It will stop at nothing to carry out its mission.

And then there are the sisters' own malevolent family secrets …

It's a great read, but it is also a fine first literary attempt which calls to mind the world of J.G. Ballard – the dystopian modernity and the somewhat pessimistic take on humanity's inherent failings.

Whether read as a rollocking, fast-paced entertainment or as a clever and well-observed comment on the human condition as it might be under even more bleak conditions in the future, *Lotus Blue* works well on both levels.

— BILL CONDIE



NON-FICTION

Surviving the 21st Century: Humanity's Ten Great Challenges and How We Can Overcome Them
by JULIAN CRIBB

Springer (2017)
RRP $51.99

WELL-KNOWN AUSTRALIAN science author Julian Cribb has long made it known that he considers the formal binomial nomenclature for our species woefully inappropriate. *Homo sapiens* translates as 'wise man', an odd label, he points out, for an ape that seems intent on doing its level best to destroy the planet.

It's a theme Cribb runs with in his latest book, in which over nine crisp chapters he dives deep into anthropogenic environmental damage and climate change. Each section is cast in the mode of a destructive human shortcoming, and the revised binomial that characteristic might, or should, attract.

Thus our tendency to overconfidence and self-worship attracts *Homo suilaudans*, our role in global warming sees us cast as *Homo pistor* (The Baker), our development of nuclear weapons and tendency to go a-warring attracts the epithet *Homo carnifex* (The Butcher), and so on.

It's a neat device that serves well to aid the author's task of organising a phenomenal amount of information – from recent science to ancient history, from geology to geopolitics – into a surprisingly breezy 216 pages, excluding references.

Any book that takes a broad view of the multiple ways in which agriculture, conflict, industry and urban development are combining to foul up this planet six ways from Sunday risks, of course, becoming little more than a droning litany of doom-laden prediction (however accurate and necessary).

Cribb, however, a veteran journo and winner of several Eureka Prizes, is too skillful a writer to allow that to happen. In each chapter he leavens his careful analysis of what's going wrong with a selection of carefully crafted suggestions about what we can do to ameliorate the situation. These range from education to corporate lobbying to civil action.

They are useful, if occasionally obvious, things to put on the to-do list, and, in the context of the book, a necessary antidote to the bad news it contains in great amounts.

He is mindful to include suggested pathways by which change may be effected. His ideas here, while generally sound, are perhaps the weakest element of the book.

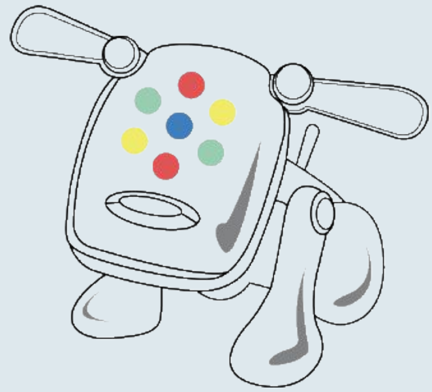
Cribb frequently advocates market mechanisms – such as price signalling, taxation, or eliminating subsidies – as means to curb environmentally destructive practices, or to encourage benign ones. These might well work in certain contexts, of course, but the focus on such strategies arguably neglects a broader analysis of whether – echoing French economist Thomas Piketty here – the capitalist system itself is inherently incapable of producing just outcomes.

Still, Cribb does at least reference Piketty, and in the final chapter makes much of the need to "reframe our economic, political, religious and narrative discourses" to achieve more human-friendly outcomes – so perhaps I'm being a little harsh.

For all its unpleasant facts, *Surviving the 21st Century* manages not to be a depressing read. Cribb's skill at storytelling, his ability to manage pace and tone, never let the narrative bog down. Occasionally, too, the idiosyncrasies of his thoughts provide surprising and welcome distraction. His tirade about teddy bear collectors, in particular, is a gem.

— ANDREW MASTERSON

THEN & NOW



IDOG

Sega Toys
QUEENSLAND UNIVERSITY OF TECHNOLOGY

IN THE FIRST of a new series, we dig into the *Cosmos* archives and look back at what was exciting the technology world in days gone by. Some have aged well, while others make you wonder why they were ever invented at all.

In this issue go back to when, if not the cosmos, *Cosmos* was young – issue number four in 2005 to be precise – and the world was being introduced to the pet robot pooch iDog.

The device, one of several products to be released that year on the back of the still-novel iPod, was made by Sega and was a music composer, speaker system and dancer all in one.

The iDog came with hundreds of inbuilt fragments of tunes and would, on request, dynamically string them together and boogie away to them.

If you wanted your own music, you could plug in an MP3 player such as an iPod, channel music from there into the dog which danced to the beat.

In 2007 an upgraded version, iDog Amp'd, was released with stereo speakers. That year it also became part of a Happy Meal promotion with McDonald's. In 2009, Sega released the stuffed iDog Soft Speaker and the iDog plush puppy. Sightings since then have been rare.

— BILL CONDIE

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

Abacus

The power of 1.00137841887

Only the slightest difference between the neutron and proton makes them weapons of mass creation

GALILEO FAMOUSLY WROTE that the book of nature is "written in mathematical language". It's true that numbers crop up everywhere in the lives of scientists and engineers. But not all numbers are equal: some numbers are much more significant than others. The number of kookaburras in New South Wales on Christmas Day may be of interest to ornithologists, but is hardly of cosmic importance.

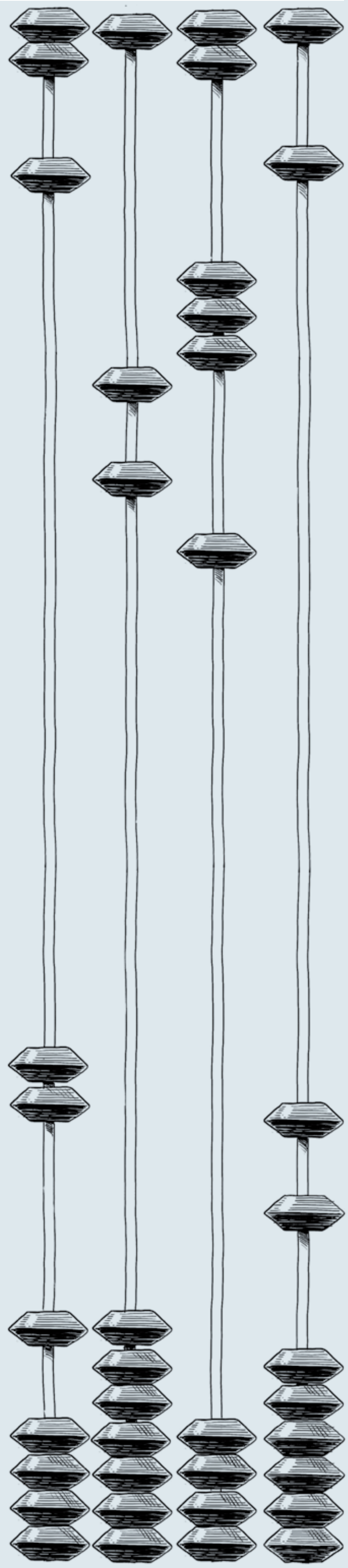
A few numbers do seem to be fundamental to the workings of the universe, however, because they describe the most basic processes of nature. High on this list are the masses of subatomic particles. Dozens of particles are known to physicists, but the most familiar are the constituents of atoms: electrons, protons and neutrons. The proton is about 1,836 times as heavy as the electron; nobody knows why nature picked that particular number. The neutron is very slightly heavier than the proton, by about 0.1%, or 1.00137841887 according to the best measurements. Why is this? Did the Great Cosmic Designer initially intend the proton and neutron to have same mass but then threw in a bit more for the neutron as an afterthought?

The neutron-proton mass difference may seem trivial but it has momentous consequences, because mass is a form of energy (remember $E = mc^2$). The neutron, as it happens, has a little more mass (and thus energy) than a proton and an electron combined. There is a general principle in nature that physical systems, when left alone, seek out their lowest energy state. Sure enough, an isolated neutron will soon, within about 15 minutes on average, spontaneously turn into an electron and a proton, a process known as beta decay. (Another particle, called an antineutrino, is also involved, but that need not concern us here because it is almost massless.) The only reason that any neutrons still exist is because, within a few minutes after the hot big bang that made the universe, some neutrons stuck themselves to protons. The strong neutron-proton binding force changes the energy balance – not by much, but enough to stabilise the neutrons.

Had the Great Designer done it the other way round, with protons about 0.1% heavier than neutrons, disaster would ensue. Under these circumstances, isolated protons would turn into neutrons rather than the other way around. Some protons would be saved by attaching to neutrons. But hydrogen, the simplest chemical element, does not contain a stabilising neutron; hydrogen atoms consist of just a proton and an electron. In this backward universe, hydrogen could not exist. Nor could there be any stable long-lived stars, which use hydrogen as nuclear fuel. Heavier elements such as carbon and oxygen, made in large stars, might never form either. Without stable protons there could be no water and probably no biology. The universe would be very different.

The fact that the universe we know, including our own existence within it, hinges so delicately on the precise value of the neutron-to-proton mass ratio has led to heated debate among scientists. Was it just a lucky fluke that the laws of physics turned out this way? Or does it suggest something more profound?

Scientists are disinclined to believe in luck, so there has been a surge of interest in the multiverse theory, according to which our universe, with its neutron-to-proton



ILLUSTRATIONS: JEFFREY PHILLIPS

mass ratio of 1.00137841887, is but one among many. Other universes will have different ratios and possibly only a tiny fraction will contain water and stars that go on to form atoms like carbon, from which life may arise. Only in that fraction could there be observers to ponder the fact. It is then no surprise that we find ourselves in a universe where the neutron mass is so judiciously poised to permit complex chemistry and our presence as thinking, observing beings.

The foregoing argument hinges on the possibility that the masses of the neutron and proton are "free parameters" – that is, they could have been different. That seemed to be the case back in the 1950s when the critical value of the mass ratio was first discussed. However, we now know that neutrons and protons are not in fact elementary particles (unlike the electron, which seems to be). Rather, they are composite bodies with smaller particles inside them. Known as quarks, these subnuclear constituents have their own masses. There is also an enormous quantity of energy inside neutrons and protons due to the immensely strong force that glues the quarks together, and this contributes to the overall mass too ($E = mc^2$ again!). This structural complexity makes it nigh on impossible to work out accurate values for the masses of the proton and neutron by analysis of their constituents – let alone figure out what it would take for the mass contribution of this quark or that quark to shift enough to upset that crucial neutron-to-proton mass ratio.

So for now, 1.00137841887 is just "one of those numbers" that nature has settled on for no reason humans can fathom. If the value were off just a tad, there would be no humans – Galileo or otherwise – to even attempt the fathoming.

JASON ENGLAND is a magician based in Las Vegas and a renowned authority on casino gambling and card handling.

Smoke & Mirrors

Divide and conquer for your day in the Sun

Anyone can perform astounding feats of calendar calculation with a little practice.

MARTIN GARDNER is the inspiration behind this column. As many readers know, Gardner wrote his own column, called "Mathematical Games", in *Scientific American* from 1956 to 1985.

It sat squarely within the nexus where recreational mathematics, puzzles, games, magic, art and science intersect. His compiled articles required 14 large volumes to contain them all.

Those, and the several dozen other books he wrote in his 95 years, comprise an incredible body of work. Every time I sit down to write, I ask myself if Martin would have been interested in the subject matter.

Recently I attended the *Gathering 4 Gardner* in Atlanta, Georgia. The G4G, as it's called by attendees, is a biennial conference of 300 mathematicians, puzzle makers, magicians and artists who consider themselves ardent Martin Gardner fans. They gather in even-numbered years to celebrate and share the latest and greatest discoveries in recreational mathematics. Gardner himself was present at the first two conferences in the early 1990s, but was uncomfortable with the celebrity attention he received. He gave his blessing for future events but never attended again.

This year's final dinner show closed with a demonstration by mathematician and acknowledged genius John Horton Conway. Conway is Professor Emeritus of Mathematics at Princeton University, with expertise in knot theory, number theory and combinatorial game theory. He is perhaps most famous for creating the computer simulation called *Game of Life*, in 1970.

Conway asked three audience members to stand. Each was asked to name their birthdate. In turn, Conway, who is nearly 80, almost instantly announced the day of the week on which they were born. The room erupted in applause.

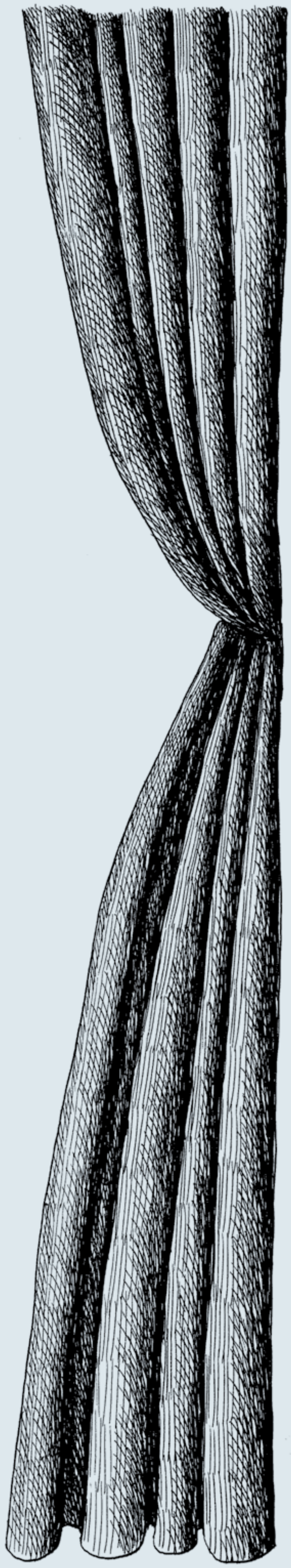
What he did is commonly referred to among magicians and recreational mathematicians as "calendar calculation". Conway uses a system he devised in the early 1970s (curiously, after a conversation with Martin Gardner) called the Doomsday Algorithm. The process involves memorising codes, century-specific days, and dividing certain numbers by 12 or four.

There is a similar but simpler method to determine the day of the week for any date. If you can do some basic division and addition in your head, you should, with practice, be able to perform the calculation in a matter of seconds.

First, you need to memorise the following "month codes":

January	1	July	0
February	4	August	3
March	4	September	6
April	0	October	1
May	2	November	4
June	5	December	6

In leap years, subtract one from the month code for January and February only! Leap years are any years where the last two digits of the year are a multiple of four. The exception to this rule are century years (those ending with 00) where the whole number must divisible by 400. Thus 1800 and 1900 were *not* leap years, while 1600 and 2000 were.



To begin, you take the last two digits of the year and divide the number by four.

Disregarding any remainder, add the result to the number you began with.

Add the month code number.

Add the day of the month.

Divide this total by seven.

Now disregard the whole number and focus on the remainder. It is the remainder that will tell you the day of the week, according to the following day codes.

1	Sunday
2	Monday
3	Tuesday
4	Wednesday
5	Thursday
6	Friday
0	Saturday

They are relatively easy to remember since they begin with Sunday as the first day of the week. The only quirk is that a remainder of zero equates to Saturday.

For dates in the 1800s, add two to your total. For dates in the 2000s, subtract one. You can do this any time *before* the final step of dividing by seven.

Let's look at an example: 17 January 1953. The first step is to divide 53 by four, ignoring any remainders. Answer: 13.

Add 13 to 53, to get 66. Add the "month code" (which for January is one) to get 67. Add the day of the month (17) to 67, making the result 84.

Finally the last step; divide 84 by seven. The answer is 12 with a remainder of zero. All we care about now is the remainder. Zero tells us that 17 January 1953 was a Saturday.

Equation: 17 January 1953

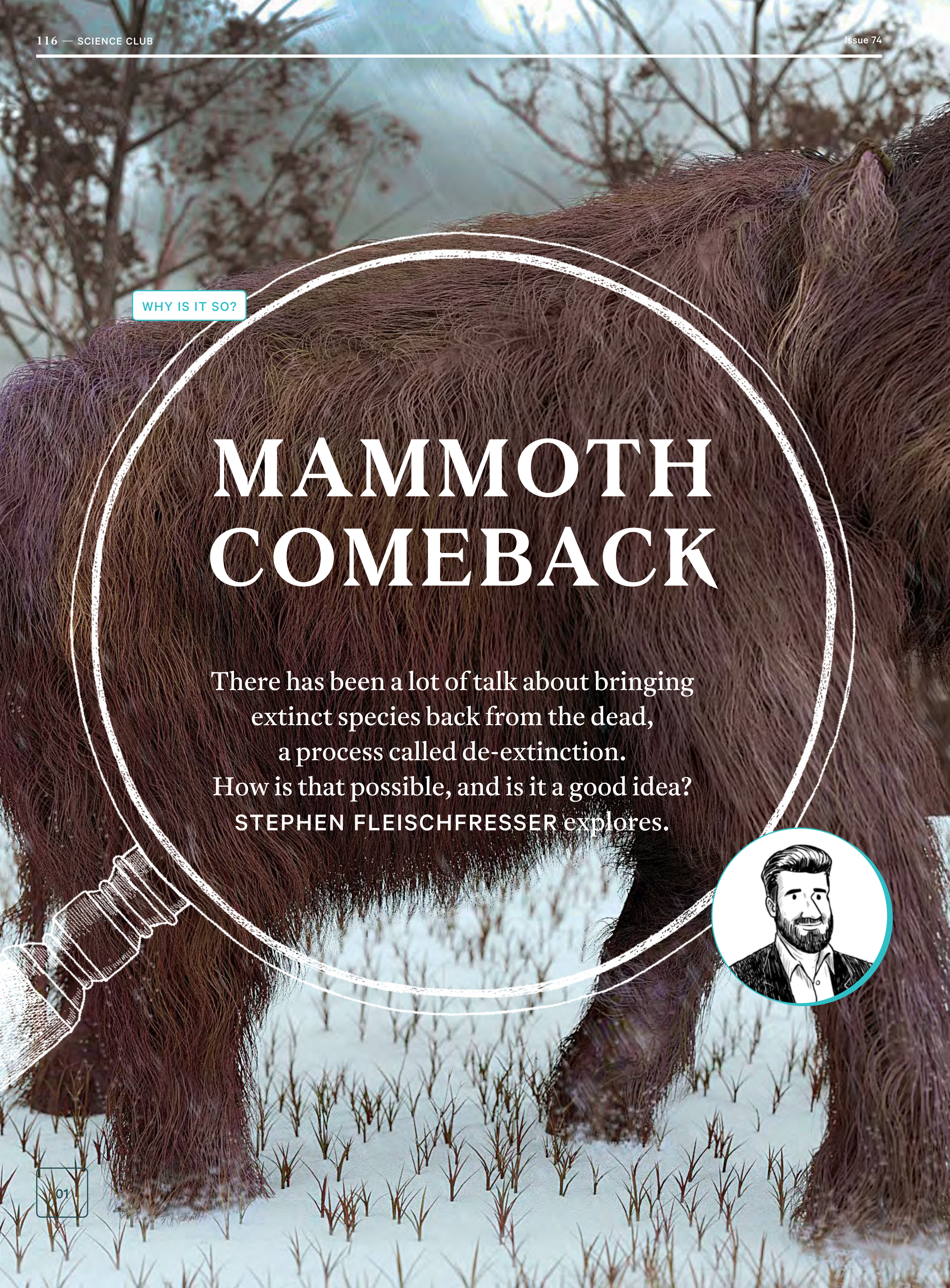
53 (year)÷4 = 13
+53 (year) = 66
+ 1 (month code) = 67
+17 (day) = 84
÷7 = 12 = remainder 0
= saturday

The mental division steps are the most difficult part of this method so here's a tip: you can "cast out sevens" as you go!

For example, take the date 6 December 1920. 20 divided by four is five. Adding five back to 20 gives us 25. If you want, you can divide 25 by seven right now and remember only the remainder (which is four). Add this remainder to the month code for December (six) to get 10. Divide by seven again and keep the remainder (which is now three). Add this new remainder to the day you want (the sixth) to get nine. Divide by seven one final time to get a remainder of two. This tells us that 6 December 1920 was a Monday.

Casting out or dividing by seven as you go at each step is usually much easier than initially doing all of the addition and then dividing the large total by seven at the very end. The result is the same either way.

With practice just about anyone can get this method down to under 15 seconds. With a *lot* of practice, you might just become the next John Conway!



WHY IS IT SO?

MAMMOTH COMEBACK

There has been a lot of talk about bringing extinct species back from the dead, a process called de-extinction. How is that possible, and is it a good idea? STEPHEN FLEISCHFRESSER explores.

01

SCIENTISTS FROM HARVARD UNIVERSITY have announced plans to create a live woolly mammoth in just two years. Wait, what? A woolly mammoth? The massive elephant-like creature with long fur and huge tusks, last seen roaming the frozen tundra in the Ice Age (both the time period and the movie)? Aren't they extinct?

Well yes, they are, but that doesn't seem to matter anymore.

We've all heard of extinction – when a species of plant or animal dies out. Some extinct species are famous, like the dodo of Mauritius or the Tasmanian tiger (or thylacine, as it is properly called).

So "de-extinction", as George Church of Harvard University explains it, is the process of bringing an extinct species back to life; and this is exactly what he intends to do with the mammoth. →

→ How on earth will he do it? The answer lies with the molecules of deoxyribonucleic acid, or DNA, unique to every living being. Within the DNA are "instructions" on how an organism will look and function. Church and his team plan to take DNA from the bodies of mammoths trapped in ice or permafrost somewhere between 4,000 and 10,000 years ago. There are many mammoths long frozen in the ice of Siberia that modern scientists have found and preserved in laboratories. From these specimens scientists can extract the DNA to de-extinct the species.

The problem is that after an organism dies its DNA tends to break up and degrade. DNA has a half-life of 521 years, which means that if we take a strand of DNA now and wait 521 years, only half of it will still be intact.. The last living mammoth died roughly 4000 years ago and many of the specimens scientists have are much older than that. So while we have whole bodies of mammoths, we don't have whole copies of their DNA.

So how do you fix that? Here comes the Asian elephant to the rescue! By using the DNA of this elephant, the mammoth's nearest living relative, scientists can patch up the holes in the mammoth DNA to produce a whole DNA sequence capable of creating a live mammoth.

The Harvard team are using the new and incredibly exciting gene-editing technology called CRISPR to do this. CRISPR – short for "Clustered regularly interspaced short palindromic repeats" – is the most precise, easiest and least expensive way to take genes and put them wherever you like.

Genes are short sections of DNA responsible for particular characteristics of an organism, such as hair colour or ear size. This amazing technology will enable scientists to take the mammoth genes and insert them into the DNA of Asian elephants to produce a complete sequence. After that, the DNA will be placed inside an egg cell of an Asian elephant, and from this will grow a live mammoth. Church and his team believe they can do this by 2019, just two short years away.

But hold on! If you're mixing mammoth and elephant DNA, do you really get a woolly mammoth?

Well, sort of. What you really get is a "mammophant", a hybrid of a mammoth and an elephant. It would totally look like a mammoth, though, with long tusks, small ears and long shaggy fur. It would even have some other mammoth traits, such as blood adapted to very cold weather. So although it might not be exactly like the woolly mammoths of the past, it will be pretty close – and half a mammoth is better than no mammoth at all, right?

If scientists can de-extinct a mammoth, it should be possible to bring other extinct species back to life. Around the world, researchers have begun work on de-extincting the dodo, the auroch (a super-huge ancestor of the modern cow), a long-lost species of zebra, cave lions and lots more. Mike Archer of the University of New South Wales and some colleagues are investigating how to resurrect the Tasmanian tiger.

But even if we can de-extinct species that have died out, should we bring back the mammoth? It's a tricky question. Mammoths, like elephants, were a social species, needing the company of other members of their own kind. If we only brought one individual back to life, wouldn't it get terribly lonely? Perhaps over time scientists could create a large number of mammoths so they have friends to socialise with. But then we'd have a huge herd of big, powerful, hungry mammoths. Where will they live?

There actually might be an answer to that. There is already a place called Pleistocene Park in north-eastern Siberia where scientists have recreated much of the ecology that would have existed during the last Ice Age. This has been achieved by returning the area to tundra grasslands, on which mammoths would have grazed 10,000 years ago. So it is here scientists are thinking of releasing mammoths into the wild.

One big question is whether it is possible to de-extinct a dinosaur. Can we finally make *Jurassic Park* a reality? Unfortunately the answer seems to be "no".

Where the mammoth has been extinct for 4,000 years and the thylacine for less than 100 years, dinosaurs have been extinct for more than 65 million years. Given DNA's half-life is 521 years, it is nearly impossible for enough genetic material to remain intact for scientists to use to de-extinct a dinosaur.

So a Jurassic Park must remain on our movie screens for now. Instead, we will have to make do with Pleistocene Park. It might not have a T-rex, but it could have mammoths – and that's pretty awesome.

STEPHEN FLEISCHFRESSER is a lecturer with a PhD in the history and philosophy of science.

IMAGES
01 Aunt Spray / Getty Images
02 Ria Novosti / AFP / Getty Images

ILLUSTRATIONS
Jeffrey Phillips

02
Lyuba, a baby mammoth preserved in Siberia's permafrost for 40,000 years.

MY WORKPLACE

There is more than one way to study the night sky, says WILLY STEVENS

The lure and lore of astronomy

Willy Stevens grew up knowing little about his ancestral Australian Aboriginal culture. Born a Muruwari man in New South Wales, he was adopted into a Kamilaroi family. But when at the age of 17 he met his biological mother, she regaled him with traditional stories, many featuring the stars.

Today, the 28-year-old's passions lie in sharing those stories of Aboriginal astronomy, passed down through millennia, with students and the wider community. He does so primarily in his role as a tour guide for the Sydney Observatory's "Dreamtime Astronomy" program.

Given this, it might seem curious that Stevens doesn't actually hold much interest in star-gazing as an academic discipline.

"For me it's about teaching culture," he explains. "I love to share my knowledge with my community."

He adds that it's the effect his work has on Aboriginal people that most inspires him. Because of the devastating effects of ongoing colonisation, many indigenous people have limited knowledge of their heritage or culture. When they attend his talks, he sees it an opportunity to share knowledge.

"I feel very humbled when Aboriginal people thank me after coming on my tour and discovering things about their culture they had never known," he says. "Learning these stories gave them a sense of pride and made them want to learn more."

— DUANE HAMACHER


JOHANNES KEPLER
BORN in 1571
IN THE GERMAN CITY OF WEIL DER STADT
Germany
YOUNG KEPLER
KEPLERS MUM
OBSERVED THE GREAT COMET OF 1577
STUDIED AT THE UNIVERSITY OF TUBINGEN
HELLO I'M TYCHO BRAHE
JOHANNES KEPLER! LOVELY TO MEET YOU
GETS A JOB WITH TYCHO BRAHE
EARTH IS AT THE CENTRE OF THE UNIVERSE!
AND IT IS FLAT!
KEPLER flees to PRAGUE
DEFENDING COPERNICAN* THOUGHT!
* THAT ALL THE PLANETS REVOLVE AROUND THE SUN
3 LAWS of PLANETARY MOTION
USING HIS LAWS...
... KEPLER SOLVED THE MARTIAN PROBLEM
HE DESIGNED HIS OWN EYE GLASSES
IN 1615 HIS MUM WAS CHARGED WITH WITCHCRAFT AND IMPRISONED.
R.I.P.
KEPLER DIED IN 1630
HIS LAST JOB WAS CASTING HOROSCOPES
TODAY NASA'S KEPLER TELESCOPE IS NAMED AFTER JOHANNES
KEPLER-62F
KEPLER-22B
KEPLER-69C
KEPLER-62E
AND A SUPERNOVA HE SPOTTED IN 1604
KEPLER SUPERNOVA
ALONG WITH A BUNCH OF PLANETS
J.PHILLIPS 2017

DID YOU KNOW

Conquering the Martian problem

IN THE DYING YEARS of the 16th century, Johannes Kepler – mathematician, astrologer and astronomer – became obsessed by Mars.

In particular, he became fascinated by the "Martian problem" – the fact that at certain times the Red Planet appeared to go backwards across the sky, before correcting itself and heading off again in the right direction. Solving the problem, he boasted, would take him just eight days. It ended up taking eight years, but solve it he did, laying the foundations for modern astronomy in the process.

Kepler was born in 1571 in the city of Weil der Stadt, not far from modern-day Stuttgart. He was raised by his mother, Katharina, a herbalist and folk healer – skills that would later dangerously affect both.

It was his mum who ignited the young boy's interest in the movement of celestial bodies. When he was just six she took him to some high ground to witness a comet. As the little boy stood on a hill staring in awe, hundreds of kilometres to the north the comet was also observed by Tycho Brahe, an astronomer 25 years older than him. Decades later, Brahe would be central to the Martian solution.

Kepler attended the University of Tubingen, where he fell under the sway of Michael Maestlin, an astronomer and mathematician. Maestlin was a fervent supporter of Nicolaus Copernicus – the man who proposed, 50 years earlier, that the Earth orbited the Sun, and not the other way around.

In 1597, Kepler published a vigorous defence of Copernican thought. It was a brave move – the theory had been condemned by the Lutheran Church, and elements within the all-powerful Catholic Church also viewed it dimly (as Galileo was to discover in 1615).

Anxious to escape religious persecution, Kepler fled to Prague, where he got a job assisting Tycho Brahe. It turned out to be a short association. Brahe died a year or so later, leaving Kepler with a lifetime's worth of meticulously recorded data concerning the movements of the stars and planets – especially Mars. Using this treasure chest, Kepler went on to formulate three laws of planetary motion, which have deeply influenced every astronomer since.

First, he deduced the planets do not move in circular orbits, but in ellipses, and that the Sun does not sit in the centre of these but off to one side.

Second, he realised the planets do not move at a constant speed, but slow down further from the Sun.

Third, he worked out the relationship between the orbits of any two planets is determined by their distances from the Sun – making their positions rigidly predictable.

With these laws he finally solved the Martian problem. He worked out that Mars took 687 days to orbit, while the Earth took just 365. This meant that at certain times the angle of view from Earth to Mars was so extreme that it made the Red Planet appear to be going backward, even though it wasn't. The Martian problem was simply an optical illusion.

When not studying the sky, Kepler pursued his other passion: optics. He designed lenses to tackle both long- and short-sightedness.

In 1615, he had to rush home because his mother had been arrested for witchcraft. This was partly because she practiced herbalism and partly, perhaps, because in a flight of fancy Kepler once wrote a novel (called *The Dream*) that that featured a woman in contact with demons from the Moon. He secured her release, but she was arrested again in 1620, served 14 months in prison, and died not long after.

Kepler himself died in 1630. In his final years he made a living from writing horoscopes.

— ANDREW MASTERSON

ILLUSTRATION
Jeffrey Phillips

TOP SIX

Physics equations that changed history

1

NEWTON'S SECOND LAW OF MOTION (1687)

$$\vec{F} = m\vec{a}$$

WHAT DOES IT SAY?
Force equals mass times acceleration.

IN OTHER WORDS ...
It's easier to push an empty shopping cart than a full one.

WHAT DID IT TEACH US?
Together with Isaac Newton's other two laws of motion (the first says you need a force to move something, the third says every action has an equal and opposite reaction), this equation forms the foundation of classical mechanics.

F=ma allowed physicists and engineers to calculate the value of a force. For instance, your weight (measured in newtons) is your mass (in kilograms) multiplied by acceleration due to gravity (on Earth, about 10 metres per second squared).

Saying you "weigh" 60 kilograms is incorrect in physics terms – your actual weight is about 600 newtons. This is the force pushing down on your bathroom scales.

BUT WAS IT PRACTICAL?
This equation was crucial to the arrival of the mechanical age. It's used in almost every calculation that involves using force to cause movement.

It tells you how far a cannonball will fly, how powerful an engine needs to be to power a car, how much lift an aircraft needs for take-off, and how much thrust is required to lift a rocket.

2

NEWTON'S LAW OF UNIVERSAL GRAVITATION (1687)

$$F = G\frac{m_1 m_2}{r^2}$$

WHAT DOES IT SAY?
Any two massive objects pull on one another across space. The force decreases rapidly the further apart they are.

IN OTHER WORDS ...
We're stuck to the Earth's surface because our planet is comparatively big with lots more mass.

WHAT DID IT TEACH US?
For centuries, the Universe had been divided into two realms – the earthly and the celestial. But Newton's law of gravitation applied to everything. The same tug that causes an apple to fall from a tree keeps the Moon orbiting the Earth. Newton gave us the first direct connection between everyday life and the movement of the heavens.

BUT WAS IT PRACTICAL?
For a long time the equation's main use was to calculate the orbits of planets. The space age saw it used to send satellites into orbit and astronauts to the Moon.

Newton admitted he did not know "why" gravity operated. It took nearly 230 years for Albert Einstein to come along and explain gravity in his theory of general relativity. Even so, general relativity is only used in extreme situations, such as when gravity is very strong, or when great precision is required, such as for GPS satellites.

In most cases Newton's 330-year-old equation is still good enough.

3

SECOND LAW OF THERMODYNAMICS (1824)

$$\nabla S_{universe} > 0$$

WHAT DOES IT SAY?
Entropy (a measure of disorder) always increases.

IN OTHER WORDS ...
It's no good crying over spilt milk. Disorder and mess are inevitable.

WHAT DID IT TEACH US?
While trying to analyse steam engine efficiency in the 19th century, French physicist Sadi Carnot stumbled upon one of the most profound equations in science.

It tells us some processes are irreversible, and may even be responsible for the arrow of time. In one of its simplest forms, it says heat always travels from a warm object to a cold one.

It can also be applied to the grandest scales. Some have applied it to describe the ultimate fate of the Universe in the form of "heat death" where all the stars are burnt out and nothing's left but waste heat.

Others have used it to describe the origin of the Universe in a moment of zero entropy (or perfect order) at the instant of the Big Bang.

BUT WAS IT PRACTICAL?
This law was important for developing technologies of the Industrial Revolution, from steam to internal combustion engines, to refrigerators and chemical engineering. In real engines, some energy is always wasted – so the law also showed that any efforts at perpetual motion were ultimately futile.

4

THE MAXWELL-FARADAY EQUATION (1831 AND 1865)

$$\nabla \times \vec{E} = -\frac{d\vec{B}}{dt}$$

WHAT DOES IT SAY?
You can create a changing electric field (left side of the equation) from a changing magnetic field (on the right) and vice versa.

IN OTHER WORDS ...
Electricity and magnetism are related!

WHAT DID IT TEACH US?
In 1831, Michael Faraday discovered the connection between two natural forces, electricity and magnetism, when he found a changing magnetic field induced a current in a nearby wire.

Later, James Clark Maxwell generalised Faraday's observation as one of his four fundamental equations of electromagnetism.

BUT WAS IT PRACTICAL?
This is the equation that powers the world. Most electric generators (whether in a wind turbine, coal-fired plant or hydroelectric dam) work by converting mechanical energy (from steam or water) to rotate a magnet. By running this process in reverse, you get the electric motor.

More generally, Maxwell's equations are still used in almost every application of electrical engineering, communications technology and optics.

5

EINSTEIN'S MASS-ENERGY EQUIVALENCE (1905)

$$E = mc^2$$

WHAT DOES IT SAY?
Energy equals mass multiplied by the speed of light squared.

IN OTHER WORDS ...
Mass is really just a super-condensed form of energy.

WHAT DID IT TEACH US?
Because of the size of the constant in the equation (the speed of light squared, an unimaginably huge number) a colossal amount of energy can be released through converting a tiny amount of mass.

BUT WAS IT PRACTICAL?
Einstein's most famous equation hinted at the potential for the huge amounts of energy released in nuclear fission, when a large unstable nucleus breaks into two smaller ones. This is because the mass of the two smaller nuclei together is always less than the mass of the original big nucleus – and the missing mass is converted into energy.

The "Fat Man" atomic bomb dropped over Nagasaki in Japan on 9 August 1945 converted just one gram of mass to energy, but produced an explosion the equivalent of about 20,000 tonnes of TNT.

Einstein himself had signed a letter to the US president at the time, Franklin Roosevelt, recommending the atom bomb be developed – a decision he later regarded as the "one great mistake" of his life.

6

THE SCHRÖDINGER WAVEFUNCTION (1925)

$$i\hbar\frac{\partial}{\partial t}\Psi(r,t) = \left[\frac{-\hbar^2}{2\mu}\nabla^2 + V(r,t)\right]\Psi(r,t)$$

WHAT DOES IT SAY?
It describes how the change of a particle's wavefunction (represented by psi, the candlestick-shaped symbol) can be calculated from its kinetic energy (movement) and its potential energy (the interactions on it).

IN OTHER WORDS ...
It's the quantum version of F=ma.

WHAT DID IT TEACH US?
When Erwin Schrödinger formulated his equation in 1925, it placed the new theory of quantum mechanics on firm footing by allowing physicists to calculate how quantum particles move and interact.

The equation looks a bit weird because it uses the mathematics of waves. (Subatomic particles are "wavy", so their interaction is described as interference of waves, rather than like billiard balls.)

BUT WAS IT PRACTICAL?
In one of its simplest forms, it describes the structure of the atom, such as the arrangement of electrons around the nucleus, and all chemical bonding.

More generally it is used for many calculations in quantum mechanics and is fundamental to much modern technology from lasers to transistors, as well as the future development of quantum computers.

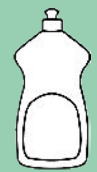
— CATHAL O'CONNELL

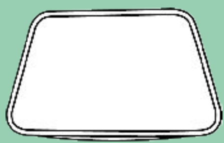
DO IT YOURSELF

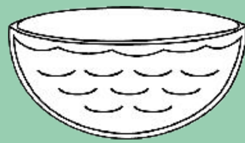
Make a soapy boat

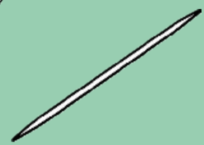
There are boats powered by the wind and boats powered by petrol, but have you ever heard of one powered by soap? It's true! And what's more you can make one of these soap-powered craft in your own kitchen, using only a few bits an bobs from around the house (and perhaps the recycling bin).

YOU WILL NEED

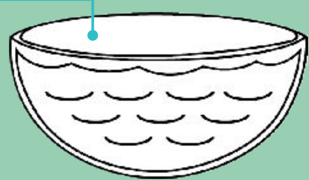

DISHWASHING LIQUID


A SUPERMARKET FOAM FOOD TRAY

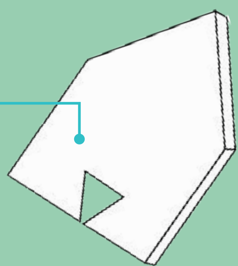

A LARGE BOWL OF WATER


A TOOTHPICK

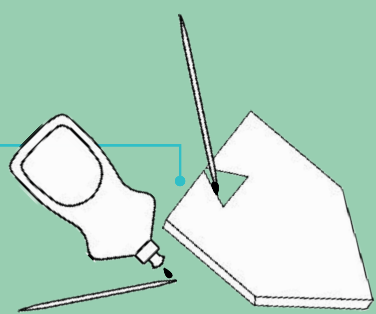
1. First, fill the large bowl with water and put it on the bench.



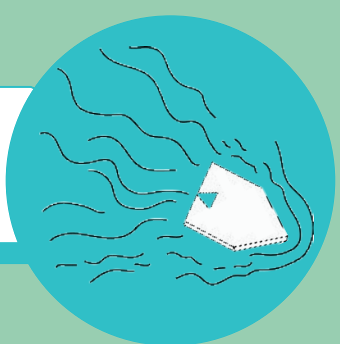
2. Cut your boat out of the foam food tray, making the shape in the picture.
The craft should be about five centimetres from front to back, and about four centimetres wide.



3. Dip the toothpick into the liquid soap and smear some around every exposed edge of the boat.



4. Now, put the boat gently on top of the water in the bowl and watch as it zooms away!



HOW DOES IT WORK?

Well, it's not magic! It's physics. The soap reacts chemically with the water, breaking the surface tension. This creates a force that pushes against the boat.

Because the boat has a pointy end and a flat end, the force pushes it in the direction that offers the least resistance – the pointy end, just like with a real ship.

But here's an interesting thing: if you put more soap on your boat and try to repeat the experiment, it won't work. Your craft will just float and not move at all.

CAN YOU THINK WHY?

It's because the soap from the first run has already changed the surface tension of the water, dispelling its force.

— ANDREW MASTERSON

DEBUNKED

Are Canadian fish being poisoned by radiation from Japan?

A NEWS STORY HAS DONE the rounds on social media this year claiming that salmon in Canada had been found contaminated with radioactive isotopes from the damaged nuclear power plant at Fukushima in Japan.

Is it true? And, if so, is there anything to worry about? The answer to the first question is "yes, sort of", but the answer to the second is "definitely not"!

The story grew from the fact that, in 2015, a single salmon caught in Osoyoos Lake in British Columbia was found to contain very low levels of a radioactive isotope called caesium-134.

The isotope is produced during nuclear fusion – the process that drives both atomic power stations and atomic bombs. Because it has a half-life of about two years, any caesium-134 that was released into the atmosphere by previous bomb tests or reactor disasters (such as Chernobyl) has long since decayed away.

Therefore, any caesium-134 found in anything at the moment can only have come from Fukushima.

So, yes, a radioactive nasty from Japan did end up in a fish in Canada. However, there is much more to the story than that.

First off, scientists have always predicted that radioactive stuff from the damaged reactor would spread around the world, through the oceans and the air.

This is simply what happens. Between 1955 and 1963, for instance, there were a whole bunch of atmospheric nuclear bomb tests, which collectively pumped out a huge amount of an isotope called carbon-14.

All over the world, people who were children during that time have higher-than-average levels of it in their muscle tissues.

In 2016, caesium-134 from Fukushima was detected in the waters off the coast of northwestern US state of Oregon for the first time. This did not surprise environmental scientists and oceanographers, who had long predicted its eventual arrival. The isotopes detected in the sea were at very low levels and didn't pose any threat to human health.

The same goes for the single Canadian salmon. In fact, the radiation levels detected in the fish were actually lower than the levels found in most other fish around the globe. This is because, every day, every living thing absorbs radiation produced naturally by cosmic rays, some kinds of rocks and minerals, and even the air itself. It's called "background radiation" and it has been around since the Big Bang.

The suspect salmon wasn't eaten, because it was used for testing. But if it had been, would it have made the person who ate it ill?

Not at all. The standard measurement for radiation in food is a unit called the becquerel. It is always expressed in terms of becquerels per kilogram.

The Canadian salmon contained 0.7 becquerels per kilogram. The World Health Organisation's recommended safe maximum limit for radioisotopes in food is 1,000 becquerels per kilogram.

So, should you ever be lucky enough to find yourself hooking a sockeye salmon in Osoyoos Lake, have no fear. Wrap it in foil with a few slices of lemon and some thyme, chuck it on the camp fire, and enjoy!

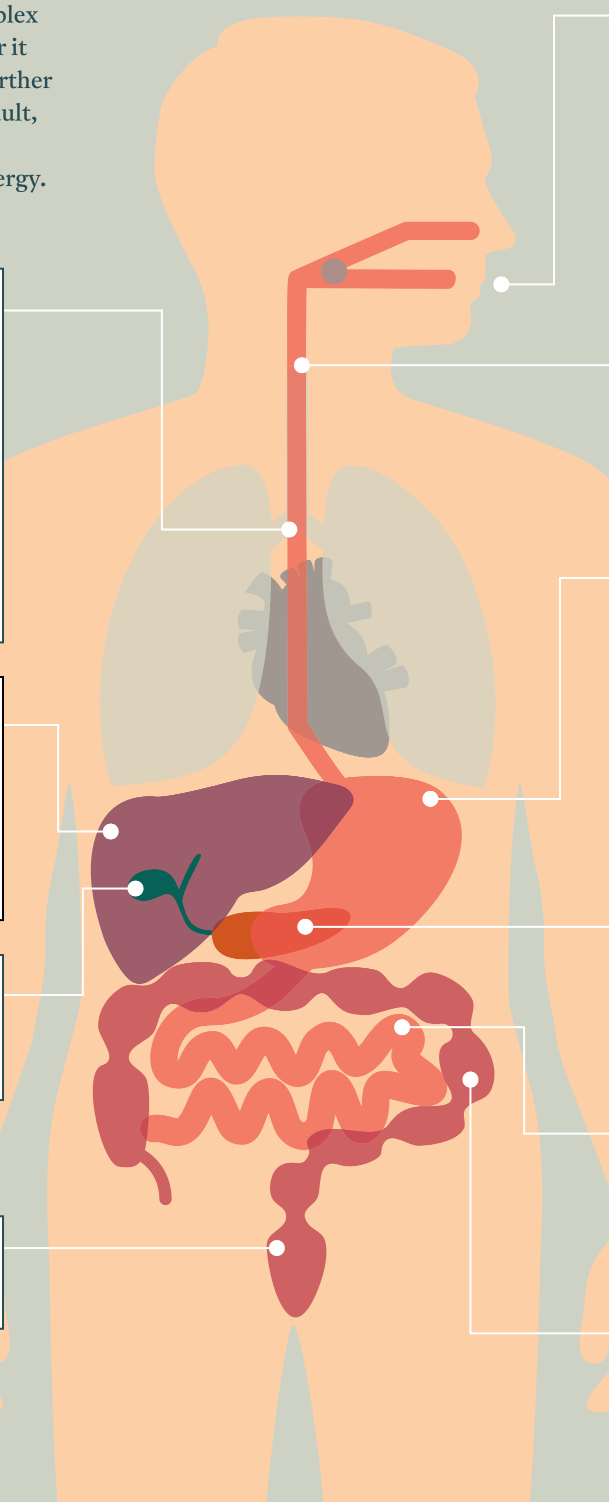
— ANDREW MASTERSON

IMAGE
Roger Phillips / Getty Images

INFOGRAPHIC

The digestive system

Your food may travel thousands of miles to reach your plate, but the most complex part of its journey is yet to begin. After it enters your mouth, there remains a further nine metres to travel in the average adult, a route of twists and turns converting organic matter into life-sustaining energy.



ESOPHAGUS
Muscular tube that food travels down from the mouth to the stomach. The esophagus has a mucous membrane of epithelium which has a protective function as well as providing a smooth surface for the passage of food. Due to the high volume of food that is passed over time, this membrane is continuously renewed.

LIVER
The liver is the second-largest organ (after the skin) and is an accessory digestive gland that plays a role in the body's metabolism. It produces bile and processes nutrients obtained from food.

GALL BLADDER
Stores and concentrates bile, before being released into the small intestine.

RECTUM
Stores waste until it leaves the body through the anus.

MOUTH
The mouth is the first part of the gastrointestinal tract and is equipped with several structures that begin the first processes of digestion. These include salivary glands, teeth and the tongue, helping to break up food into small pieces and mixes it with saliva

PHARYNX
Muscles in the pharynx push the food into the esophagus, allowing the body to swallow.

STOMACH
Stores and breaks up food. Secretes gastric acid, mainly hydrochloric acid and sodium chloride, that get digestion underway. The stomach is a distensible organ and can normally expand to hold about one litre of food.

PANCREAS
Secretes enzymes for the digestion of fats and proteins into the small intestine and regulates blood glucole levels.

SMALL INTESTINE
Is the main site food is digested, Food starts to arrive in the small intestine one hour after it is eaten.

LARGE INTESTINE
Absorbs water from digestive waste and forms and stores feces.

INSPIRED BY SCI-FI

The helicopter

SCIENCE FICTION SOURCE:
Jules Verne's 1886 novel
Robur The Conqueror
(also known as *The Clipper of the Clouds*)

THE HERO OF VERNE'S adventure novel invents the world's first "heavier than air" flying machine – the *Albatross* – kept aloft by propellers atop tall masts.

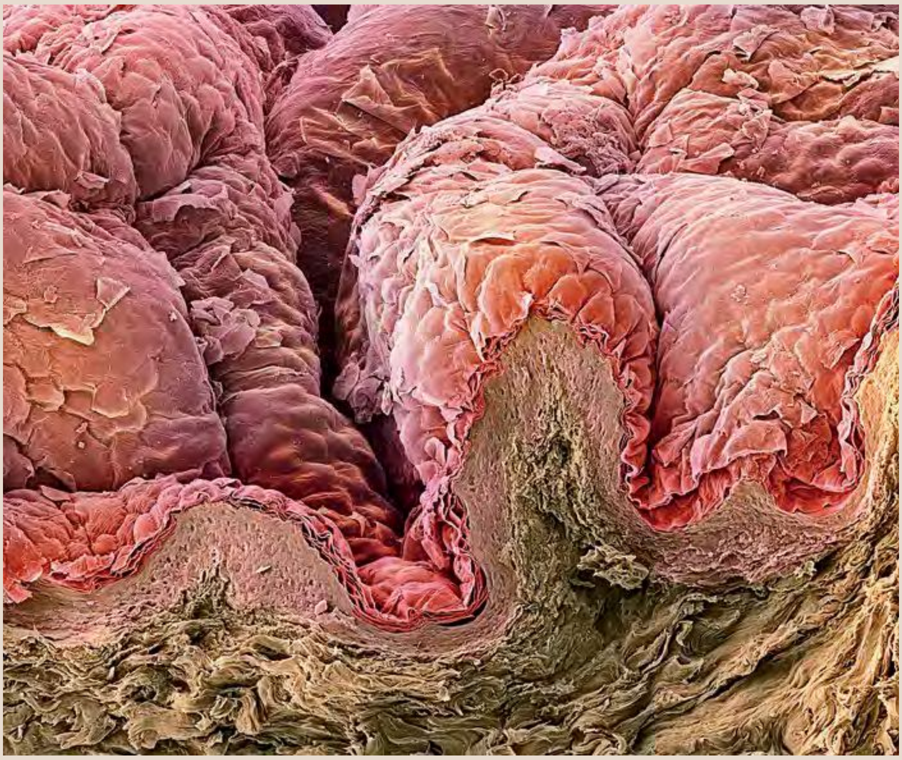
At the beginning of the 20th century, a 12-year-old Russian boy called Igor Sikorsky read Verne's novel and built his first helicopter, powered by a rubber band. He went on to become one of the pioneers of aviation, designing the first commercial airliner, the Ilya Muromets, in 1914.

After emigrating to the United States in 1919, following the Russian civil war, Sikorsky started a successful aviation company, aided by funds from composer Sergei Rachmaninov. He trialled several helicopter designs in his lifetime, before eventually succeeding in 1939 with his VS-300 (pictured), which is regarded as the first modern helicopter, and the first to be mass-produced.

— CATHAL O'CONNELL

IMAGE
Bettmann / Getty Images

WHAT IS THIS?



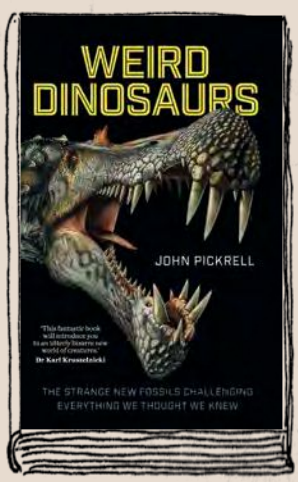
CREDIT: STEVE GSCHMEISSNER / GETTY IMAGES

The above image from a scanning electron microscope features something you probably come into contact with every day.
What is it?

Email your answer to competitions@cosmosmagazine.com with your name and address by 31 May. Five correct entries will win a *Cosmos* prize pack.

COMPETITION

QUESTION
In what year did the *Velociraptor* gain feathers?



Email your answer to competitions@cosmosmagazine.com with your name and address by 31 May. Five correct entries will win a copy of *Weird Dinosaurs,* written by John Pickrell.

Why did dinosaurs grow so huge? Did they all have feathers? And what do sauropods have in common with 1950s vacuum cleaners? *Weird Dinosaurs* examines the latest breakthroughs and new technologies radically transforming our understanding of the distant past.

MIND GAMES

Quiz

Q1. Where is 90% of the world's fresh water held?

Q2. Sea horses have six copies of which gene that is involved in gestation and hatching?

Q3. What is the name of the star that boasts seven newly discovered Earth-sized exoplanets?

Q4. The genus of parasite known to cause malaria is called what?

Q5. Which plant is known to contain salicylic acid, the active ingredient in aspirin?

Q6. What is the name of the first of the round objects identified in the Kuiper Belt that led to Pluto losing its status as the Solar System's ninth planet?

Q7. Which German physicist was the first to describe – in 1916 – the theoretical possibility of black holes?

Q8. Approximately how many active land volcanoes does our planet host?

Q9. If all of Antarctica's ice sheets were to melt, by how much would global sea levels rise?

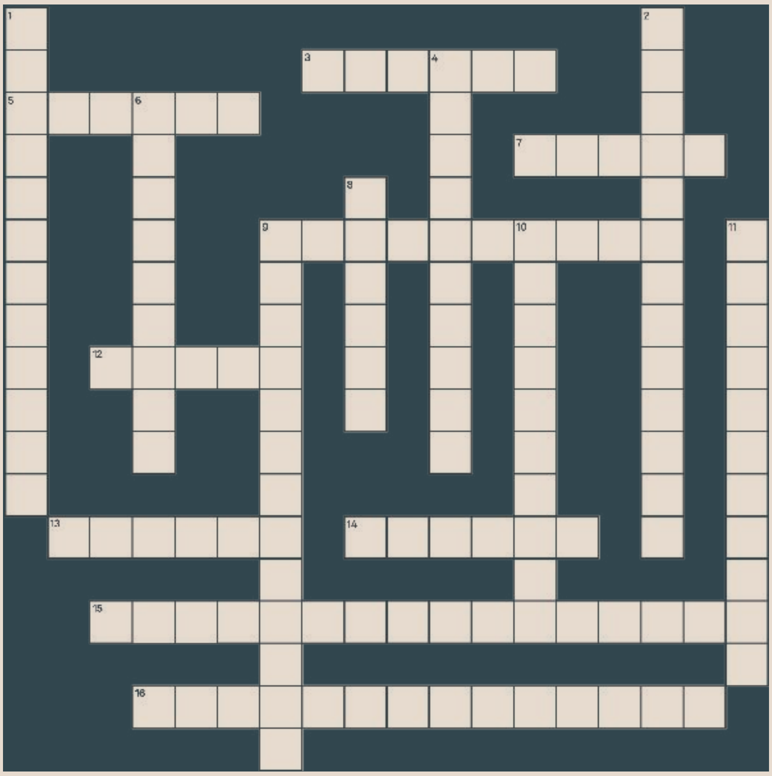
Q10. According to the International Mineralogical Association, how many of our planet's 5,208 mineral types are anthropogenic?

Q11. By what percent have fatalities due to malaria fallen since the year 2000?

Q12. Described as a fluffy, feathered poodle from Hell, which dromaeosaur related to *Velociraptor* has the largest feathered wings found on a dinosaur to date?

Answers will be published in issue 75.

Cosmos crossword



ACROSS

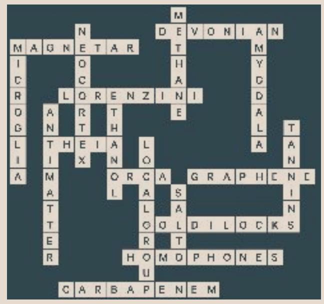
3. Testes contain _ cells which support sperm production by generating testosterone.
5. The name of New Zealand's largest glacier.
7. The acronym given to a chemical produced by malaria parasites that causes mosquitos to be drawn to drink the blood of individuals already infected with the disease.
9. An organism infected with a disease that infects disproportionally more secondary contacts than other individuals infected.
12. The smallest species of baleen whale.
13. A spinning, highly magnetic neutron star that emits a beam of light.
14. A plant polymer found in the cell walls of terrestrial plants that helps jam set.
15. A scientific pursuit focused on recreating past shifts in the Earth's magnetic fields.
16. The most common chronic joint condition which sees the breakdown of cartilage's natural lubrication system.

DOWN

1. Small organelles inside the cells of animals, plants and fungi that act as the cell's energy source.
2. The common name of the human disease lymphatic filariasis.
4. The scientific name of zebrafish (5, 5).
6. A mineral that is capable of being magnetised, found in small amounts in clay.
8. A climate cycle in the Pacific Ocean caused by increased sea surface temperatures, which impacts global weather patterns (2, 4).
9. An organism infected with a disease that infects disproportionally more secondary contacts than other individuals infected.
10. The event in which the last existing member of a species dies.
11. A narrow region of convection that allows hot material from the Earth's core-mantle boundary to move rapidly to the surface (6, 5).

Answers will be published in issue 75.

SOLUTIONS: COSMOS 73 CROSSWORD



QUIZ

1. 30 kilograms
2. Six million years ago
3. The FOXP2 gene
4. Temperature
5. Three times larger
6. Cosmic microwave background
7. Her arm bones were stronger than her leg bones
8. Peak rings
9. Mexico
10. Coelurosaur
11. Basal radial glia
12. An Earth day

WINNERS

COMPETITION

The main protein that makes up spider silk is spidroin.

Congratulations to our winners for answering correctly. Each will each receive a *Cosmos* prize pack:

Steve Thyer, Lesmurdie, WA; Aimee Butler, Bothwell TAS; Georgia Jarrett, Wareemba NSW; Anna Liang, Carindale QLD;

PORTRAIT

Carmel Johnston, earth-bound astronaut

"I REALLY WANTED AN AVOCADO," says Carmel Johnston, revealing a potential stress point in NASA's plans to send a crewed mission to Mars within two decades.

In August last year Johnston and five colleagues finished an experiment designed to monitor psychological pitfalls arising from sending astronauts to the Red Planet.

The exercise involved spending 12 months inside a small dome built on Hawaii's Mauna Loa volcano – a facility expressly designed to test people in isolated, confined and extreme environments. The dome has just 111 square metres of space, including a kitchen, two bathrooms, shower and bedroom cubicles. Going outside required donning a full spacesuit, of which there were only two.

Food was delivered every couple of months, all of it freeze-dried, powdered and processed. On a real Mars mission, growing fresh food is likely to be a critical challenge.

"Because we were living in a culturally sensitive area in Hawaii, we couldn't create acres and acres of garden outside," says Johnston, who has a master's degree in land resources and environmental sciences. "Ideally you would have the systems in place to grow all of the food you need. You have to think about fresh protein, too. Perhaps you would eat insects instead of ground beef – that's a real possibility."

— ANDREW MASTERSON

IMAGE
Cyprien Verseux