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TEACHING PHYSICS TO MONKS CITIZEN SCIENCE ALL-SEEING SATELLITES

COSMOS

THE SCIENCE OF EVERYTHING

Issue 86

THE FUTURE IS PERSONAL

TECHNOLOGY

Body-powered sensors:
too much information?

HEALTH

Embryoids, organoids,
and gene therapy

EDUCATION

ABC by algorithm

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SPIES AT SEA
Birds catch fishers,
not fish

STARS IN THEIR EYES
Astronomy's hidden
women

SUPER KELP
Forestry for
a warming ocean

HUBBLE TROUBLE • CLOUDY DELIGHTS • PUZZLES • WHAT EYES SEE



**Reef sails for storm!**

Miniaturised by an advancing supercell storm and its menacing shelf cloud, a sailing fleet – and lonely outlier sloop – brace for heavier weather near Sydney, NSW. Characterised by a persistently rotating updraft (vortex), supercells are the rarest, but potentially most damaging, of thunderstorms. They can dump immense volumes of rain or hail and, in certain areas and conditions, form tornadoes. Shelf clouds form when cooler air flows beneath the supercell's warmer, moisture-rich air. To learn more about clouds go to page 99.



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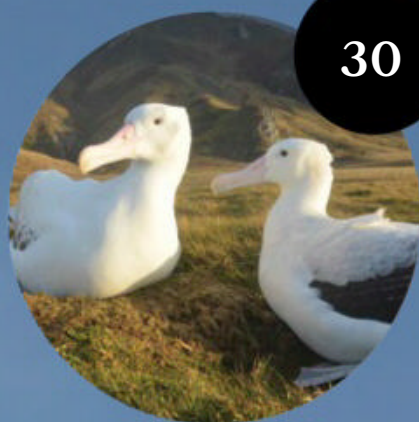
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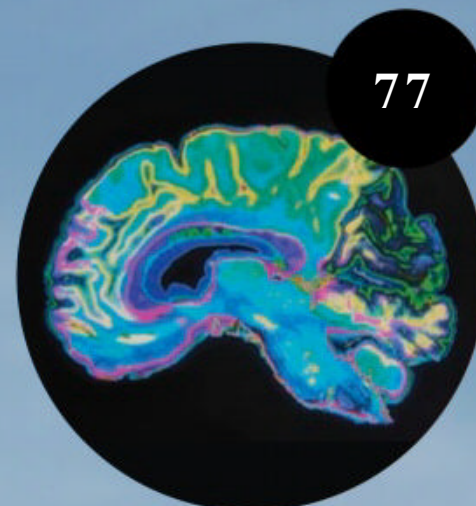
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BEHIND THE SCENES THIS ISSUE

It’s important to pick a shady spot from which to capture the perfect shot, as shown by editor Ian Connellan, who went butterfly spotting for this issue (below, story p.107). Ilya Mandel and Leslie Atkins Elliott got a taste of India’s exciting street life when they visited Gaden Monastery to teach physics to monks (right, story page 66).



ABOUT THE ROYAL INSTITUTION OF AUSTRALIA

The Royal Institution of Australia is an independent charity dedicated to connecting people with the world of science through news, videos, events and educational resources.

Our mission is to find new ways for people to discover and understand science and how it shapes the world around us.

Everything we do, from the stories we tell to the teachers we support and the events we run, is about connecting Australians – especially young Australians – with the wonders of science.

We do this through *Cosmos* magazine and the cosmosmagazine.com website, SCINEMA (our international science film festival), and Australia’s Science Channel with its STEM teaching resources and comprehensive career guides.

Why do we do this? Our vision is for science to be woven into the fabric of society. We want to help people understand science and its relevance in day-to-day decision making, and empower people to understand the world’s many challenges, and *Cosmos* is an integral component in achieving success.



FROM THE EDITORS

THE SEASON'S CHALLENGES have seen us constantly reflecting on – and immensely grateful for – the role of science and technology in understanding how our Earth is changing, the likely results of that change, and what we all ought to be thinking about to make things better – or, at least, no worse.

As unprecedented bushfires stained the summer skies in eastern and southern Australia, it seemed natural that our thoughts turned to water and sky.

In this issue you'll meet the marine researchers who are getting help from the world's most magnificent pelagic bird, the wandering albatross, to find illegal, unreported and unregulated (IUU) fishing vessels operating in Southern Ocean waters. Many deep-ocean fishers play by the rules and adhere to various protocols protecting fishing stocks and seabirds; the "dark" fishing IUU crew do not.

Further north (but still on the cool side, in Tasmania), we meet marine biologists seeking a "super-kelp" to bolster Australia's declining temperate-climate reefs. Staying on the ocean blue, you'll also join locals in the mid-Pacific on the atoll, where a collaboration between science and traditional culture is improving the lot of a popular food fish.

Bushfires always make us long for rain, so

turning to weather guy Nate Byrne to tell us about clouds made a shower of sense. Nate got his start – cue interesting combination – through a degree and physics and the Royal Australian Navy. We trust you'll enjoy his favourite less-typical clouds as much as we do.

Nate's nifty personal story points to the issue's other strong theme – how science and technology are increasingly capable of narrowing focus for an individual fix.

We take a training run with Drew Turney through the impending Internet of Disposable Things. Paul Beigler guides us through the complex trials and ethical dilemmas of embryoids, and *Cosmos's* Editor-at-Large, Elizabeth Finkel, ponders how decades of overlapping genetics research can lead from blue-sky lab work to genuine hope for salvation. And Karen Hao reports from China to reveal the billion-dollar tech firms using AI to tailor individual approaches that help students learn.

Last but far from least, we learn about an immense international astronomy effort to map the stars, and meet the project's remarkable workers – the "lost women" of Australian astronomy.

From the blackness of space through cloudy sky to deep blue seas, we trust you enjoy *Cosmos* 86.

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NEWSLETTER

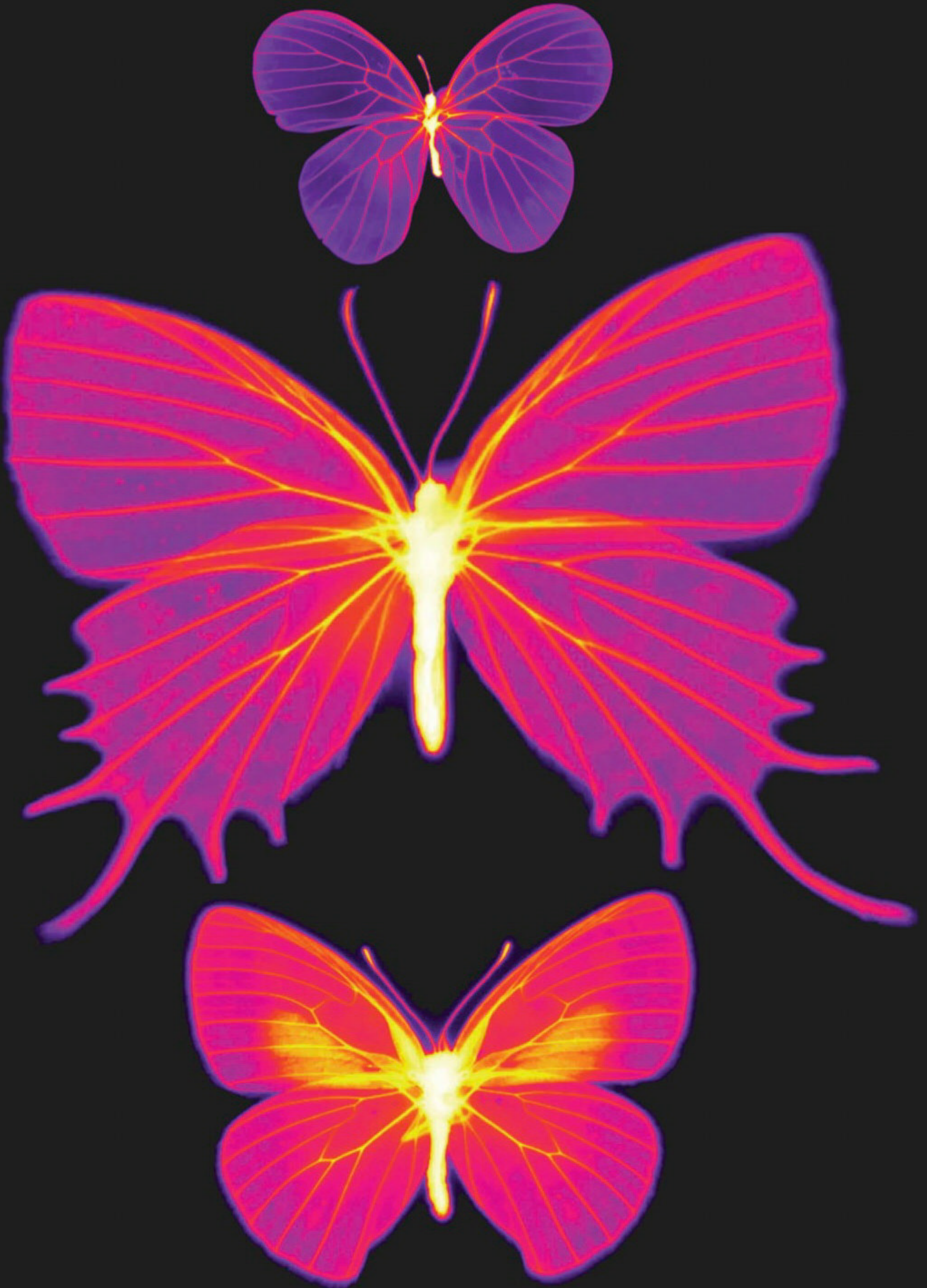
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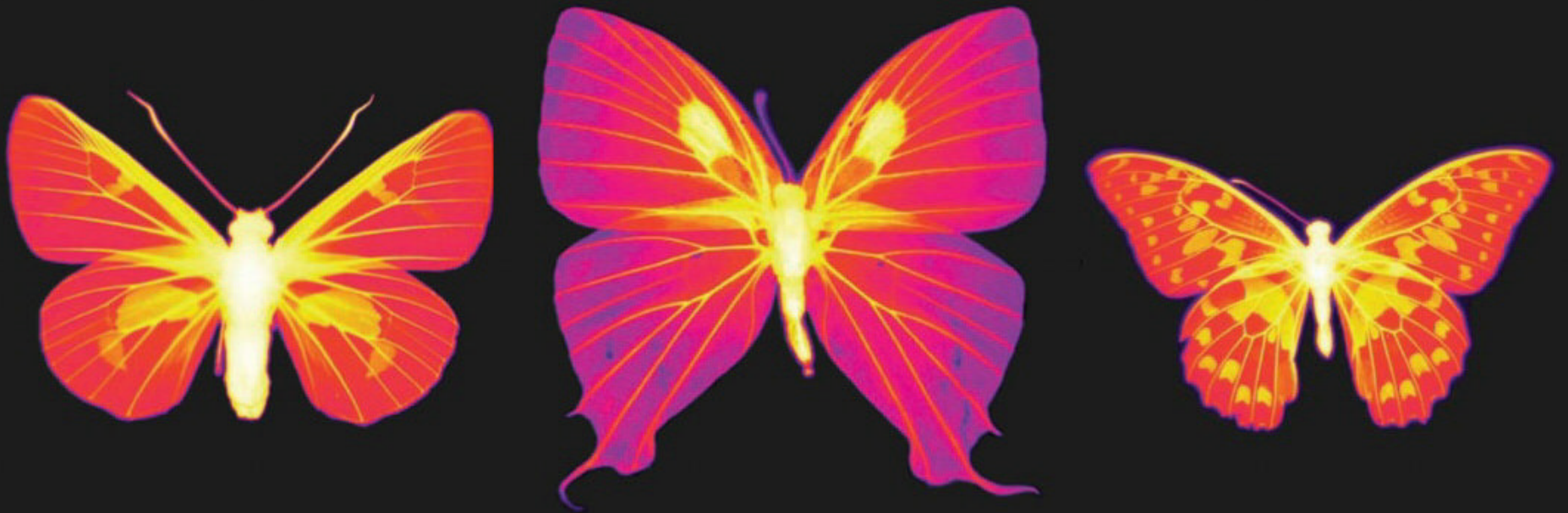
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DIGEST

SCIENCE YOU MIGHT HAVE MISSED



BIOLOGY

How and why butterflies keep their wings cool

Butterflies regulate their wing temperatures through structural and behavioural adaptations, new research shows. And they need to.

Far from being colourful but lifeless membranes, the wings contain a network of cells that require a constrained range of temperatures for optimal performance, according to a team of US engineers, mathematicians and biologists led by Columbia University.

Writing in the journal *Nature Communications*, they describe how delicate wings with a small thermal capacity can both overheat rapidly in the sun and cool down too much while flying in a cold environment.

“Butterfly wings are essentially vector light-detecting panels by which butterflies can accurately determine the intensity and direction of sunlight, and do this swiftly without using their eyes,” says Nanfang Yu, from Columbia Engineering.

By removing the wing scales to enable them to peer into the interior of the wings, then staining the neurons found within the wing, Yu and colleagues found that butterfly wings are an incredibly complex network of mechanical and temperature sensors.

They also discovered a “wing heart” that beats a few dozen times per minute to facilitate the directional flow of insect blood through a “scent pad”, or androconial organ, located on the wings of some species.

“Most of the research on butterfly wings has focussed on colours used in signalling between individuals,” says Columbia biologist Naomi E Pierce.

“This work shows that we should reconceptualise the butterfly wing as a dynamic, living structure rather than as a relatively inert membrane.

“Patterns observed on the wing may also be shaped in important ways by the need to modulate temperatures of living parts of the wing.”

Yu’s lab designed a non-invasive technique based on infrared hyperspectral imaging – with each pixel of an image representing one infrared spectrum – that enabled them to make accurate measurements of the temperature distributions over butterfly wings.

They then mimicked the butterflies’ natural environment in the lab, allowing them to quantify the contributions of several factors to the wing temperature. These included the intensity of sunlight, the temperature of the terrestrial environment,

and the “coldness” of the sky, which can serve as an efficient heat sink of thermal radiation from heated wings.

They found that in all simulated environmental conditions, despite diverse visible colours and patterns, the areas of butterfly wings that contain live cells (wing veins and scent pads) are always cooler than the “lifeless” regions of the wing due to enhanced radiative cooling.

Behavioural studies of living butterflies from six of the seven recognised butterfly families showed that they use their wings to sense the direction and intensity of sunlight – the main source of warmth or overheating – and to respond with specialised behaviours to prevent overheating or overcooling of their wings.

“Each wing of a butterfly is equipped with a few dozen mechanical sensors that provide real-time feedback to enable complex flying patterns,” Yu says.

“This is an inspiration for designing the wings of flying machines: perhaps wing design should not be solely based on considerations of flight dynamics, and wings designed as an integrated sensory-mechanical system could enable flying machines to perform better in complex aerodynamic conditions.” – NICK CARNE

PALAEONTOLOGY

Java man not so old after all

First human species out of Africa reached Asia later than thought.

The oldest human remains in Southeast Asia may not be as old as we thought they were.

An Indonesian-Japanese team of scientists has overturned a decades-old estimate of *Homo erectus* remains from Central Java province in Indonesia, shaving off several hundred thousand years from the age of the globe-trotting hominin, the first to disperse out of Africa.

The new estimate, published in the journal *Science*, puts *Homo erectus* at the fossil-rich Sangiran dome by around 1.3 million years ago, and certainly no earlier than 1.5 million years ago.

That's at least 300,000 years younger than a long-standing estimate from the 1990s, which suggested the oldest *Homo erectus* remains at Sangiran could be up to 1.8 million years old.

The age has remained controversial, though, because some studies have come up with much younger estimates for *Homo*

erectus at Sangiran, ranging from 1.3 to 0.6 million years old.

To figure out whether the fossils were older or younger, Shuji Matsu'ura from the National Museum of Nature and Science in Tsukuba City, Japan, and colleagues used two separate dating techniques not previously employed at the site.

Uranium-lead dating, which measures the crystallisation age, and fission track dating, which measures the volcano eruption age, of zircon grains show that volcanic ash just below the fossil-bearing layers are only 1.3 million years old.

The younger age of first appearance at Sangiran fits with other remains on Java that have been dated to 1.49 million years old.

It also puts to bed ideas that the birthplace of *Homo erectus* could have been in Southeast Asia. It now seems much more likely that *Homo erectus* arose in Africa and dispersed out through Georgia in the Caucasus, where the oldest *Homo erectus* remains – aged 1.85 million years – have been found. From there, they dispersed into Asia.

– DYANI LEWIS



ARCHAEOLOGY

Studying wasp nests to put an age on art

Rock paintings are younger than suspected, scientists say.

Scientists believe famous pre-historic rock paintings in Western Australia's Kimberley region are younger than previously thought after dating the remnants of mud wasp nests found over and beneath them.

The Gwion Gwion paintings have been notoriously hard to date, but evidence has suggested they were painted as far back as 17,000 years ago and over the span of several thousand years.

Now a team led by Damien Finch from the University of Melbourne, with input from the Australian Nuclear Science and Technology Organisation, has presented findings in the journal *Scientific Advances* suggesting they were more likely painted during a narrow timeframe about 12,400 years ago.

Working with the traditional owners of the sites, they analysed mud nests of wasps built on rock walls, which sometimes incorporated charcoal from regular local brushfires.

By dating the charcoal in the nests, they estimated when the nests were built. By dating nests that had been painted over, they determined the maximum age of the artwork.

By dating nests on top of paintings, they found minimum ages.

– NICK CARNE



Moves like a marsupial, climbs like a primate

Koalas really *are* built for life in the treetops.

Australia's cuddly koala seems to have evolved tree clambering abilities that rival those of the apes and monkeys that never made it to the continent.

Technically a marsupial – bearing its young in a pouch like kangaroos and wombats – *Phascolarctos cinerus* has relatively long limbs with two thumb-like digits on powerful grasping hands and feet. And it is more comfortable in the trees than on the ground.

Christofer Clemente, from the University of the Sunshine Coast, and colleagues were therefore curious to know whether it uses the same movement strategies as tree-dwelling primates.

As described in the *Journal of Experimental Biology*, the researchers ran experiments at Queensland Zoo's Wildlife HQ, filming six koalas in their semi-natural enclosures using several high-speed cameras synchronised to give a 3D reconstruction of their movements.

This took a few months, because koalas spend a lot of time sleeping. They also moved straight to the nearest tree when placed on the ground – even attempting to climb up the team's tripods.

Eventually, the researchers gained around 40 minutes of footage from more

than 200 videos, from which they analysed 198 movements on the ground, ascending and descending and moving along a narrow horizontal beam.

They found that, unlike other mammals such as cats and dogs that use two legs from the same side to support each other, koalas use a gait that allows greater stability from diagonally opposite leg pairs when climbing.

“As far as we can tell, they are the closest thing we have to primates in Australia,” says Clemente, “likely because of the similar gripping structures on the hand. They do this more so than other tree species like possums, from which they share a common ancestor.”

Unlike primates, though, their speed was more consistent with their sleepy demeanour, only reaching 2.5 kilometres per hour – although they were surprisingly agile.

“We occasionally saw leaps of over one metre from branch to branch, or a koala moving along a branch while hanging underneath just using their forelimbs,” says Clemente.

On the ground their movements were more like marsupials, walking then bounding like rabbits. They achieved speeds of up to 10 kilometres per hour – relatively slow for their body mass, but possibly slower than speeds they are capable of, the authors suggest.

– NATALIE PARLETTA



That sounds a bit fishy

‘Acoustic enhancement’ may help with reef restoration.

Young fish can be attracted to degraded coral reefs by the sounds of healthy reefs, new research suggests.

Australian and British scientists placed loudspeakers on patches of dead coral on the Great Barrier Reef and found “acoustic enrichment” doubled the number of fish in an area compared with patches where no sound was played. And the fish stayed.

This “could help to kick-start natural recovery processes”, says Tim Gordon from the University of Exeter, UK, lead author of a paper in the journal *Nature Communications*.

Colleague Steve Simpson says healthy reefs are remarkably noisy. “[T]he crackle of snapping shrimp and the whoops and grunts of fish combine to form a dazzling biological soundscape. Juvenile fish home in on these sounds when they’re looking for a place to settle.”

– AMELIA NICHELE

GENETICS

Lola found in ancient chewing gum

Genetics researchers sequence DNA from birch pitch.

This is an artistic reconstruction of “Lola” who, Danish researchers believe, lived around 5700 years ago. They obtained her entire genome, and learned a lot about her likely diet, from the DNA in a specimen of chewed birch pitch.

The team led by Hannes Schroeder from the University of Denmark determined the DNA was from a female and, based on genetic variation in several genes, that she likely had dark hair, dark skin and blue eyes.

Writing in the journal *Nature Communications*, they suggest Lola was more closely related to western hunter-gatherers from continental Europe than hunter-gatherers from central Scandinavia.

Birch pitch is obtained by heating birch bark and has been used as an adhesive since the Middle Pleistocene (760,000 to 126,000 years ago).

Small lumps of it have been found at archaeological sites and have often included tooth imprints, suggesting they were chewed.

In the non-human ancient DNA found in their specimen, Schroeder and colleagues detected bacterial species characteristic of the oral microbiome, some of which are known pathogens such as *Porphyromonas gingivalis*, which are implicated in gum disease.

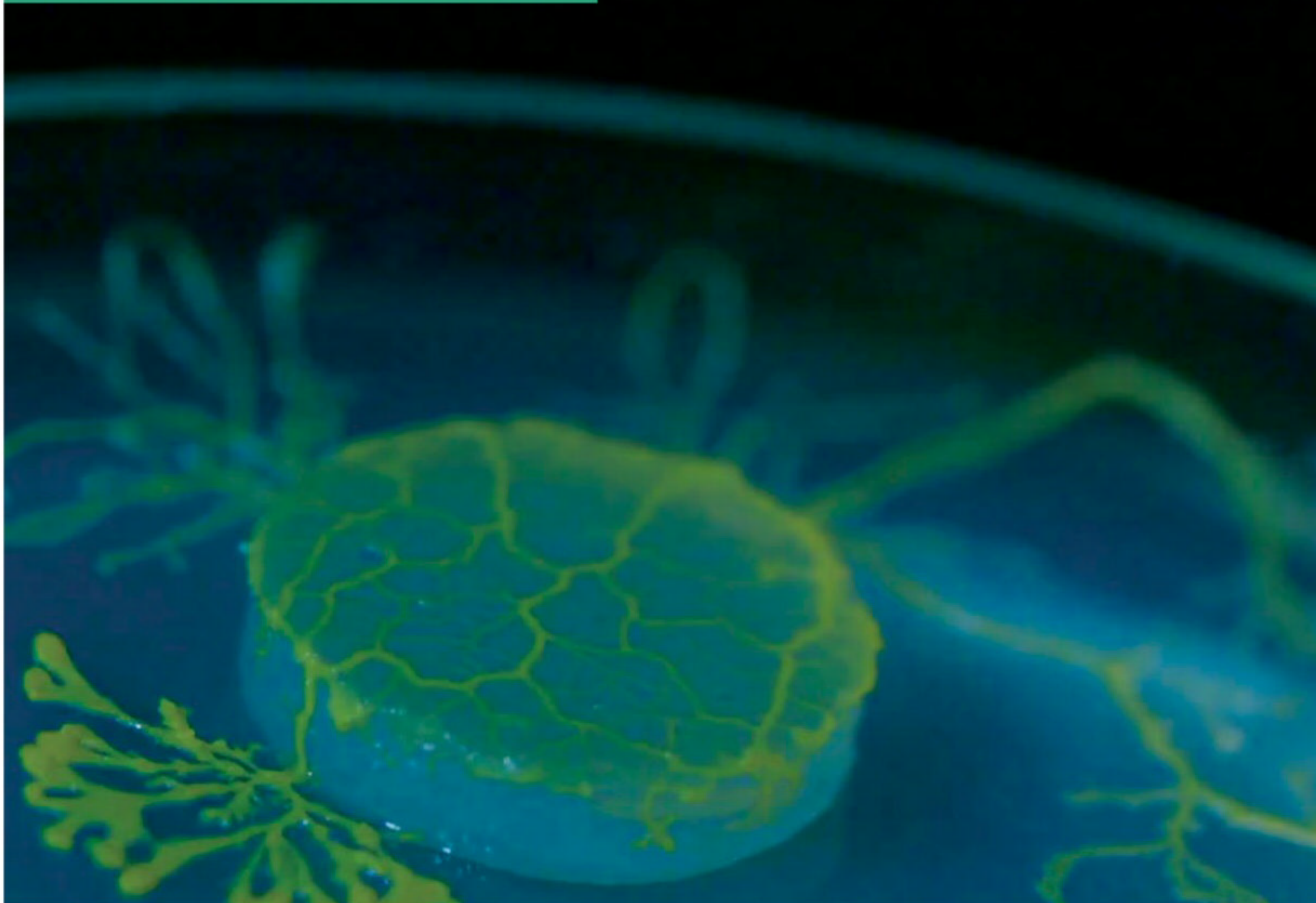
—NICK CARNE



TOM BJÖRKLUND;

MENAGERIE

Slime mould



PALAEOLOGY

Action in amber

Fossil reveals 16-million-year-old hitchhikers.

How did tiny crawling soil dwellers get around during the early Miocene? If this snapshot in amber from the Dominican Republic is anything to go by, they hitchhiked.

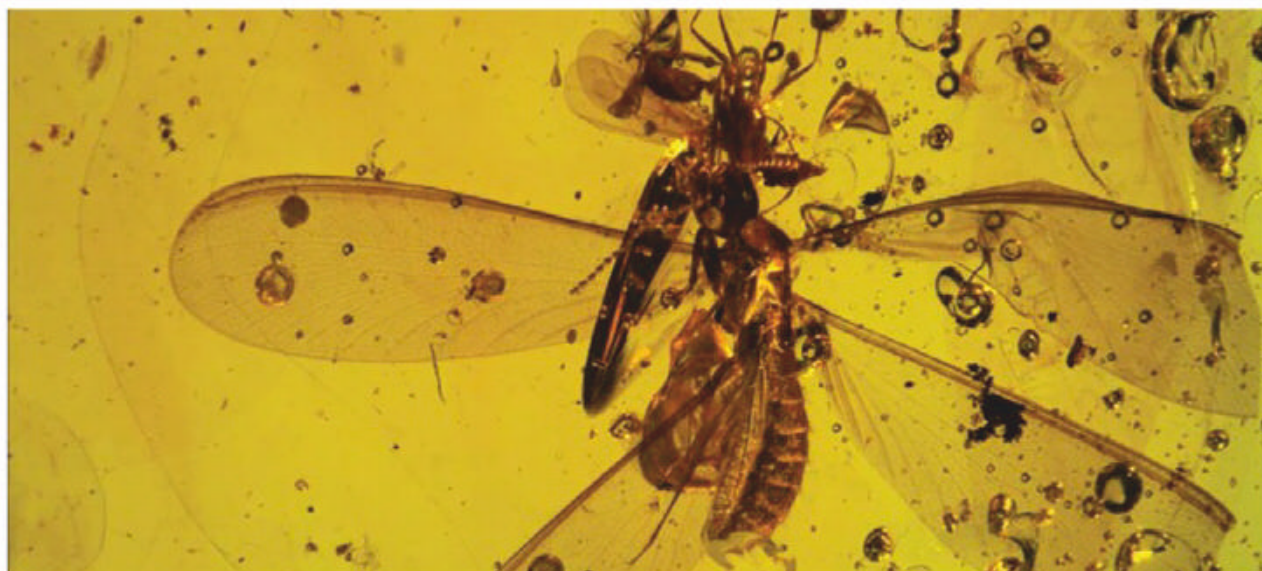
The fossil reveals a number of tiny arthropods called springtails (Collembola) still attached to the wings and legs of a large winged termite, while others are gradually floating away from their host.

In a paper in the journal *BMC Evolutionary Biology*, researchers from the New Jersey Institute of Technology (NJIT), US, and Muséum national d'Histoire naturelle, France, say the discovery

highlights the existence of a new type of hitchhiking behaviour among wingless soil-dwelling arthropods.

It also could help explain how symphypleonan springtails (one of three main groups) achieved dispersal worldwide.

“The existence of this hitchhiking behaviour is especially exciting given the fact that modern springtails are rarely described as having any interspecific association with surrounding animals,” says NJIT’s Ninon Robin. — AMELIA NICHELE



N. RUBIN, C. D'HAESE & P. BARDEN; GETTY

In the Paris Zoo, near lions, tigers and bears, lies an organism that precedes humans on Earth by some 500 million years. The yellow, sponge-like being has neither neurons nor a brain, yet it has the potential to revolutionise our understanding of intelligence.

The remarkable single-celled amoeba is called a slime mould, affectionately nicknamed “the blob”. It slowly covers ground in search of prey by extending finger-like protrusions called pseudopods.

Slime moulds have been known to solve mazes by “remembering” the dead ends. In one study, given nutrient

“station” points, they recreated a Tokyo rail system map more efficiently than its actual construction.

“Le blob” has sent a “big wave of visitors” through the gates of Paris Zoo, according to spokeswoman Vanessa Leroy. But these organisms are more than just a zoo exhibit.

Audrey Dussutour of France’s National Center for Scientific Research was drawn to discover their full capabilities. Could slime moulds habituate against substances they would normally avoid?

Dussutour placed dishes of oatmeal a short distance away from a slime mould. To reach its tasty meal, the mould had to grow across gelatin bridges laced with harmless but bitter chemicals. In the first experiment, it took 10 hours to cross the bridge.

However, after just six days the slime mould began ignoring the deterrent. It had learnt.

“That such organisms have the capacity to learn has considerable implications,” says Dussutour.

A follow-up study revealed that slime moulds could also share learnt information via cell fusion, and remember their habituation after a year of hibernation.

These studies have drawn considerable attention to these otherworldly creatures.

Leroy explains that visitors are bursting with curiosity when confronted by the unknown organism. “People take the time to look at the real specimen,” she says. “Presentations are followed by many people, who ask more questions than usual.

“Questions go from very basic such as, ‘Is it dangerous?’, ‘Can it be eaten?’, to very specific questions from fanatics or scientists, such as ‘Has its genome already been sequenced?’ or, ‘Have hybrids been produced and what are their characteristics?’” Leroy says.

With research on this curious organism far from finished, le blob has been guaranteed permanent accommodation at the Paris Zoo. “The zoo, as part of the National Museum of Natural History, is actively involved in research, and the blob is of course a primary subject,” says Leroy.

“So we plan on presenting in the exhibit results and future directions of such studies.”

— ELLIE GRIFFIN

BIOLOGY

Honeybees can surf to safety

On water their wings work like hydrofoils.

When a honeybee falls onto water it can essentially surf to safety, research engineers in the US have discovered.

While the water sticking to its wings robs it of the ability to fly, that very stickiness allows it to drag water, creating waves that propel it forward. The wings act much like hydrofoils.

The motion has never been documented in other insects, and may represent a unique adaptation by bees, says Chris Roh, who worked with California Institute of Technology colleague Mory Gharib.

Writing in the journal *Proceedings of the National Academy of Sciences*, they report that bees don't seem able to generate sufficient force to free themselves directly from the water, but their wing motion can propel them to the edge, where they can pull themselves onto land.

The research stemmed from a chance observation. As Roh noticed a bee stuck on the still water of a pond, the overhead sun cast the shadows of the bee and the waves created by its flailing wings directly onto the bottom.

The shadows showed the amplitude of the waves generated by the bee's wings, as well as the interference pattern created as the waves from each wing crashed into each other.

They then recreated the conditions in their lab, studying 33 bees individually for a few minutes at a time, before giving them time to rest and recover.

They noted that a strong, large-amplitude wave with an interference pattern was generated in the water at the rear of the bee, while the surface in front lacked the large wave and interference.

This asymmetry propels the bees forward with the slightest of force – about 20 millionths of a Newton. For reference,

they say, an apple held in your hand exerts about one Newton of force on your palm due to gravity.

Slow-motion video revealed the source of the asymmetry: rather than just flapping up and down in the water, the bee's wings pronate, or curve downward, when pushing down the water and supinate (curve upward) when pulling back up, out of the water.

The pulling motion provides thrust, while the pushing motion is a recovery stroke. In addition, the wingbeats in water are slower.

The dorsal (top) side of the wing remains dry, while the underside clings to the water. The water that remains attached to the underside of the wing gives the bees the extra force they use to propel themselves forward.

Hydrofoiling is a lot more taxing for the bees than is flying, however. Roh estimates bees could only keep up the activity for about 10 minutes.

– NICK CARNE



IN FOCUS: HEALTH

01

What causes that “deer-in-the-headlights” reflex, where people freeze momentarily in response to a potential threat? If we’re anything like flies, it could be serotonin. US researchers have discovered that when a fly experiences an unexpected change in its surroundings, the release of the chemical helps to temporarily stop it in its tracks.

03

Researchers are developing a dye that could allow a person’s vaccination record to be injected into their body at the same time as a vaccine. It would then be stored beneath the skin for up to five years, avoiding the all-too-common problem of vaccination details being lost, and follow-up vaccinations missed.

05

Australian researchers have developed a new way of analysing data from individual human cells by combining conventional techniques with machine learning algorithms. The resulting process, which they liken to fingerprinting cells, allows single cells with a unique genomic profile to be identified from a tissue sample.

02

Stop fretting about your split ends. A new study suggests they actually allow your hair to endure greater tension before it breaks. Thin hair tends to be stronger than thick hair. Elephant hair is four times thicker than human hair, for example, but only half as strong.

04

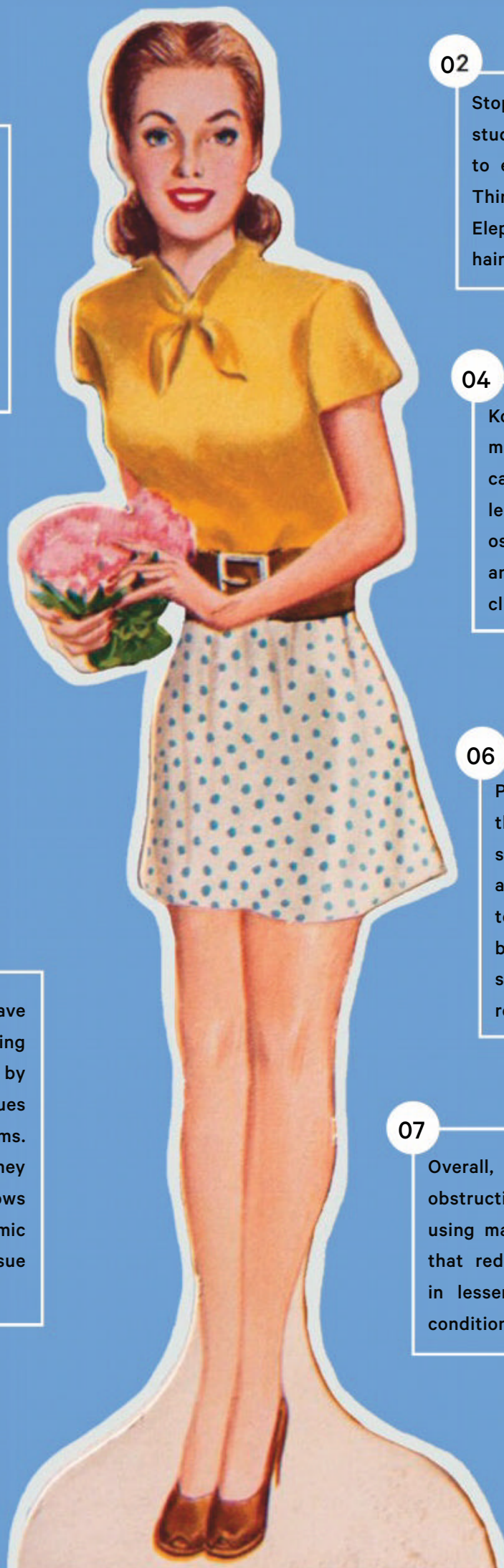
Korean researchers have invented a magnetic microbot that delivers stem cells to damaged cartilage in the knee, a discovery that could lead to treatments that prevent debilitating osteoarthritis. The device was tested in animals, but they are seeking approval for clinical trials in humans.

06

Pathology appears to be a new focus for the inexorable march of AI into medical science. In January, just days apart, US and Dutch scientists separately unveiled technology they say can match and even beat trained humans in classifying surgical samples for brain and prostate cancers respectively.

07

Overall, obesity is the primary risk factor for obstructive sleep apnoea. Now US researchers using magnetic resonance imaging have found that reducing tongue fat is a primary factor in lessening the severity of the debilitating condition.



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GENETICS

Life clock ticking

Study suggests genetics can predict a species' maximum lifespan.

Researchers from CSIRO and the University of Western Australia have figured out a way to tell how long a species' life clock will keep ticking.

"Our method for estimating maximum natural lifespan is based on DNA," says Ben Mayne, a postdoctoral fellow with CSIRO. "If a species' genome sequence is known, we can estimate its lifespan."

The "lifespan clock" screens 42 selected genes from short pieces of DNA in 252

vertebrate species. The density of these genes is correlated with lifespan to predict how long members of a given vertebrate species may live.

The authors suggest their findings – which are published in the journal *Scientific Reports* – may inform research into the ecology and evolution of living and extinct species, the protection of threatened species, and sustainable fishing.

When studying extinct animals, researchers used a species' descendent as reference. The genome of the modern African elephant allowed lifespan estimations for the extinct woolly mammoth and straight-tusked elephant.



“Using our method, we found the maximum lifespan of the bowhead whale is 268 years – 57 years longer than people thought,” Mayne says.

“We discovered that extinct woolly mammoths lived for 60 years and the recently extinct Pinta Island giant tortoise from the Galápagos lived for 120 years.”

The Pinta Island giant tortoise genome is known from the last surviving member of the species, Lonesome George, who died at the Charles Darwin Research Station on Santa Cruz Island in 2012.

The researchers also studied humans and found our maximum natural lifespan to be 38 years.

This matches lifespan estimates of early modern humans – before advances in medicine and lifestyle extended human life in many parts of the globe.

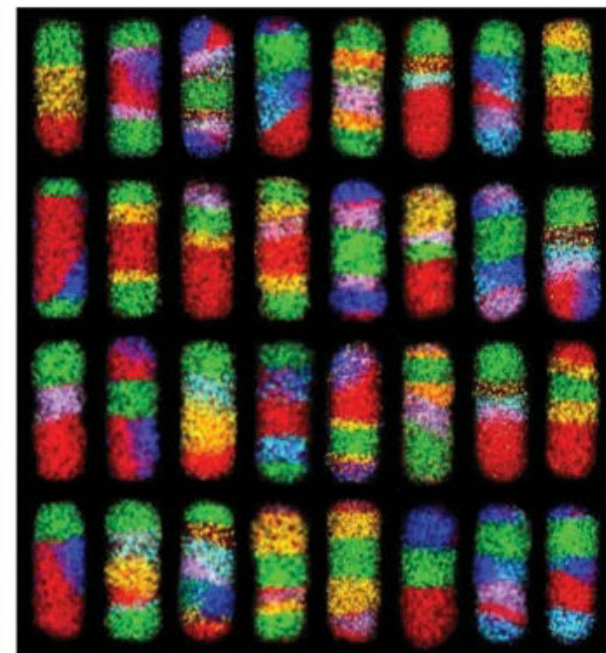
Using chimpanzees as reference, the study found that Neanderthals and Denisovans had a maximum lifespan of 37.8 years, similar to modern humans living around the same time.

Despite the successful outcome when studying vertebrates, the researchers were unable to accurately estimate the lifespans of invertebrates – possibly because many invertebrates do not exhibit the study’s chosen genes to the same extent as vertebrates.

– IAN CONNELLAN

CHEMISTRY

A mega library of nanoparticles



Creating it took no more than the basic principles of chemistry, researchers say.

US researchers have developed a way to produce 65,000+ types of complex nanoparticles, each containing up to six different materials and eight segments, with interfaces that could be exploited in electrical or optical applications.

It’s a simple approach, using straightforward chemistry and a mix-and-match, modular strategy, they say in a paper in the journal *Science*, but the resulting nanoparticles are among the most complex ever made. Each is about 55 nanometres long by 20 wide: by comparison, a human hair is about 100,000 nanometres thick.

To create them, Raymond E Schaak and colleagues from Pennsylvania State University took simple nanorods composed of copper and sulfur then sequentially replaced some of the copper with other metals using a process called cation exchange.

By altering the reaction conditions, they could control where in the nanorod the copper was replaced. They repeated the process with other metals, which could also be placed at precise locations.

By performing up to seven sequential reactions with several different metals, they could create a rainbow of particles

In the image above (taken with an electron microscope) each colour in each nanorod represents a different material.

– NICK CARNE

SOCIETY

Culture vultures may live longer

Study highlights health benefits of engaging with the arts.

Those who think enjoying a good dose of culture is arty-farty could be missing out, with a new study linking arts appreciation to living longer.

Researchers at University College London, UK, found that people who regularly go to the theatre, concerts, the opera, museums or art galleries have a lower risk of dying than those who refrain.

This adds to evidence linking art engagement with physical health and wellbeing. The “universality of art and the strong emotional responses it induces”, leads some researchers to suggest it has evolutionary benefits, write Daisy Fancourt and Andrew Steptoe, although others question whether art is “an evolutionary parasite”. They argue that creativity and imagination have been linked to increased survival throughout human evolution and that arts engagement enhances cognition, empathy, social perception and emotional intelligence.

The arts could also give life a greater sense of meaning, reduce risk-taking behaviours, get people out and reduce sedentary behaviour and loneliness – all of which are associated with better health outcomes.

Titled “The art of life and death”, the study, published in the *British Medical Journal*, followed more than 6000 adults aged 50 and older for 14 years in the English Longitudinal Study of Aging.

Participants self-reported arts engagement at the study’s inception, along with a comprehensive range of demographic, behavioural, socio-economic and health factors. Mortality data was sourced from National Health Service Records.

While cognition, mental health and physical activity were protective, arts involvement was independently linked to lower mortality after these variables were factored in, and this persisted through several analyses.

Overall, people who engaged in the arts once or twice a year had a 14% lower chance of dying than those who never got involved, while enjoying culture more regularly was associated with a 31% lower risk.

In a related commentary, Nicola Gill and co-authors from Canterbury Christ Church University, UK, note that people with lung disease, depression or loneliness, who could derive the most benefits, were least likely to engage in the arts.

“Work must now be done to ensure that the health benefits of these activities are accessible to those who would benefit most,” they write – including children.

“The current study should add weight to growing concerns about the decline in arts subjects and music in schools and universities.”

– NATALIE PARLETTA

BIRTH, DEATHS & MARRIAGES

Of the 49 new Australian species published between 1 December and early February, a new type of gall fly sounds like a candidate for the “least exciting” list – until you start to consider context.

As Taxonomy Australia director Kevin Thiele reports, *Fergusonina nodulosa* is “pretty tiny”, and develops in galls (abnormal growths) of only a few millimetres diameter.

“The interesting thing is that the discovery of this one species involves a whole host of relationships with other species,” says Thiele. “For a start there’s the iconic river red gum [*Eucalyptus camaldulensis*] that the fly lays its eggs in to form the galls. Then there’s an obligate nematode that lives in the fly. Then there are three species of moths that lay their eggs in the galls produced by the fly. Then there are 13 species of wasps that parasitise either the gall fly larva or the larvae of the moths.”

The 49 newcomers include three arachnids, two crustaceans, a flatworm, two fungi, 21 insects, 12 new plants and eight new vertebrates.

Alongside *F. nodulosa*, Thiele pointed to five new types of earless dragon (*Tympanocryptis* spp) in South Australia, and the rare guinea-flower *Hibbertia tuberculata*, which was first collected more than 30 years ago in the West Australian goldfields.

Thiele says that it’s important to recognise new species in areas disturbed by such things as mining or land clearing to ensure that endemic species are adequately conserved.

“The guinea-flower wasn’t recognised as distinct or named until this year, when more specimens were collected for surveys of potential new lithium mines,” he says. “Now that the species has a name... its conservation will need to be taken into account when new mines are planned and approved.”

On the other hand, acts of nature – particularly bushfires – have produced less thrilling outcomes for native species.

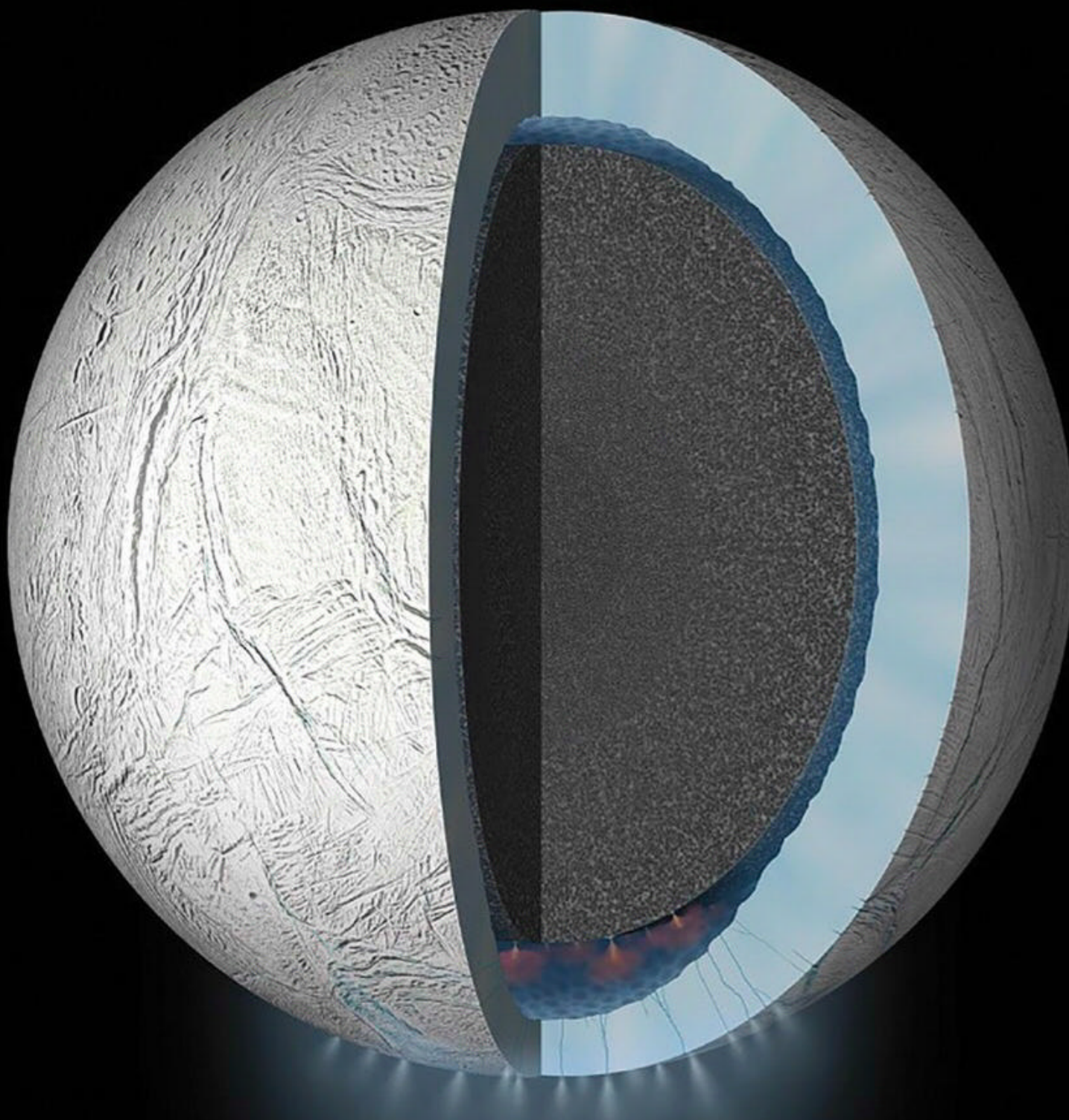
In early February, the Federal Department of Environment released a provisional list of 113 animal species identified “for urgent management intervention” in the wake of the 2019/20 Australian bushfires. The list includes 13 bird, 19 mammal, 20 reptile, 17 frog, five invertebrate, 22 crayfish and 17 fish species.

Included are species not currently listed as threatened under the *Environment Protection and Biodiversity Conservation Act 1999* or by the IUCN – but which mostly have more than 30% of their range within the burnt areas. The new analysis incorporates each species’ potential vulnerability to fire.

A worldwide eucalypt species assessment in the latest IUCN Red List update reveals that almost 25% are threatened with extinction. More than 800 of the world’s 826 known eucalypts – comprising the *Eucalyptus*, *Corymbia* and *Angophora* groups – occur only in Australia. Species identified in the assessment include the koala food tree (*E. moluccana*), the striking rose mallee (*E. rhodantha*), and the critically endangered Bandalup silver mallet (*E. purpurata*), which is threatened by mining in its restricted range.

An ancient spider species found only on Kangaroo Island, SA, could be extinct as a result of recent fires. The assassin spider *Zephyrarchaea austini* is only known to occur in KI’s Western River Wilderness Protection Area. Queensland Museum’s Mike Rix, who first described the spider, told the ABC that the area was “significantly impacted” by fire and that *Z. austini* “may have been gravely impacted if not wiped out”. It’s feared other species may have been burnt to extinction in the massive fires, but much remains unknown: site assessments and analysis will stretch over months. – IAN CONNELLAN





SPACE

Exploring the inner complexity of Enceladus

Subsurface ocean composition hints at habitable conditions.

US researchers say a new geochemical model reveals that carbon dioxide from Saturn's moon Enceladus may be controlled by chemical reactions at its seafloor.

Studying the plume of gases and frozen sea spray released through cracks in the moon's icy surface suggests an interior more complex than previously thought, according to their paper in *Geophysical Research Letters*.

Analysis of mass spectrometry data from NASA's Cassini spacecraft indicates that the abundance of CO₂ is best explained by geochemical reactions between the

Moon's rocky core and liquid water from its subsurface ocean.

Integrating this information with previous discoveries of silica and molecular hydrogen points to a more complex, geochemically diverse core.

"Based on our findings, Enceladus appears to demonstrate a massive carbon sequestration experiment," says lead author Christopher Glein, from Southwest Research Institute (SwRI), Texas. "On Earth, climate scientists are exploring whether a similar process can be utilised to mitigate industrial emissions of CO₂.

"Using two different data sets, we derived CO₂ concentration ranges that are intriguingly similar to what would

be expected from the dissolution and formation of certain mixtures of silicon- and carbon-bearing minerals at the seafloor."

Adding to this complexity, the researchers say, is the likely presence of hydrothermal vents inside Enceladus. At Earth's ocean floor, hydrothermal vents emit hot, energy-rich, mineral-laden fluids that allow unique ecosystems teeming with unusual creatures to thrive.

"While we have not found evidence of the presence of microbial life in the ocean of Enceladus, the growing evidence for chemical disequilibrium offers a tantalising hint that habitable conditions could exist beneath the moon's icy crust," says SwRI's Hunter Waite.
— NICK CARNE

TECHNOLOGY

Artificial neurons can behave like real ones

Researchers successfully create them on tiny silicon chips.

The authors of a study in *Nature Communications* exhibit the kind of calm rationality that makes one believe. They point out that neuromorphic silicon devices replicating biological nerve functions have been proposed before, but problems have hampered attempts to develop them.

The design of devices such as silicon neurons, synapses and brain-inspired networks is not meant to copy the behaviour of biological cells, they say, but to search for the organising principles of biology that can be applied to practical devices.

However, an increasing focus on implantable bioelectronics to treat chronic disease is changing this paradigm and “instilling new urgency in the need for low-power analogue solid-state devices that accurately mimic biocircuits”.

The British/Swiss/New Zealand team’s paper describes a way of making silicon chips that are smaller than a fingertip but reproduce the electrical behaviour of biological neurons. This, they say, could lead to the development of bionic chips to repair biological circuits in the nervous system when functions are damaged or lost to disease.

They designed microcircuits modelling ion channels that integrate raw nervous

stimuli and respond in a similar way to biological neurons, then recreated the activity of individual hippocampal and respiratory neurons in silicon chips.

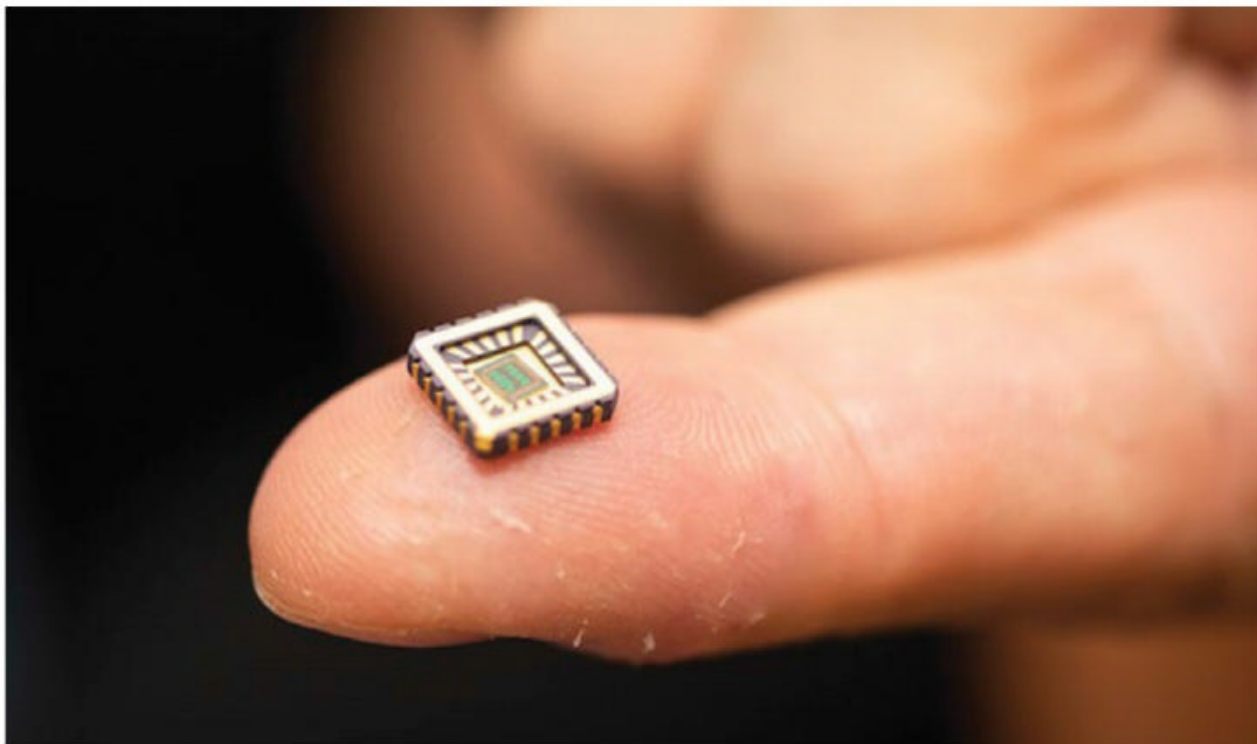
In a series of 60 electrical stimulation protocols, they found that the solid-state neurons produced nearly identical electrical responses when compared to biological neurons.

“We can very accurately estimate the precise parameters that control any neurons behaviour with high certainty,” says Alain Nogaret, from the University of Bath. “We have created physical models of the hardware and demonstrated its ability to successfully mimic the behaviour of real living neurons.

“Our third breakthrough is the versatility of our model, which allows for the inclusion of different types and functions of a range of complex mammalian neurons.”

Nogaret and colleagues note that respiratory neurons, such as those they have modelled, couple respiratory and cardiac rhythms and are responsible for respiratory sinus arrhythmia.

Loss of this coupling through age or disease is a prognosis for sleep apnoea and heart failure. They suggest that a device that adapts biofeedback in the same way as respiratory neurons may offer a potential therapy in the future. – IAN CONNELLAN



SPACE

First results from close to the sun

Parker Solar Probe data paint a complex picture.

The first results from NASA’s Parker Solar Probe reveal that the Sun’s outer atmosphere is even more complex than scientists thought.

Launched in 2018, Parker’s mission is to dive ever closer to the Sun, eventually getting to just more than six million kilometres from its surface.

The two encounters to date have not gotten any closer than 24 million, but that’s less than half the distance between the Sun and Mercury, and twice as close as any prior spacecraft.

One surprise, says Daniel Verscharen, a space-plasma physicist at University College, London, who was not part of the Parker team, is that the Sun’s magnetic field has frequent “switchbacks” in which, for a few minutes, it suddenly reverses direction.

Something similar had been seen from further away, “but we had no idea that they would be so strong and would occur so often”. These reversals cause the velocity of the solar wind to alternately increase and decrease and may contribute to heating the Sun’s corona.

Also interesting, Verscharen says, is the discovery that the plasma has turbulent fluctuations or “instabilities”. Such turbulence is another way in which energy can be transferred from the magnetic field to the plasma, thereby heating it. – RICHARD A LOVETT

One can imagine an old wizard, Albus Dumbledore perhaps, peering into the clear globe of this mystery object.

Invented in 1853 by Scottish Gaelic scholar John Campell, this object consists of a 10cm (4") diameter glass sphere mounted in a bowl with evenly cut grooves in it. The metal base plate must be mounted level, and is squared on the right-hand end and rounded on its left-hand end, which must point due north.

In 1879 it was adapted and improved by physicist and mathematician Sir George Gabriel Stokes.

We know you can Google, but where's the fun in that? Tell us what you think it is. The correct answer – and the most creative reply – will be published in the next issue. contribute@cosmosmagazine.com.au



TECHNOLOGY

Pavlov's plastic

Inanimate material can be “trained” to behave like small artificial muscles, a new study suggests.

Picture a robot and images of futuristic humanoids of metal and code come to mind. However, researchers in Finland are creating a tunable “micro-robot” that could become an important asset for biomedical procedures.

It's made from liquid crystal polymer networks (the base for most plastics) layered with a coat of dye that responds to heat. It converts energy into a bending motion, much like a human finger curls, thereby “walking” at roughly the speed of a snail.

The method, published in the journal *Matter*, represents the first time an inanimate material has “learnt” an action. Researchers used conditioning with heat and its association with light to produce a response – something like training a pet.

“Our research is essentially asking the question if an inanimate material can somehow learn in a very simplistic sense,” says senior author Arri Priimägi, from Tampere University of Applied Sciences.

Learning can be considered a sequence of processes through which a biological system or organism modifies its behaviour based upon past experiences.

The full complexity of learning is unknown, and involves perception, memory, motor functions, consciousness, and reward-seeking, many of which have been connected solely to living organisms.

However, simple organisms learn by fundamental learning forms such as habituation, sensitisation and classical conditioning.

In the micro-robot, classical conditioning was used to prompt a response – bending – to an initially neutral stimulus: light.

“My colleague, Professor Olli Ikkala from Aalto University, posed the question:

‘Can materials learn, and what does it mean if materials would learn?’” says Priimägi.

“We then joined forces in this research to make robots that would somehow learn new tricks.”

The conditioning process to associate light with heat includes turning the material blue as the dye on the surface diffuses throughout it. This increases the overall light absorption, which boosts the photothermal effect (an increase in energy in atoms caused by the absorption of a particle of light) and raises the micro-robot's temperature.

It then “learns” to bend when exposed to light as it self-heats.

Besides walking, the material can recognise and respond to different light wavelengths that correspond to the coating of its dye. This characteristic makes the material a tunable soft micro-robot that can be remotely controlled – an ideal material for biomedical applications.

“I think there's a lot of cool aspects there,” says Priimägi. – IAN CONNELLAN

PALAEONTOLOGY

Tiny fossils are first known baby dinosaurs from Australia

Discovery reveals dinosaurs were breeding near the South Pole.

A collection of tiny fossilised thigh bones, some just 2.5 centimetres in length, are the first remains of baby dinosaurs ever found in Australia.

Discovered in NSW and Victoria, the bones belonged to baby herbivores that were small enough to sit in the palm of a hand.

As Australia was much further south 100 million years ago – when these babies were tottering around in their nests – they are also proof that dinosaurs were breeding in southern polar environments within the Antarctic Circle.

The discovery adds to evidence that



“dinosaurs were remarkably climate-tolerant, thriving from equatorial to polar latitudes”, write the authors of a paper in the journal *Scientific Reports*.

The NSW fossils, from the outback town of Lightning Ridge, were so small they may have belonged to embryonic dinosaurs

that weighed around 150 grams and were less than 20 centimetres in length from head to tail.

“They were just about at, or prior to, the point of hatching from the egg,” says co-author Phil Bell, from the University of New England. – JOHN PICKRELL

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Hubble trouble, boils and bubbles



How quickly is the Universe expanding?
It's a question currently causing a crisis in
astrophysics – and as **Katie Mack** explains,
that's a wonderful problem to have.

IT'S OFTEN SAID that science is self-correcting. First, a scientist presents a result, openly admitting that they may have made a mistake somewhere along the way. Next, other scientists step in to check their numbers, reproduce the experiment, or, better yet, test the conclusion via an entirely different, independent method. If all parties agree, we have a consensus, and people begin to cautiously trust the original conclusion.

It doesn't stop there, of course – anything we think we know in science can change based on new data or analyses – but if you're going to rank the believability of different kinds of results, those supported by more than one group in more than one way should be highest on your list.

The tricky part is when experiments disagree. Hard science should never be a

matter of opinion; it's all based on the idea that there is a right and replicable answer, and through rigorous experimentation and logical thought, we will find it. Any disagreement about some fundamental property of the natural world has to be a mistake, and if we retrace our steps carefully enough, we'll find it.

Or, alternatively, the whole framework on which we've based our understanding of the experiments is wrong.

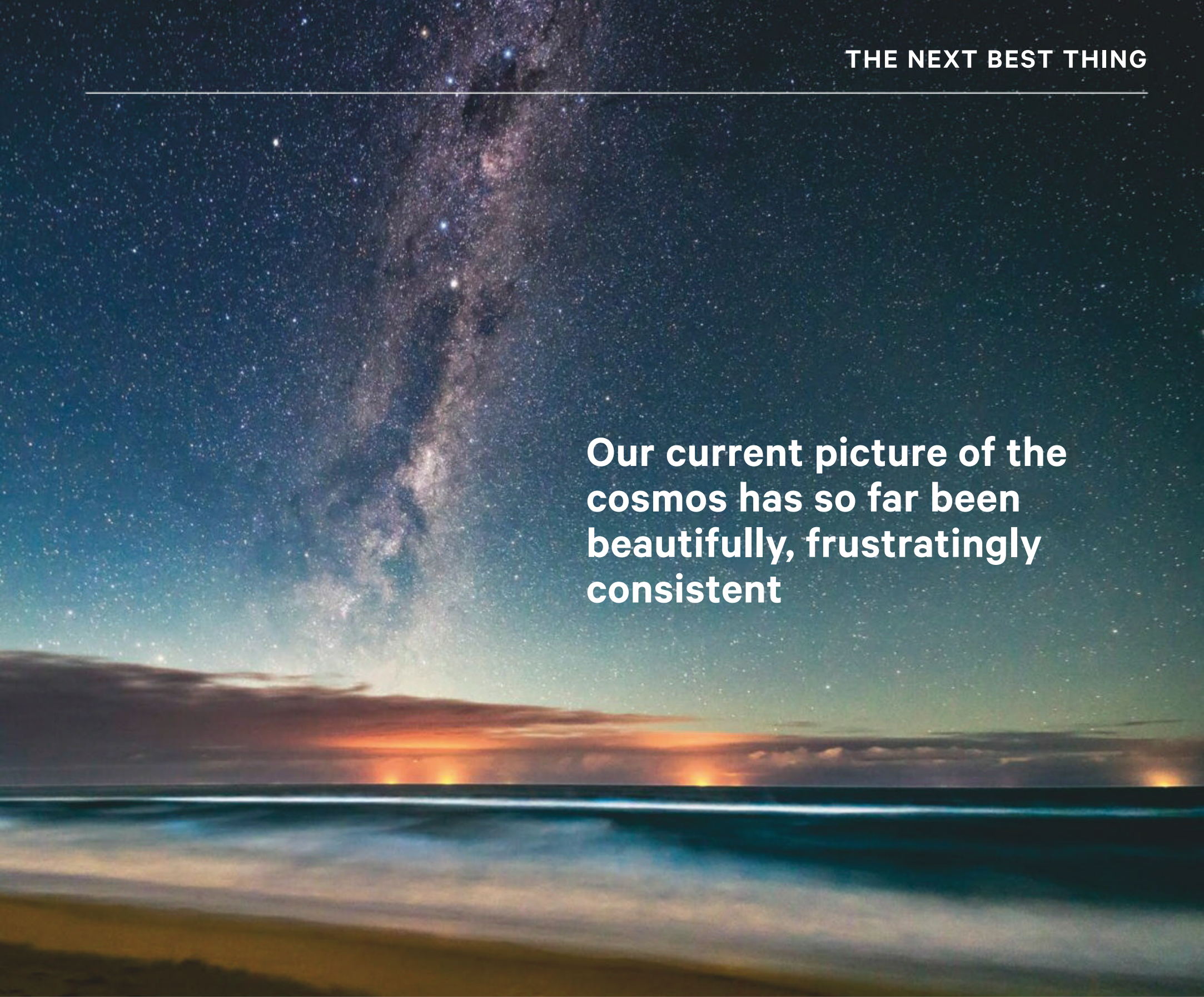
This is the dilemma we're facing now in cosmology. It concerns what seems like a very straightforward question: How quickly is the Universe expanding?

In the last few years, it's become clear that two of the methods previously considered to be the most precise and reliable ways to measure this have been pointing us toward different answers. In

one method, we observe a large number of galaxies around us and measure how quickly they seem to be receding. The other is based on looking at the most distant light in the Universe – the cosmic microwave background – and carefully measuring the sizes of hotter and colder spots in that light to conclude something about the shape of space and the whole history of cosmic expansion.

While the galaxy method might seem far more straightforward, it's complicated by the fact that it requires us to know the distances to those galaxies very precisely. And because we figure that out by observing stellar explosions, it requires us to have an extremely good understanding of how stars work, in a range of galactic environments.

Astronomers have always expected both methods to give us the same answer: a



Our current picture of the cosmos has so far been beautifully, frustratingly consistent

number called the Hubble Constant, named after the first astronomer to measure it. But as both sides get more precise data, it's becoming clear that the answers disagree. This is sometimes called the "Hubble tension"; other times it's called a "crisis in the cosmos".

So, what's the solution? It may be that one side is making a mistake in its data analysis. Or perhaps missing some important bit of astrophysical data that would lead to a different result. The only other possibility is that both measurements are essentially correct, but they're not actually measuring the same thing, which would mean our big picture is incomplete, and the evolution of the cosmos is more complicated than we thought.

Based on the headlines, you'd think that this last possibility would be the nightmare

case. It would, after all, mean that the very precise accounting we've made of the makeup and/or evolution of the Universe was never correct, and we've been missing something important all this time.

But from an astronomer's viewpoint, it's less of a nightmare and more of a dream come true.

Our current picture of the cosmos has so far been beautifully, frustratingly consistent with every measurement we've thrown at it. This so-called Concordance Cosmology has passed every observational test, painting for us a precise picture of exactly what the Universe is made of, and in what quantities. Even general relativity, a theory of gravity first written down by Einstein in 1915, has yet to show any cracks.

In science, when everything works as expected, it might be personally satisfying,

but it doesn't give you any hint as to how to make your theories better. Cosmology is in desperate need of just such a clue, in part because the two most important components of the cosmos, dark matter and dark energy, are so far entirely unexplained.

We don't know yet what the solution to the Hubble tension will be. It's entirely possible that it will turn out to be an unaccounted-for fluke of stellar evolution, or some glitch in a data analysis pipeline, rather than bona fide new physics. But whether or not this "crisis" leads us on a path to a better understanding of the cosmos, we'll keep hoping to see something truly unexpected in the data – something weird that will tell us where to go next.

As Irish comedian Dara Ó Briain once said, "Science knows it doesn't know everything. Otherwise, it would stop".

2020 vision

Humans see the world three kinds of cone cells (receptors used for colour vision) that give us the world, usually in reasonable focus, in red, green, blue (RGB) colour. It can be easy to overlook how different life looks from a different perspective.



Diurnal birds have an extra cone cell that's sensitive to UV wavelengths. Additionally, each cone contains a drop of oil that acts in a similar fashion to a camera lens, allowing them to better differentiate hues.



Sharks are much more sensitive to light, but lack the receptor cells to see in colour – prey in monochrome.



Composed of thousands of individual optical receptors called ommatidia, a fly's compound eyes can't focus with anything like human accuracy, but they allow a 360-degree view and are awfully good at picking up the slightest of movements – such as someone trying to swat their owner.

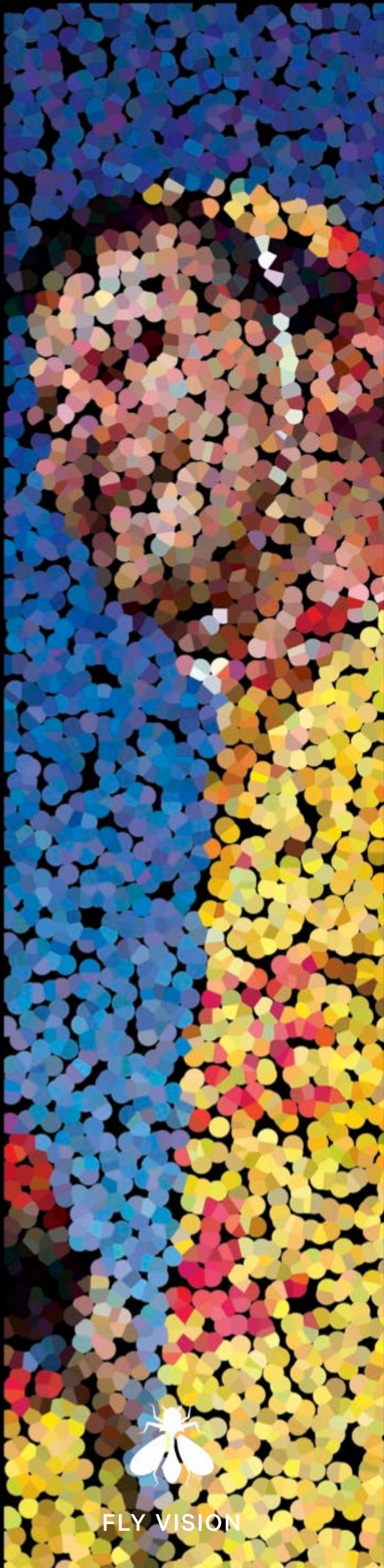


Snakes are dichromatic – they see in two primary colours, blue and green. Most types are sensitive to UV light, and some species also have vision in infra-red, allowing them to heat-seek as well.



Computer vision, or CV, is the field of study aimed to get computers to “see” and interpret imagery such as photographs and video. All information, no matter how complex, is stored by binary combination: 1 or 0.





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FROM THE FRONT LINE

Future flock

Some free-range chooks lay substantially more eggs than others, and Manisha Kolakshyapati, from The University of New England, is trying to find out why.



Manisha Kolakshyapati, animal researcher
at The University of New England

Growing up in Nepal, Manisha Kolakshyapati was surrounded by animals. Her father was a professor in agriculture and the family lived on a university campus. “We had access to a whole lot of animals and I enjoyed being around them – I liked it there,” she says.

It therefore wasn’t a huge surprise when Kolakshyapati decided to follow her father’s footsteps, working with animals and exploring how to improve food production. Initially studying veterinarian science in Nepal, she went on to pick up two postgraduate degrees – a Masters in Animal Science, from the Swedish University of Agricultural Sciences, and a Masters of Food Science from the University of Helsinki.

She returned to Nepal to work as a scientific researcher and veterinarian for the government, and now she’s working on a PhD at the University of New England.

The focus of much of Kolakshyapati’s early research was on broilers, but for the past two years she has been targeting egg production, and in particular production in free-range chickens.

The rise of consumer interest in and

demand for free-range eggs has led to a substantial increase in production in Australia and elsewhere over the past decade. In 2010 just 25% of Australia’s eggs were free-range, now it’s around 40% of the 100 million eggs sold each week. Of our 19 million egg-laying chickens, about 10 million are housed in cages, with the rest in barn or free-range production.

Free-range flocks often perform poorly compared with hens housed in barns or cages and within free-range chook populations, some chickens are better layers than others. Kolakshyapati set out to find out why and quickly discovered that the reasons are surprising.

“Chickens always form subpopulations,” she says. “In free-range populations, some hens will always go outside if given the opportunity. We call these ones the rangers. Others prefer to stay inside the sheds. We call these the stayers.”

Different farms have different percentages of stayers and rangers. For example, in the UK (perhaps where conditions are colder outside) up to 50% of a free-range population may be stayers, but

in Australia the average percentage is 10%.

Kolakshyapati initially thought that the rangers would be using more energy to move around further, so would probably not be as productive in terms of laying eggs as they would be using the energy for mobility. “But the ones that were going outside were producing more eggs,” she says. “We were expecting the positive production difference in the stayers, but it’s happening the opposite way.”

The surprising result has led Kolakshyapati and other researchers on a quest to try to determine why – considering factors such as genetic differences or dietary differences (rangers may be ingesting more dirt, or pasture or microbes that could be helpful).

One of the key differences she has found is that the stayers seem to be more fearful birds, and this is likely to be affecting their production. When she took a group of stayers and a group of rangers into a different environment, the stayers showed more fearful behaviours – for example, in their interaction with a new environment.

“If a hen is stressed, she will allocate



energy towards a physiological stress response and, if this is a chronic state of stress, it will have long-term impacts on welfare and productivity,” she says.

“Evaluating the egg albumen corticosterone level, an indicator of physiological stress, we showed that stayers were less resilient to stress and took more time to recover after a stressful event. Stayers likely allocate more of their energy to a physiological stress response, leaving less energy for production, growth and maintenance.”

While the corticosterone results indicated that the stayers were less resilient to stress compared to the rangers and a control group, these results aren’t definitive on their own and are being compared with behavioural studies to develop a better picture in regards to the link between fear and poor egg production.

The differences between the rangers and the stayers might resolve over time. “With time, most of the stayers started going out more,” Kolakshyapati says. “We see that the heavier pullets end up being

rangers, and the lighter ones are stayers. So it might be related to weight.”

There’s no doubt Kolakshyapati still has great enthusiasm for her subject, even as her PhD moves into its third year. This is particularly helpful as she looks at the role of gut microbiota and the role it could have on egg laying. “Studies into environmental enrichment could also show an effect,” she says. “The free rangers seem to like a new environment, so maybe that could be a factor. The more we look into it, the more we find to look into.”

Winged watchmen

Updrafted into service in the fight against illegal fishing, these graceful airborne giants could be the key to defending devastated ocean ecosystems. JAMES URQUHART reports.

WITH WINGSPANS ALMOST the length of a car – the largest of any bird – small and inconspicuous they are not. But albatrosses have been turned into spies of the high seas to uncover suspicious fishing vessels.

The concept could, for the first time, reveal the extent of illegal and undeclared fishing that devastates ocean ecosystems, while enabling authorities to swoop in based on intel received from these feathery giants.

To illuminate the shady goings-on in the open ocean, a team led by Henri Weimerskirch, a marine ecologist at the French National Centre for Scientific Research, recruited two endangered albatross species that sound like codenames already – wandering and Amsterdam – as covert ocean-going operatives in Operation Sentinel.

Employing albatrosses as spies isn't that crazy. The birds share a common goal with boats: if anything is going to seek out a fishery's haul, it's going to be an albatross. What's more, albatrosses spend their lives covering vast areas of ocean; it's estimated that in a 50-year lifetime wandering albatrosses travel

distances equivalent to going to the Moon and back 10 times.

Writing in the *Proceedings of the National Academy of Sciences*, the researchers describe taping data-logging devices to the backs of 169 birds nesting on three islands in the southern Indian Ocean over six months. The devices are able to detect and locate any boats emitting radar signals within a 30-kilometre radius. The birds then took to the skies from their nesting grounds and surveyed a remote expanse stretching from South Africa to New Zealand, between Antarctica and Australia's southern coastline.

"This research makes a fantastic contribution to our understanding of the scale and distribution of legal fishing and the presence of 'dark' fishing activities, which is fundamental to improve enforcement," explains marine ecologist Jessica Meeuwig, Director of the Marine Futures Lab at the University of Western Australia. "We know that distant water fishing fleets are now covering over 90% of the world's oceans."



Previous pages: On the remote Crozet Islands, a nesting wandering albatross pair watch their fledgling stretch its wings. Albatross and many other seabird species are irresistibly drawn to fishing vessels, such as this French long-liner (below) in Kerguelen waters, by such things as fish refuse, bait and other factors, making them ideal observers for illegal, unreported and unregulated (IUU) vessels. The job isn't without dangers: few IUU vessels adopt low-cost measures to protect birds, such as planting flags and fluttering streamers next to lines, weighting lines with sinkers, or using noise cannons to scare them away.

LIGHTING UP THE DARK

Oceans cover more than 360 million square kilometres of the Earth's surface. Navy patrols are rare, expensive and simply can't monitor every boat. Many vessels possess a GPS transponder that beams out their whereabouts, but such Automatic Identification Systems (AIS) were designed for avoiding collisions rather than tracking, and are only required on larger boats.

For the unscrupulous fisher, that's an invitation to simply switch off their AIS and "go dark". Some go further, tampering with their signal to produce false locations. Global Fishing Watch – a US-based non-profit that tracks fishing boats using AIS data – has shown just how wild this false data can get, with fishing boats located in the unlikeliest of places, including the Himalayas and Antarctica.

But boats need radar to "see" other ships, land and obstacles by bouncing radio waves off them; illegal fishers use it to detect and evade patrols. Weimerskirch's latest project – Ocean Sentinel – has exploited this vulnerability to find operators hiding in plain sight.

His team had previously equipped albatrosses with devices to study their behaviour and time spent around fishing boats. Lightweight, solar-powered and roughly the size of a small smartphone, the tech featured GPS to monitor the bird's whereabouts, while a radar sensor picked up signals from boats to reveal their location.

To be effective in real-time, however, the gadgets needed an essential upgrade. Previously, researchers had to wait until birds returned to their nests to

download the data – a long wait when adult foraging trips can last up to 30 days and juveniles remain at sea for several years.

The latest devices have an extra antenna that streams data via satellites to a central website within minutes of detecting radar. This can be viewed anywhere with an internet connection, allowing researchers to compare AIS locations and pinpoint rogue operatives in real time.

"This is the first estimate ever of the proportion of vessels, especially fishing vessels, that do not use their AIS system for identification and location," explains Weimerskirch. Overall, 353 vessels were detected – 100 of which weren't using AIS. Within regulated national waters, where AIS is legally required, a quarter of boats weren't transmitting signals. In international waters, a third of boats didn't beam an AIS signal.

"This is really exciting," says David Kroodsma, Director of Research and Innovation at Global Fisheries Worldwide. "Just a few years ago we couldn't track, publicly, any of the world's industrial fishing vessels. Now, with AIS and new technologies like this, we will be able to know where all of the world's industrial fishing is taking place."

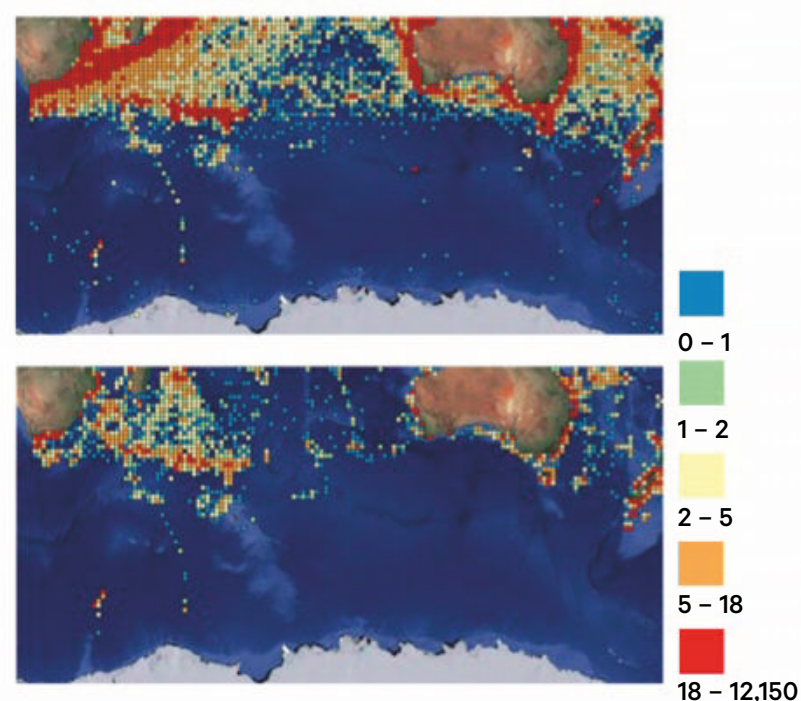
SWEET JUSTICE

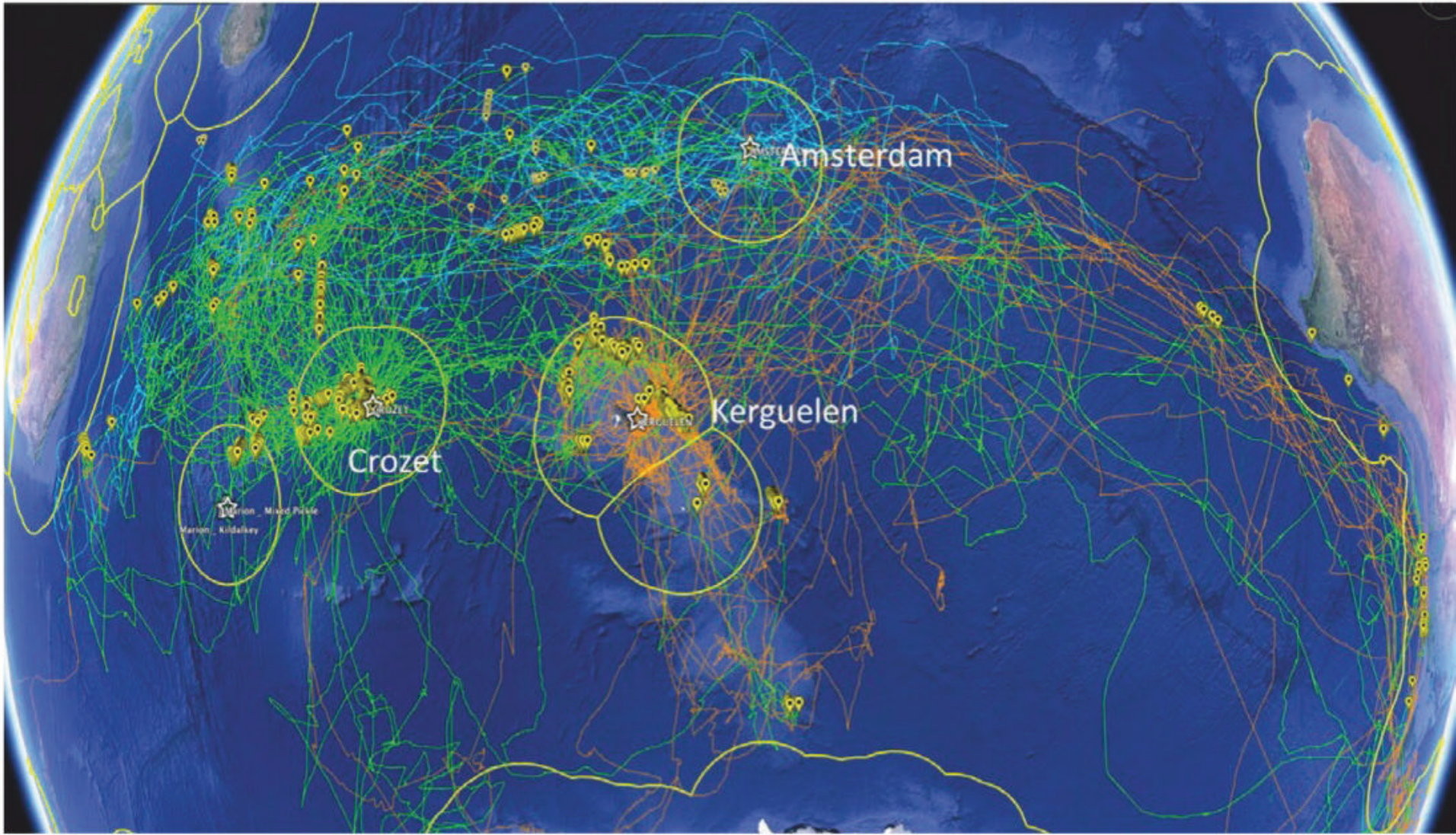
Illegal, unreported and unregulated fishing is a serious threat to the sustainability of world fisheries by overexploiting fish stocks. A worldwide study estimated that one in every five fish is caught through such illicit activity, which could be as high as 26 million tonnes of fish every year.

This has profound consequences for marine



Charts showing the AIS locations for vessels in the south Indian Ocean between Africa and New Zealand in March 2019, comparing the total number of vessels (below) and fishing vessels only (bottom) in squares of 125 km.





A centurion logger (below), with short GPS antenna and radar detector at the front, solar panel and long Argos antenna for satellite data transmission.



ecosystems, from even less food for birds already struggling to maintain numbers to the indiscriminate killing of anything – sharks, turtles, dolphins, seabirds, you name it – that happens to get caught up in nets and hooks.

Albatross declines, for example, are closely linked to commercial longline fisheries, as birds are inadvertently lured by thousands of baited hooks. While official regulations at least try to limit damage caused by industrial fishing, those efforts are undermined by activities that go unchecked, away from prying eyes.

“Our system is relatively easy to implement,” says Weimerskirch. “The big problem is the limited presence of navy and coast guard ships for enforcement.”

Even so, it may make fishers think about who is watching them before entering restricted areas or fishing without a license.

Weimerskirch thinks it’s unlikely that albatross informants would be persecuted by fishers. “The data-loggers are difficult to be seen on the bird, the birds are not very close to the vessels, there are hundreds of

Southern Indian Ocean, with the tracks of Crozet wandering albatrosses (green), Kerguelen wandering albatrosses (orange), and Amsterdam albatrosses (blue). Radar detections are yellow markers. Yellow lines delimit national economic exclusive zones.

birds flying around, and the sea is very rough.” In any case, by the time a bird was in range of harm, a boat’s location would already be in the computing cloud.

The researchers have started tests elsewhere, including Hawaiian and New Zealand waters, and suggest the tech could be adapted for smaller seabirds – or even turtles and sharks. One thing is clear from the latest study, though: to be the best spy, age and species matter. Older birds encountered boats more frequently than youngsters, while wandering albatrosses were found to be more attracted to boats than Amsterdams.

“This new source of data can help drive governments and fisheries organisations to close the loop on illegal fishing,” suggests Meeuwig. “And there is something deliciously ironic that albatrosses – seabirds endangered largely due to industrial fishing – are highlighting the scale of illegal industrial fishing activities. ©

JAMES URQUHART is a science journalist based in Scotland.

Windows to the stars



For seven decades, the world worked to map the heavens – a massive endeavour that ran from the 19th century to the era of manned space flight, taking in two world wars and vast social change. Here, we explore Australia’s role in the project and the lives of those who measured the stars: the “lost women” of Australian astronomy.

By IVY SHIH

TO AN UNTRAINED EYE, the glass plate resembles a dirty tile covered with tiny black spots – as if an ink-filled paintbrush had been gently flicked across its surface. But in fact the plate is a piece of the night sky – the glass-plate negative from a photograph taken over a century ago. Each black speck – shown on these pages – is a single star.

There are thousands of such plates – the precious residue of one of the most ambitious international astronomy projects undertaken in the 19th century. The goal was to use photography to map the entire sky and create a complete record of the stars, known as the Astrographic Catalogue (AC), and a separate project of printed images called the *Carte du Ciel*.

Originally estimated to take only a few years, the project would span more than seven decades in Australia. Behind the scenes were female “human computers” who diligently measured and calculated the position of tens of thousands of stars, whose work has remained mostly unnamed and unrecognised for decades (see p 39).

Toner Stevenson was manager of Sydney Observatory in 2004 when she first saw the glass plates with observatory curator Nick Lomb. Each was 160mm², with a curved corner at bottom left. She’d been reading about the AC for her doctoral thesis and had come across a sentence saying that the star measurements were why the project took so long.

The search for an answer led her to Macquarie University’s library and a basement lined with

shelves stocked with thousands of cardboard boxes – each containing up to a dozen glass plates in paper covers, where they had rested for 20 years.

When Sydney Observatory stopped being a research station, Macquarie University astronomer Alan Vaughan volunteered to find a place to store the thousands of plates in its collection, and the University signed an agreement with the Museum of Applied Arts and Sciences, which currently operates Sydney’s Powerhouse Museum and Museums Discovery Centre, as well as the Sydney Observatory.

Each glass plate was wrapped in a paper cover with notes and observations; Vaughan was their caretaker from 1986. He recalls finding a 1910 cover with the notation “Halley’s Comet”. The glass plate inside had an image of the comet itself – a dark brushstroke across the surface rendered as it streaked across the sky.

The collection included the original logbooks and catalogues, which preserved all the data of exposure – including date, time, weather, observer, length of exposure, the relative ascension and declination (coordinates) and the plate number.

“I thought: This is an incredible story because this is the sky captured during a single epoch, because most of the photographs were taken over 20 years from 1895 to 1915,” says Stevenson, who now manages the University of Sydney’s School of Philosophical and Historical Inquiry. “So it was capturing something we could never capture again.”

Circa 1900, an astrographic measurer uses the “Repsold” micrometer – measuring machine – at Melbourne Observatory to catalogue the stars of the southern hemisphere. One of the glass plates is shown on these pages.

THE GREAT STAR CATALOGUE

At Paris Observatory in 1887 a remarkable meeting of astronomers from around the world produced a startling idea – to create a map of the skies using the latest photography and measuring techniques. It would capture the position of the stars in both northern and southern hemispheres.

The task of compiling the work would fall to 18 observatories around the world. The sky was divided into zones, allocated to different observatories. In Australia, observatories in Melbourne and Sydney were the first to take part. Adelaide came on board shortly after to assist Melbourne; Perth joined the effort in 1900, taking over the zones originally assigned to Rio de Janeiro Observatory. Together the Australian contingent would go on to map 43% of the southern hemisphere – one of the richest concentrations of stars because the Milky Way galaxy crossed right through it – and 17% of all the stars recorded.

The AC aimed to record the position of all the stars, and the *Carte* sought to be one of the most detailed photographic charts of the heavens. Each would require separate glass plates. The plan was to make photographic charts of all stars down to the 14th magnitude (some 40 million stars) and catalogues of the positions of stars down to the 11th magnitude (two to three million), based on accurate measurement of the photographs.

Coated with a special dry gelatine emulsion, the stellar photography plates were first exposed to a *réseau* plate – the same size as the photographic plate, but coated in silver and ruled into a grid of fine lines five centimetres apart. The *réseau* plate was placed in direct contact with the photographic plate and exposed for four to five minutes to imprint the *réseau* grid on the emulsion. The result was a photographic slide traversed by a grid of very fine lines – indispensable as reference marks in determining the placement of the stars. The plates were then ready for star photographs.

Male astronomers took the photographs using special “astrographic telescopes”. Every four-to-six-minute exposure was arranged so that a plate would show a number of standard stars, from which the rest of the stars on the plate – varying from 300 to 1000 – could be measured. In Australia, most of the photographs were taken by 1915; some were later retaken. Each contained hundreds, if not thousands, of stars.

Ensuring precise measurements was an intricate process. Originally the plates were to be measured at a central facility in Paris, but a change of plans saw the work transferred to individual observatories; Melbourne and Sydney shared a measuring bureau located in Melbourne.

The women who observed, catalogued and calculated the star positions on the AC had outstanding mathematical ability, with the analytical skill to measure and calculate the stars’ positions. They worked on purpose-built measuring machines called micrometers and used standard astrometry reduction formulas to determine the true star co-ordinates.

They worked in pairs, exchanging roles to measure each star on each photographic plate twice – once on the front face and again when the slide was turned 180 degrees. The photographic plate was placed in a micrometer and the star’s X and Y co-ordinates were measured and calculated. The measurer on the micrometer would read out the data, which was entered into logbooks by the second measurer. Afterwards the mean of the two measurements was calculated and also entered into the logbook.

Co-ordinate measurements were compared between measurers in an effort to eliminate human error. Given that the plates overlapped, each star could be measured three or four times. Given front, reverse and overlap measurements, each glass plate was handled multiple times. According to contemporary reports in the project’s early years, on average 170 stars could be measured in an hour.

HISTORY IN THE MAKING



1887 Director of Sydney Observatory Henry C. Russell attends the first International Astrophotographic Congress in Paris on the 16th April. An ambitious project is launched to map the entire celestial sphere. Sydney and Melbourne observatories invited to take part.

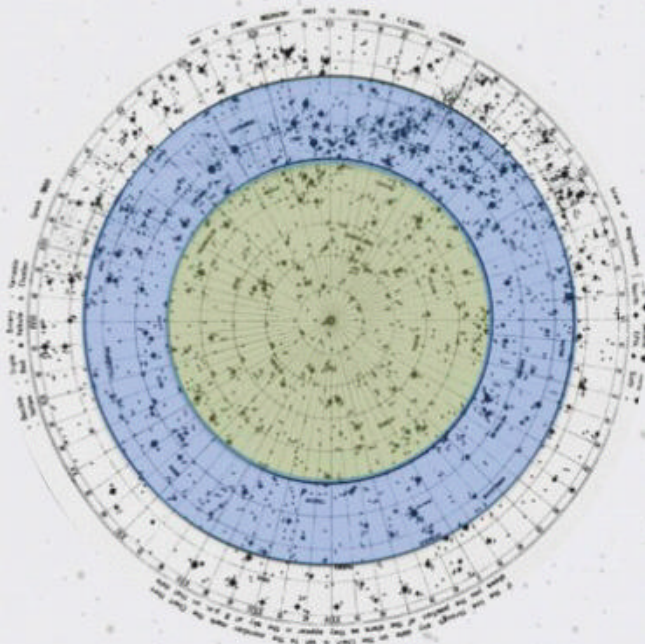
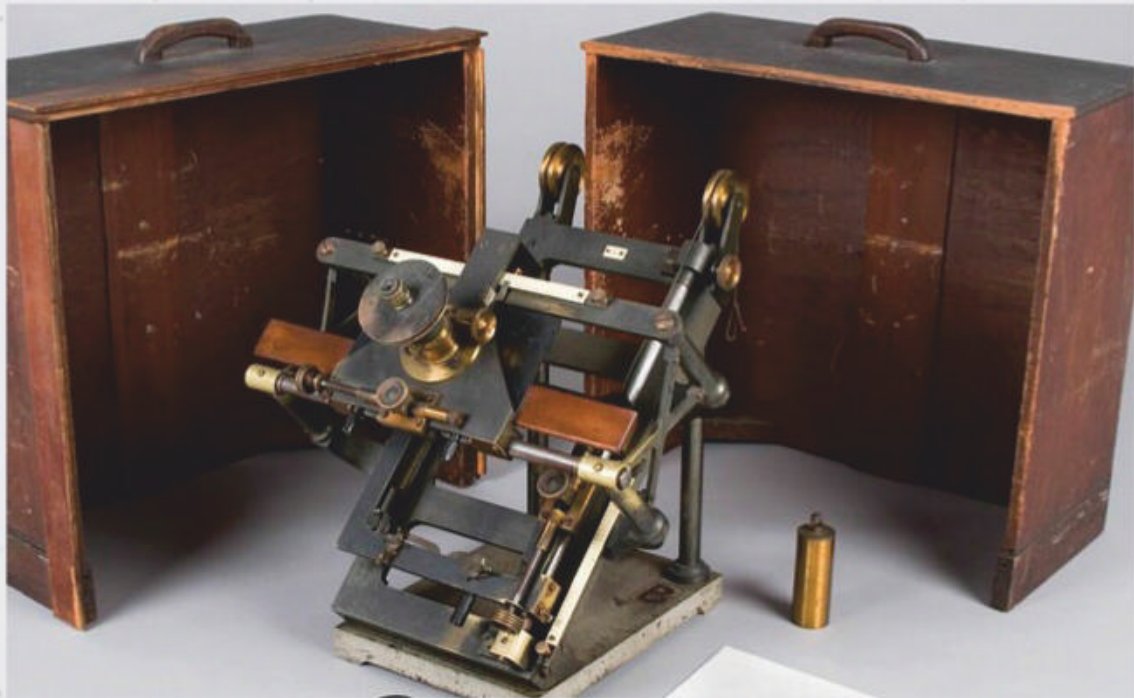
Through the decades of the Astrographic Catalogue project, the world went from horse and cart to the moon.



1888
AUSTRALIA'S FIRST ELECTRIC
STREET LIGHT (TAMWORTH)



1890
THE MAN FROM SNOWY
RIVER PUBLISHED



Using micrometers (above), measurers catalogued up to 1000 stars on each glass plate. The southern hemisphere's circumpolar star chart (above right) was largely created through the observatories in Sydney (shown in blue) and Melbourne (green).

THE WORTH OF STELLAR HISTORY

When the Sydney AC's final volume was published in 1964, Australia's involvement officially came to an end. The global endeavour to chart the heavens had lasted almost eight decades. Stevenson estimates that over that time Australia's astronomers charted and measured the positions of more than 1.5 million stars. They photographed 142,021 glass plates and published over 50 catalogue volumes. Stevenson's research indicates that Sydney and Melbourne completed their *Carte* photography; Perth exposed only 100 plates before abandoning the project after 1903.

The global astronomy and scientific community managed the immensity of the AC and *Carte* projects through the opening and closing of observatories and multiple funding and budget cuts. Work had waxed

and waned but seemed to be a constant through a world changing around it. The project had continued through the Great Depression and two world wars. Even when Melbourne Observatory ceased research in 1945 and closed in 1948, Sydney Observatory decided to complete the unfinished measurements and take the projects through to completion.

Astronomy had also moved on. In the 1940s, Ruby Payne-Scott's work in radio physics and radio astronomy cemented her as an Australian pioneer – she is among the first female radio astronomers. In 1961, the Parkes radio telescope was opened. Just five years after Australia's work on the AC finished, Apollo 11 landed on the moon.

Now it only takes months to image the night sky. The Cerro Pachón ridge in north-central Chile will soon host the new 8.4-metre Large Synoptic Survey Telescope at the newly named Vera C Rubin Observatory, which is capable of surveying the entire southern hemisphere sky in just three days.

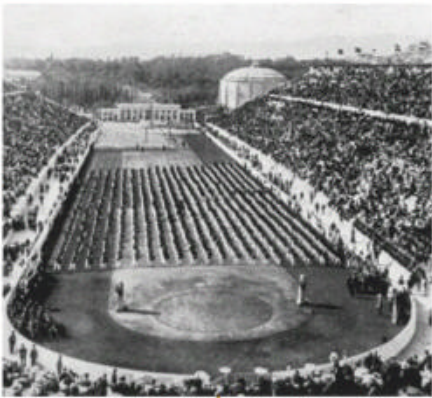
The Astrographic Catalogue aimed to record the position of all the stars, and the *Carte* sought to be the most detailed photographic chart of the heavens



1890 Construction of the "star camera" at Sydney Observatory is completed. Its technology is at the forefront of celestial photography.



1891 The first glass plate is measured at Sydney Observatory.

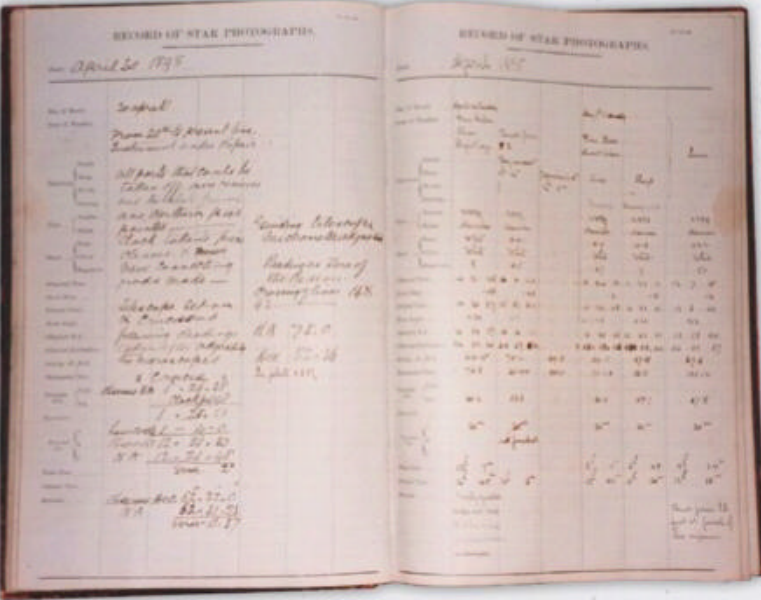


1896
FIRST MODERN OLYMPICS



1899
SECOND BOER WAR STARTS

Filed in numbered bespoke boxes, the glass plates and their attendant logbooks are held at the Powerhouse Museum, Sydney. Only 650 plates have been digitised.



The goal is to take 800 separate images of each region of the night sky over 10 years.

Given this, it seems easy to view the AC and *Carte* as historical remnants of humanity’s ambition and attempt to have some degree of mastery over the heavens. But the glass plates and catalogue have a legacy that’s still playing a part in modern astronomy.

Each glass plate’s smattering of black spots is the light of stars past – a unique window to the state of the night sky up to a century ago. The plates are effectively time capsules that allow astronomers to study the evolution of galaxies. Space is a constant roil of activity and motion of celestial bodies, dying, colliding and being born. Within the plate images are data that opens up new possibilities in astronomical research.

This is because of the speed at which light travels. It takes 1.25 seconds for moonlight to reach Earth. The Sun’s light takes more than eight minutes. Whenever we peer through a telescope at Proxima Centauri, Earth’s closest star other than the Sun, we’re looking at starlight that began its journey to Earth 4½ years ago.

As Alan Vaughan’s research student 20 years ago, Lesa Moore painstakingly created a digital catalogue of the glass plates at Macquarie University. She spent months going through the plates, transcribing what they contained.

“The idea [was] to get... the variability and the movement in the stars so we can understand how little sections of space are

evolving,” says Moore, who is now web editor at the Astronomical Society of New South Wales.

Keen to see the potential data locked in the glass plates, in 2006 Vaughan used a custom-built suitcase lined with rubber pillows to transport 650 plates to Cambridge University, where the Automatic Plate Measuring Machine at the National Astronomy Facility was capable of scanning each image in layers, thus ensuring every star was included.

When the images came back from Cambridge, Vaughan and Moore assessed the quality of each plate and, using software, extrapolated the stars’ positions and modern co-ordinates to determine how much they had moved in the time since the photograph was taken.

“To get a historic baseline and see things change in time is very difficult in astronomy,” Moore says. “We can’t wait around and see a star go supernova. We have to get all of the information from what we can see today and however far back our records go. So any kind of historic record, even sketches that date back before photography, are useful in understanding how celestial objects and systems evolve.”

The entire AC collection is now housed at the Powerhouse Museum. When Moore was cataloguing the fragile glass plates, she found that the years hadn’t been kind to them. Some were broken; the silver coating on some had oxidised to a solid black; mould had started to take hold on others.

On one glass plate, Moore could make out, among the smattering of dots, the curve of something that didn’t resemble any celestial body. Its identity remained a mystery until the plate was scanned at Cambridge. It was a partial fingerprint – a mark among the stars to remind us of those who captured and catalogued the sky.

Former medical researcher IVY SHIH is a science writer and communicator based in Sydney.

COLLECTION: MUSEUM OF APPLIED ARTS AND SCIENCES. PHOTOGRAPHER CHRIS BROTHERS



1892 The first glass plate is measured at Melbourne Observatory.



1902 WOMEN ACHIEVE FEDERAL SUFFRAGE



1911 The first Perth Astrographic Catalogue is published.



1913 MODEL T FORD

Veiled beneath the Astrographic Catalogue’s canopy of stars was a corps of female “computers”, who measured and recorded the stars’ positions – and much more besides.

By **TONER STEVENSON**

COLLECTION: MUSEUM OF APPLIED ARTS AND SCIENCES. PHOTOGRAPHER NITSA YIOUROS.



Mary Allen and Ethel Wilcocks measuring astrographic plates at Sydney Observatory in 1941. The “computers” worked in pairs, one reading measurements off the micrometer and the other recording them in a logbook.

PERCHED AT TWO STURDY TABLES are four young women working in pairs. One, an observer, is concentrating deeply, looking down into a microscope at stars on a fragile glass-plate negative. The window shines onto a mirror that reflects light to illuminate the stars on the photograph. The observer has positioned the glass plate so she can see a single square of the réseau grid lines. She turns tiny screws to move the microscope up, down

or across and focusses the eyepiece on a single star-speck within the grid, making sure the réseau lines align with a square – made from taut spider-web silk – visible through the eyepiece.

Guided by a glass reticle with a graduated X-Y axis scale, she reads out the co-ordinates for the star’s position to her partner, who writes them down in a neatly ruled logbook with a sharpened pencil. Then she compares the size of the star with a slide of “standard star” brightness dots, which she passes in front of the eyepiece using tweezers.

Around the women are dark timber bookshelves filled with logbooks, manuscripts ready for the printer, and hundreds of boxes containing thousands of photographic glass-plate negatives taken at Melbourne Observatory and by their own Sydney Observatory astronomers.

It’s 1948. The observer – Winsome Bellamy – and her three colleagues have been employed to finish the Astrographic Catalogue, which Sydney and Melbourne observatories had begun back in 1887. The machines they are using were designed in 1904 and their methods are the same as used decades earlier.

When I interviewed Bellamy years later, she recalled that she found the work routine: “We had turns about to use the machine, because your eyes became very tired with looking through the micrometer. The other person would sit and write the figures down. We did about half an hour, or perhaps



1913
CANBERRA FOUNDED



1914
WWI STARTS



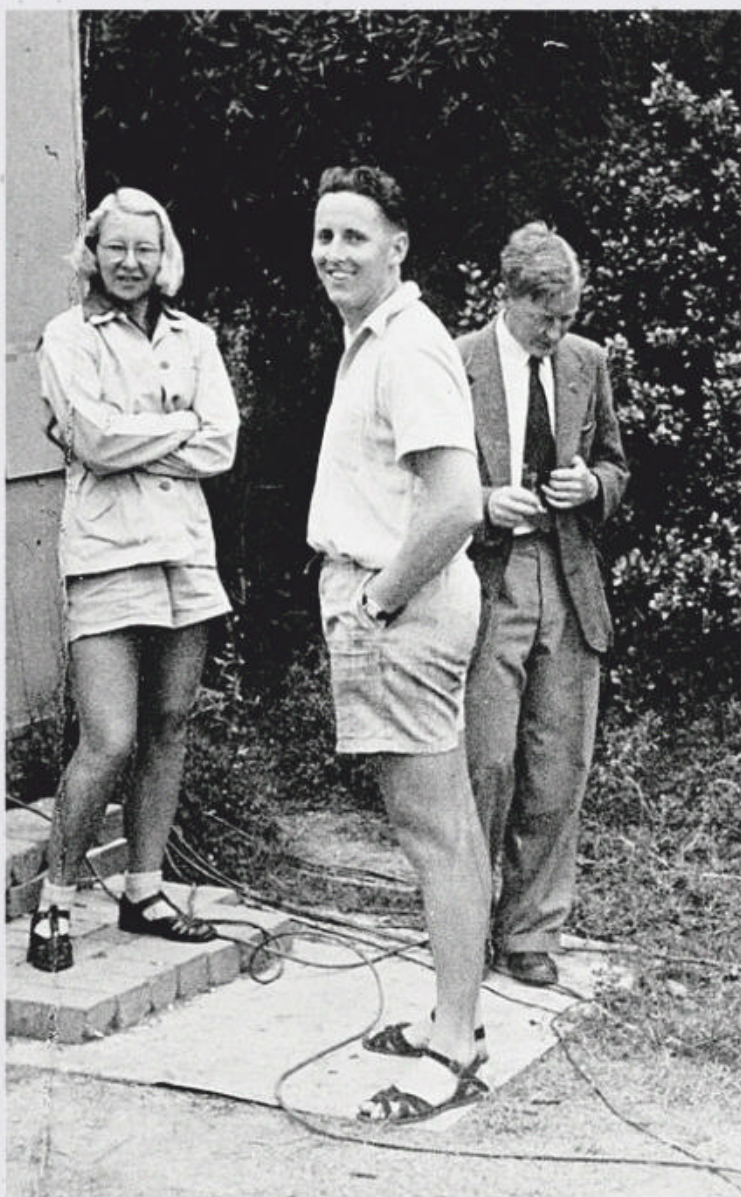
1922
VEGEMITE FIRST SOLD

1922
CWA FOUNDED (IN NSW)



1921
EDITH COWAN FIRST WOMAN ELECTED TO PARLIAMENT (IN WA)

Physicist Ruby Payne-Scott (below, at left, in 1948) was one of the global pioneers of radio astronomy. In the late 1940s, she worked with Alec Little, centre, to design and build equipment to map solar radio emission strength. Like the female AC computers, Payne-Scott is better known now than during her lifetime.



longer on the machine. And then we would swap places and the other one would have a turn.

“The four of us were working beside each other with the two different machines. But we talked all the time, while we were doing it, and swapped gossip and jokes. And we had a great time apart from work.”

BELLAMY WAS AMONG the more than 70 women employed to measure, log and calculate the position of stars for the AC at Adelaide, Sydney, Melbourne and Perth observatories. They were called “computers”, “star measurers” and “clerical assistants”.

But they were far more than an anonymous group of women who measured. They were fascinating individuals who produced new knowledge about stars, particularly those in the southern hemisphere, and they had agency within the observatories that has not previously been recognised.

They have in common their contribution to astronomy – and the fact that their work has been almost forgotten.

Women had worked in astronomy as daughters, wives and sisters of astronomers for centuries, but the first Australian woman paid a regular wage for her work was Mary Emma Greayer

(1861-1910), who was employed in 1890 on a temporary clerical contract at Adelaide Observatory.

Greayer was educated to the equivalent of today’s School Certificate. Her sister married William Cooke, an assistant astronomer at Adelaide Observatory, to which Greayer became a regular visitor. It appears she was genuinely interested. Charles Todd, the Government Astronomer, must have noticed her aptitude, because she left teaching to start work as one of two observatory computers.

The attendance books reveal that she did a lot more than computations while working from 7:30pm to 10pm, two or three evenings a week. And when I found the observation logbooks, I was surprised to see her initials regularly noted as “observer”; she was determining star positions, looking through the large transit telescope and reading out the location and magnitude of stars, sometimes to Cooke and sometimes to assistant astronomer Richard Griffiths, alternating with them to record their observations.

Greayer was, in all ways, doing the work of an astronomer, and she was one of the first women to be elected to the South Australian Astronomical Society, where she presented papers. Although she didn’t have access to a university education, she clearly had an aptitude and passion.

Other passions were developing during those long stellar nights, however, and in 1899 she married Griffiths and had to resign – as married women were required to do. Todd lamented her departure and wrote to other government astronomers comparing her to the renowned German comet discoverer Caroline Herschel.

MELBOURNE OBSERVATORY was the first Australian institution to establish an AC measuring bureau – imitating what the Paris Observatory established in 1890 – by employing women as computers and



1923 The first Sydney Astrographic Catalogue is published.

1926 First Melbourne Astrographic Catalogue is published.



1927
AUSTRALIA’S PARLIAMENT
HOUSE OPENS



1932
SYDNEY HARBOUR BRIDGE



1939
WWII STARTS

Greayer was doing the work of an astronomer, and was one of the first women to be elected to the SA Astronomical Society, where she presented papers

Mary Emma Greayer (pictured below c1895 with Adelaide Observatory staff Charles Todd and William Ernest Cooke) commenced employment as a computer. She went on to observe reference stars – coordinates that formed the foundation for measuring the position of other stars. She had to resign in 1899 when she married.



measurers. In Australia in the early 20th century, women were generally paid 54-64% of a male salary when the work was specifically identified as “women’s work”. This made women attractive as a cheap source of labour.

In 1902, an anonymous journalist writing about the Melbourne Observatory women in “The Women’s Corner” section of the *Brisbane Courier* said: “Their hours are from 9am to 5pm on weekdays and to noon on Saturdays, an hour being allowed for lunch. Their salary is £40 a year. (The editor has only one remark... no man would undertake it at more than double the amount).”

Charlotte Emily Fforde Peel (1877-1974) was selected as an “astrographic computer” in 1898 due to her outstanding mathematical ability – demonstrated in the exam set by the observatory. She had been a teacher and was transferred from the Education Department at the age of 21 as the most promising of the first six women to work on AC star measurement.

The women were trained for six months or longer and Peel became their leader, checking the accuracy of their measurements, timing each woman’s efficiency against it and calibrating

the measuring machines. It was estimated that 80 stars per hour could be measured using the high-cost, finely tooled machines made by Repsold, from Hamburg, Germany, and pace as well as accuracy was essential.

Peel was performing the same duties as Dorothea Klumpke, the first woman with an advanced degree in astronomy, who was the Director of Paris Observatory’s Bureau des Measures from 1890.

Melbourne Observatory, which had been a male-dominated building, had to become more feminised. The women’s spaces were separated from the men’s; there was a fear that the men would be distracted. Isolation had its benefits, and the women often formed strong friendships with their measuring partners and socialised after work. Logistics, such as a lack of outhouses (toilets) had to be solved. New conveniences were built in 1903 – but not connected until years later. This understandably caused angst.

Peel was officially gazetted as “assistant astronomical computer” in 1900. She was the first woman to hold a permanent position in astronomy in Australia. She worked on the AC for 20 years and only left when she married Robert Sangster, the observatory librarian, in 1919.

WHEN PERTH OBSERVATORY joined the AC program and established its “measuring bureau”, Prudence Valentine Williams (1891–1968) – already identified as an outstanding student by winning a gold medal in her leaving exam – was one of two women employed as junior clerks in 1906. She was 16, but highly intelligent and capable, and soon became the leader of a growing number of employed women.

Williams was passionate about astronomy and was elected to the Astronomical Society of Western Australia. Her work ethic and diligence



1945 Melbourne Observatory stops research operations.



1947
WOOMERA RANGE OPENS



1948 Winsome Bellamy starts at Sydney Observatory as a ‘computer’ and continues to its completion.

1948 Sydney Observatory takes over the Melbourne zone of the Catalogue.



1951
FIRST HOLDEN UTE



Photographed in 1949 by their 21-year-old colleague Winsome Bellamy, star measurers (above, from left) Verlie Maurice, Renee Day, Patricia Lawler, Jean Campbell and Margaret Colville enjoy lunch in Observatory Park, Sydney.

were extraordinary, but even more remarkable are her letters to the observatory director HB Curlewis, where she championed the rights of the women.

In 1913, through her letters, and with the support of the Government Astronomer, Williams managed to gain a stepped increase in wages for the women, which effectively meant their wages doubled within a few years. She also successfully argued for her level of responsibility to be acknowledged financially and by title as Librarian and Astrographic Supervisor. Her demands that the women become permanent public servants was never granted, however.

In 1914 a male astronomer reported the women for spending too much time talking. Williams wrote to Curlewis that “...Mr Nossiter must have a vivid imagination when he states that some days we talk almost incessantly; he is evidently judging us by himself, as for about two months... he and Mr Whitby talked almost incessantly”.

Williams explained that the four women had twice measured, calculated and prepared for publication 21,221 stars within a six-month period, ending pithily: “...I am afraid he cannot show a corresponding amount of work for the same period.” Curlewis supported the women.

Williams and the other women were identifying not only star positions and brightness, but also unusual images of double stars and anything that seemed out of the ordinary. Their double-star observations were published by an astronomer without recognition of their work in identifying and measuring the stars.

Williams left the observatory in 1918 to care for her brother, who was returning from the Great War. She is not mentioned again in astronomy.

WHEN MELBOURNE OBSERVATORY closed in 1948, Sydney Observatory undertook the completion of the AC and a new group of women, including Winsome Bellamy, then 20, were employed. Like the women who’d preceded them, they had no higher education in astronomy.

“I finished my training as a children’s nurse,” says Bellamy. “And my mother got very sick and I had to be home decent hours. We had three small children at home... So, I got a job with the public service. They

Bellamy became dedicated to the project, bringing in spiders from home so their web-silk could be used for the cross hairs in the measuring machines.

didn’t tell me what I’d be doing.... I had not experienced anything to do with astronomy before and I found it boring.”

Although she was employed temporarily, Bellamy stayed on



1955
VIETNAM WAR STARTS



1961
PARKES TELESCOPE OPENS



1962
INDIGENOUS AUSTRALIANS
GRANTED RIGHT TO VOTE



1964 Sydney Astrographic Catalogue is completed

for 20 years and became dedicated to the project, bringing in spiders from home so their web-silk could be used for the cross hairs in the measuring machines and other instruments. She enjoyed the company of the different women who came and went every few years, mainly leaving because they married. Only single women could be employed in most areas of the public service.

When Sydney Observatory set up its measuring bureau, a new wing was added and the women had their own space and library. Bellamy was featured in photographs for the newspaper when a new measuring machine was purchased; she was herself an avid photographer of the social life at the observatory.

During lunchbreaks the women played badminton or, when it rained, fixed a net onto a large table to play table tennis. The young astrographic measurers enjoyed their lunches overlooking Observatory Hill. Every now and then they dressed up to attend one of the many weddings that would signal the end of working life for one of their colleagues.

Winsome Bellamy – shown below at the micrometer in 1954 – spent 20 years completing measurements and calculations for the Astrographic Catalogue.



Through the AC, colonial state government astronomers were connected with new methods of science via international co-operation and collaboration. It was at the forefront of what we now call “big data” – but it’s not a well-known project.

Sydney Observatory director Harley Wood wrote about the AC in his 1964 doctoral thesis: “It must be understood that this work is essentially that of a team. The photographs on which the catalogue is based were taken mainly before my arrival... The measurement of the plates was performed mainly by assistants without scientific training. Throughout the years 19 assistants have been engaged with me in this work, with not more than four being employed at any one time.”

Wood acknowledged Bellamy’s work, and that of her close co-worker, Margaret Colville, in the publication of the catalogue of stars.

The women were essential to that team. With the exception of Charlotte Peel and the acknowledgement she received for comet observation, even when the women discovered unusual phenomena such as double stars, they were obscured from recognition in scientific papers.

Dorothea Klumpke described the work of producing astronomical catalogues as “astronomical labour”. She acknowledged that it was tedious, but “truly scientific” in its nature.

According to Klumpke, women have: “qualities prerequisite for producing lasting results – concentration and enthusiasm, powerful levers that move worlds. Ours is a work of the night and day! ... astronomical science now becomes universal! She knows no boundaries, no rank, no sex, no age!” ☺

DR TONER STEVENSON is the manager of Sydney University’s School of Philosophical and Historical Inquiry. She was manager of Sydney Observatory from 2003 to 2015.



1965
WOMEN ALLOWED TO ENTER
PUBLIC BARS



1969
APOLLO 11 MOON LANDING

**EQUAL PAY
IS A
HUMAN RIGHT**

1974
EQUAL PAY FOR MEN AND
WOMEN ENSHRINED IN LAW



2015 Astrographic dome is returned to Sydney Observatory in a new building. The Melbourne Astrographic Telescope is installed at Sydney Observatory. Winsome Bellamy attends the opening at Sydney Observatory.

Eyesⁱⁿ the SKY

Around 2000 satellites are circling the Earth right now, with that number set to double by the end of 2020. What do they do, how can we use them, and are they really watching us? By RICHARD A LOVETT.



A detailed photograph of a satellite in orbit above Earth. The satellite is covered in crinkled, reflective silver insulation. It features two large, rectangular solar panel arrays extending from its body, each covered in a grid of dark solar cells. A prominent, large, white, circular parabolic dish antenna is mounted on the front of the satellite. The background shows the Earth's surface with blue oceans and white clouds, and the blackness of space at the top of the frame.

EARLY LAST SPRING SpaceX launched a “constellation” of 60 Starlink satellites – the start of a program that will put nearly 1800 new satellites in orbit by the end of 2020, with as many as 40,000 to follow. In the days after the launch, the satellites deployed into a string of bright dots moving in tandem across the sky. “They looked absolutely surreal,” says Chris Johnson, space law advisor to the Secure World Foundation, which is dedicated to promoting sustainable uses of outer space. “People thought it was an alien invasion [or] a missile launch.”

It was also a wake-up call about the increasing cloud of satellites watching our every move.

Not that most of these satellites are specifically designed to spy on us. The Starlink program is intended to provide space-based internet service to the entire planet, thereby ending the divide between internet “haves” and “have-nots” and promoting a more equal-opportunity future.

Other satellites provide telecommunications and the GPS signals we routinely use when we ask our cars or phones to give us directions.

Space-based cameras and other Earth-studying sensors also play important roles in making sure other aspects of modern life run smoothly: “everything from weather monitoring to tracking ships at sea”, Johnson says. They can also help stave off public health risks, by spotting places where conditions are ripe for the proliferation of mosquitos and the spread of West Nile virus, malaria, Zika virus, or chikungunya fever, for example, or by helping direct emergency responders after an earthquake or typhoon.

According to Johnson, it’s even possible to track the

number of cars in the parking lots of stores, such as “all the Wal-Marts in America”, using that to see whether business is increasing or slumping – information of value not just to the company, but to investors trying to decide whether to buy its stock.

All told, says Kevin Pomfret, a former satellite imagery analyst turned space-law attorney with the firm of Williams Mullins, in Tysons, Virginia, there are a “host” of ways in which satellite information can be used, “which people don’t realise, because they are behind the scenes”.

I personally first became aware of the power of this information a few years ago, when I got to wondering if the course of a local five-kilometre road race was accurate. (In my spare time, I’m a coach, and one of my runners had run a time that seemed too fast to be real.)

The race was a simple out-and-back, and I knew where it started and that the turnaround had been at a

activities by conducting them in remote areas, far from spies. Now, even ordinary citizens can spot such activities from space, as happened in 2018, when a variety of people and organisations, including the Australian Strategic Policy Institute in Canberra, used Google Earth and related sources to prove that “vocational schools” for China’s Uighur Muslims were actually detention camps, complete with watchtowers, reinforced walls and razor wire.

But it also means you can peer into your neighbour’s backyard or see if their car was at home when the satellite flew over. The images are good enough that when I try them on my own neighbourhood, I can see lounge chairs circling swimming pools in apartment buildings, count the number of people waiting at a nearby bus stop, and easily distinguish cars from vans, trucks and buses.

What I can’t do is read licence plates, identify individual people, or determine which bus the people at the bus stop eventually board. Partly, that’s because even the best commercially available satellite images don’t have the kind of resolution needed to do this. Whatever you might see in science fiction movies, and whatever might become possible for the military, “we’re not going to have licence-plate readers in space in the near future”, Pomfret says.

Furthermore, even the best images are merely snapshots – isolated in space and time.

That said, it is possible to compare images taken at separate times. Planet Labs, an Earth-imaging company based in San Francisco, California, is running a constellation of satellites dedicated to taking images of the complete surface of the Earth at least twice a day at resolutions up to 72 centimetres/per pixel. Based on that, Planet used images of the Chinese city of Wuhan, the epicentre of the coronavirus epidemic, to show that by late January the city had become “almost bereft of cars and people” in response to China’s efforts to quarantine the rapidly expanding virus. “A January 28 image of a bridge across the Yangtze [River] shows it deserted of vehicles,” the company said in a 30 January press release – a radical change from a 12 January image showing a “surge” of vehicles “flooding” across the same bridge.

But impressive as that is, it’s not the same as tracking individual people. Nor are satellite images ever likely to pose much risk to that kind of privacy, Pomfret says, because even if the technology becomes available to recognise individual people from space – or to read licence plates – satellites aren’t likely to be the easiest way of doing it.

It’s possible to track the number of cars in the parking lots of stores, using that to see whether business is increasing or slumping – information of value not just to the company, but to investors trying to decide whether to buy its stock.

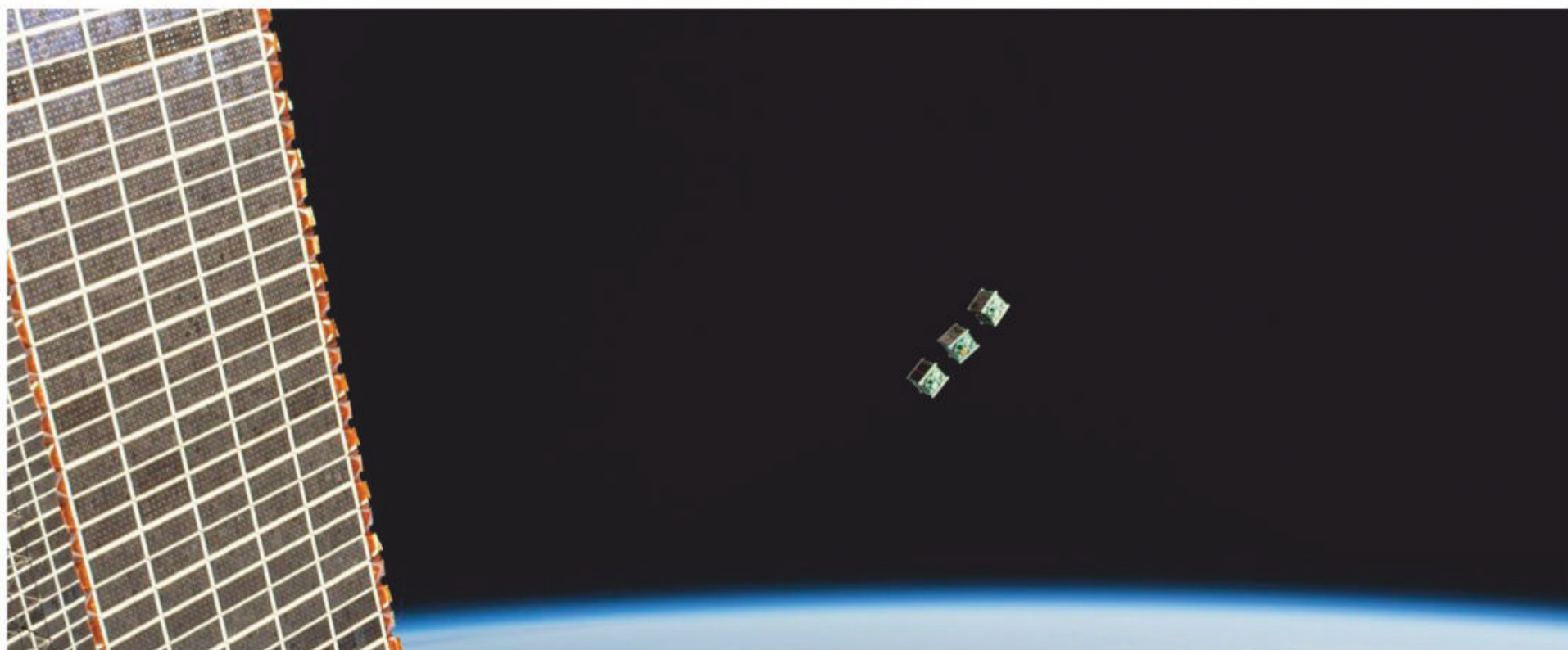
mailbox, near a farmhouse driveway. I discovered that the satellite images were good enough that I could not only find the farmhouse but see the mailbox. Based on that, I used an internet app which allowed me to overlay a satellite image and mouse click a route to measure the course – and found it to be 300 metres short.

Curious, I tested the app’s measuring abilities on a college football field and a local track. The track came up within a half metre of the correct distance: impressive, because it wasn’t easy to measure around the curves. But the stunner was the football field. American football fields are 100 yards long. I got 100.1 yards – limited mostly by my ability to position the cursor. I had, I realised, discovered an incredibly precise measuring tool, which I have since used many times. But more importantly, it was my personal introduction to the power of satellite-based monitoring technologies, and how many potential uses there are for them.

“[It’s] everything you can imagine,” Johnson says. “A lot of companies are still trying to imagine what else we can use imagery for.” Overall, he says, “people are trying to get a grip on how this changes everything in our society”.

One change, of course, is that it’s now possible for anyone to peer at almost anything on the globe.

In some ways that’s a good thing. Not all that long ago, it was easy for governments to hide clandestine



Three tiny CubeSats are ejected from the Japanese Small Satellite Orbital Deployer. The 10cm³ satellites from Nepal, Sri Lanka and Japan were released into Earth orbit for technology demonstrations.

There are a number of other platforms out there, both in the air (such as drones) and on the ground (closed-circuit TV cameras, licence-plate readers, or even Amazon ring doorbell cameras), collecting information about individuals, he says, “so at a general level, satellites aren’t going to be the most effective way to do it”.

Johnson adds that the place where privacy issues are most likely to arise won’t be so much from the satellite images themselves, but from the “big data” consequences of “marrying” these images to ground-based data. For example, he says during our interview, “right now, I’m on a cell phone. The metadata is stored somewhere. I’m also using Wi-Fi on my phone. I’ll go to lunch and use my credit card. I’ll probably walk through CCTV cameras. We’re creating a lot of data in our daily activities.”

In other words, if you’re looking for something to fear, don’t fear the satellite images themselves. Fear the combination of how those images might be linked up with everything else.

PJ Blount, a law professor and PhD cybersecurity researcher at the University of Luxembourg, says that legally there are two basic ways of dealing with this. One is the US system, which is based on the premise that anything in public view is open to surveillance by anybody, including the government – although there are laws that keep the military from using its satellites to peer down on US citizens.

Many of the legal cases related to this, he says, have involved the use of airplanes to spot marijuana-growing operations or environmental infractions by large companies, focussing on the question of whether the government needed to get a judge to issue a warrant in order to obtain the information. That’s potentially an issue for the government, he says, but not for commercially available information.

“If anyone can buy the imagery, in the United States there are very few limitations.”

Europe is different. It has a privacy law known as the General Data Protection Regulation (GDPR), which includes what has become known as the “right to be forgotten”, prohibiting the accumulation of individual-level cyber data on individuals who prefer to avoid it. “In Europe, you have very good control of your data,” Blount says. “You can call a company and say, ‘Take it out.’” In Europe, he says, the company will comply, but in the US, the answer is ‘No, I don’t have to’.

According to Steven Freeland, a professor of international law at Western Sydney University, Australia’s approach is closer to Europe’s than America’s, with the goal being to facilitate the use of appropriately public data without compromising data privacy. The law also calls for “an operating environment characterised by ubiquitous encryption” – a good thing for preventing hacking, but not for keeping government agencies who know the encryption codes from using them.

“So,” Freeland says, “mixed signals... At this point, Australia is not on the European Commission’s list of countries outside the EU that have an adequate level of data protection.”

Meanwhile, Pomfret believes that people concerned about privacy should remember the many benefits satellites have already given us, and realise that the privacy issues with satellite images aren’t all that different from those with anything else. “My feeling is that lawmakers are going to be less concerned about the platform and more concerned about the data and how it’s used.”

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





Unsung Reef

Australia's corals may get all the headlines, but its kelp-dominated temperate reefs are as important and imperilled. Now they're finally getting the restoration focus they deserve.

Photography Justin Gilligan
Story Stephanie Stone

Bull kelp washed up on the coast of Tasmania

AS THICK SHEETS OF cold mist crept over the docks in Tasmania's Pirates Bay hours before the sunrise, Simon Wally and Shane Bloomfield donned raingear still damp from the days before and loaded well-used gear onto the boat. The sky and water were both still inky when they cast off to check the lobster traps they'd dropped the previous afternoon.

When the men pulled up their traps, they found southern rock lobsters (*Jasus edwardsii*) inside, although fewer and smaller than they used to expect. The pots also held a few eastern rock lobsters (*Sagmariasus verreauxi*), a warm-water species that never used to venture into southern Tasmania. Their haul was a snapshot of a changing fishery.

The Great Southern Reef, a 71,000 square kilometre band of kelp-dominated coastline that stretches from Brisbane around Tasmania to Kalbarri, brings in more than \$7 billion annually in fishing and tourism dollars alone. Yet the reef wasn't named until a multi-disciplinary team of scientists published a paper in 2016 arguing for its recognition.

The Reef's relative obscurity could be due to the understated qualities of the organisms that define it: kelp and other seaweeds. These are macroalgae, lumped into the same hodge-podge taxonomic group as amoebas and slime moulds – but comparisons to plants are inevitable.

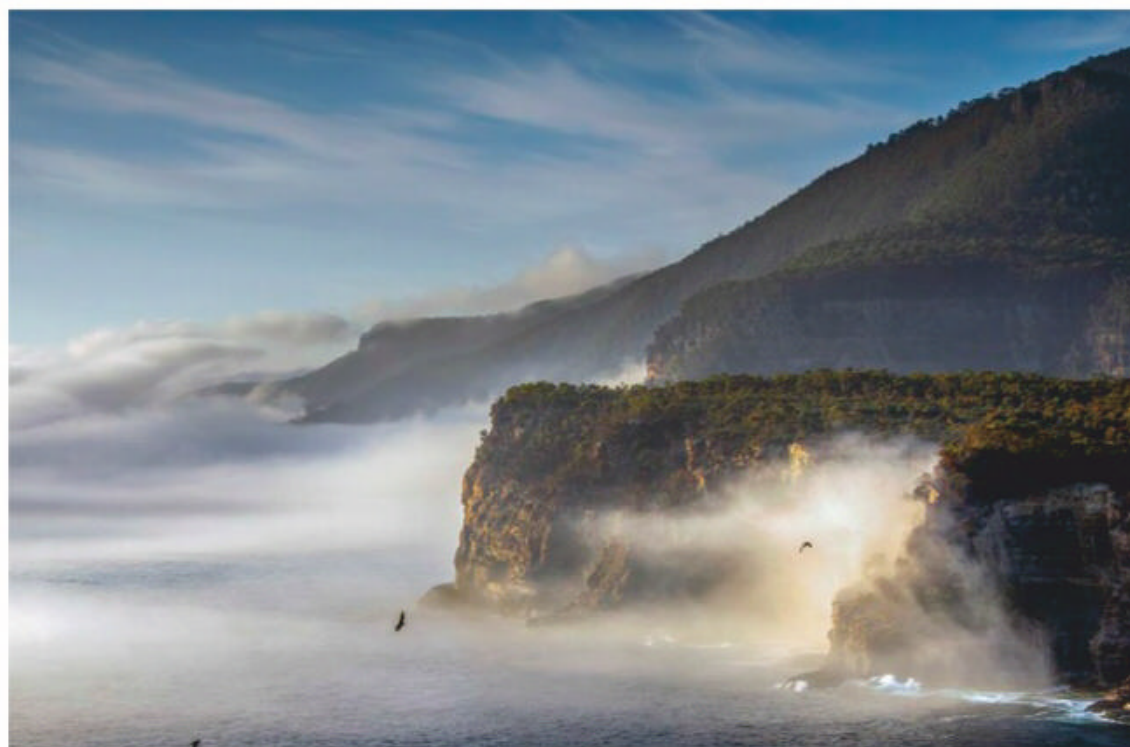
They photosynthesise; they have leaf-like structures, called blades, that capture sunlight and convert it to storable carbohydrates; they have root-like structures, called holdfasts, that anchor them to the bottom. Stem-like structures, called stipes, carry their blades toward the sun – growing, in the case of giant kelp, at an astonishing rate of 50 centimetres per day. Like a rainforest's trees, seaweeds are the foundation of their world.

"They support entire ecological communities," explains Adriana Vergés, a marine ecologist at the University of New South Wales. "Hundreds of species that get shelter, food, and habitat from these seaweeds."

Kelp requires cool, nutrient-rich waters to thrive. Long-term exposure to higher temperatures weakens kelp, slows its growth rate, and impedes its ability to reproduce. In addition to these direct impacts, ocean warming allows new herbivores, including tropical fish and urchins, to move into kelp forest terrain.

In Tasmania, ocean warming is occurring about four times faster than the global average. Giant kelp (*Macrocystis pyrifera*) has been hit the hardest; over the past 75 years, the species has disappeared from 95% of its former range.

This dramatic decline was first documented by



marine ecologist Craig Johnson from the University of Tasmania (UTAS), who compared aerial photographs taken from the 1940s through 2011 to track the species' shrinking range. Now, he says, this "iconic and very important coastal marine community is essentially gone from much of the east coast of Tasmania".

In 2015, Johnson and a group of UTAS colleagues transplanted healthy common kelp (*Ecklonia radiata*) onto more than a hectare of barren seafloor off the eastern Tasmanian mainland.

Within six weeks, the team's patches were crammed with a wide range of animals and other algae species. For the next 18 months, they studied the growth and reproduction success of the kelp.

"One of the primary things we learned is that there is a critical minimum patch size and density that must exist for kelp patches to be self-sustaining," says Cayne Layton, a postdoctoral researcher who works with Johnson. "Juvenile kelp struggle to survive where there is insufficient adult kelp."

In rough seas off Tasmania's Tasman Peninsula (top), crayfisherman Shane Bloomfield (opposite above) tosses a southern rock lobster into a container on the deck of his cray boat. Cray catches are being affected by warming waters and the decline of kelp forests. King Island kelp harvester John (opposite below) stacks up a trailer load of bull kelp (*Durvillaea potatorum*), with vigilant kelpie Bruce on watch. The kelp yields alginates that are used to produce gels and pastes, pharmaceuticals, shampoos, and more.

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Unlike most anemones, southern swimming anemones (top; *Phlyctenanthus australis*), like this one in waters off Maria Island, Tasmania, are mobile. They're able to release their grip on a perch and swim, albeit clumsily, to a new patch of kelp in the surrounding forest.



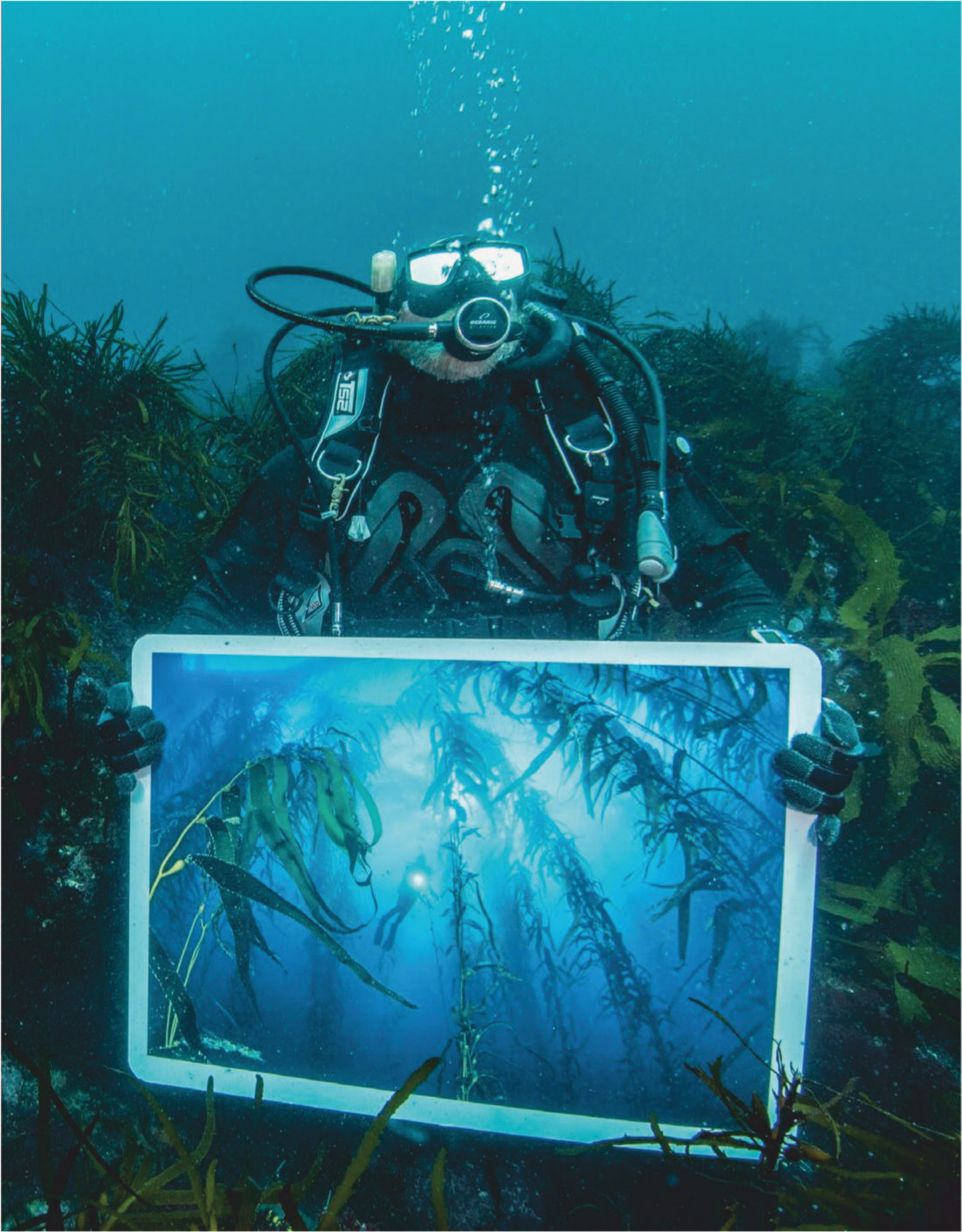
Weedy seadragons (middle; *Phyllopteryx taeniolatus*) are similarly poor swimmers. This male in Tasman Peninsula waters carries eggs on the underside of its abdomen – it's one of few species whose males care for eggs. The loss of kelp forests is a major threat to these delicate reef fish.



Spotted handfish (bottom; *Brachionichthys hirsutus*) are bottom-dwellers in the Derwent River Estuary, near Hobart. The handfish's speedy decline in range and abundance led to it being the first marine fish listed as endangered under the Federal *Environment Protection and Biodiversity Protection Act 1999*.

Forests of giant kelp (*Macrocystis pyrifera*) are missing from more than 95% of the species' historic range. Among those enduring (opposite) were communities near the Actaeon Islands in southern Tasmania, but recent reports suggest that these too may have disappeared.







The Great Southern Reef's eastern Tasmanian waters yield a stunted kelp crop (opposite) compared to the giant forests of 25 years ago – illustrated on the screen held by dive school operator Mick Baron. Innovative responses to climate-change-induced warmer waters include this patch of transplanted kelp (left) off Maria Island, being checked by marine ecologist Craig Johnson. The tent over some of the transplants measures photosynthetic rate, an indicator of health. Some east-coast Tassie stores still sell crayfish (rock lobster), but most commercially caught are exported.



In November 2018, UTAS and the Climate Foundation launched an initiative to identify and cultivate giant kelp individuals that are better adapted to a warming ocean. The team plans to grow these “super kelp” specimens to look for individuals that can withstand the region’s predicted future conditions.

The fact that 95% of eastern Tasmania’s giant kelp forests are already gone might make their efforts seem almost futile. But in the remaining 5% the scientists saw hope, and that optimism has so far been vindicated.

Early in 2020 Layton reported that “over the new year the first results of our preliminary lab tests came out and yes, we’ve found super kelp”. Layton says the results are so important that the research team is re-running the experiment immediately.

“And we’re moving ahead with the next step at the same time,” he says. “What we’ve done [in early January] is outplanted some of those super kelp into the wild. We’ve got three sites in south-east Tasmania where we’re attempting forest restoration for giant kelp. At those sites we’ve replanted some of the five families that are the best performers.”

While reversing climate change is the true solution to much of the degradation these valuable ecosystems are sustaining, innovative approaches like these might at least buy them – and us – valuable time. ☺

This story is edited from *bioGraphic*, an online magazine about nature and sustainability powered by the California Academy of Sciences.

THE NEW

PATHFINDER

01

RCP (RESPIRATORY
CALORIMETER PELLET)

03

02

SMARTHEART

05

FOREVER FRESH

RNIE OF [temporary] THINGS

Cash in your silicon chips – paper and plastic are about to make a comeback. As sensors fill the world with an endless stream of data on every aspect of our lives, Moore's Law dictates that traditional silicon-based systems won't keep up with demand.

A worldwide race is on to master the production of flexible, biodegradable, low-cost alternatives, giving rise to the Internet of Disposable Things.

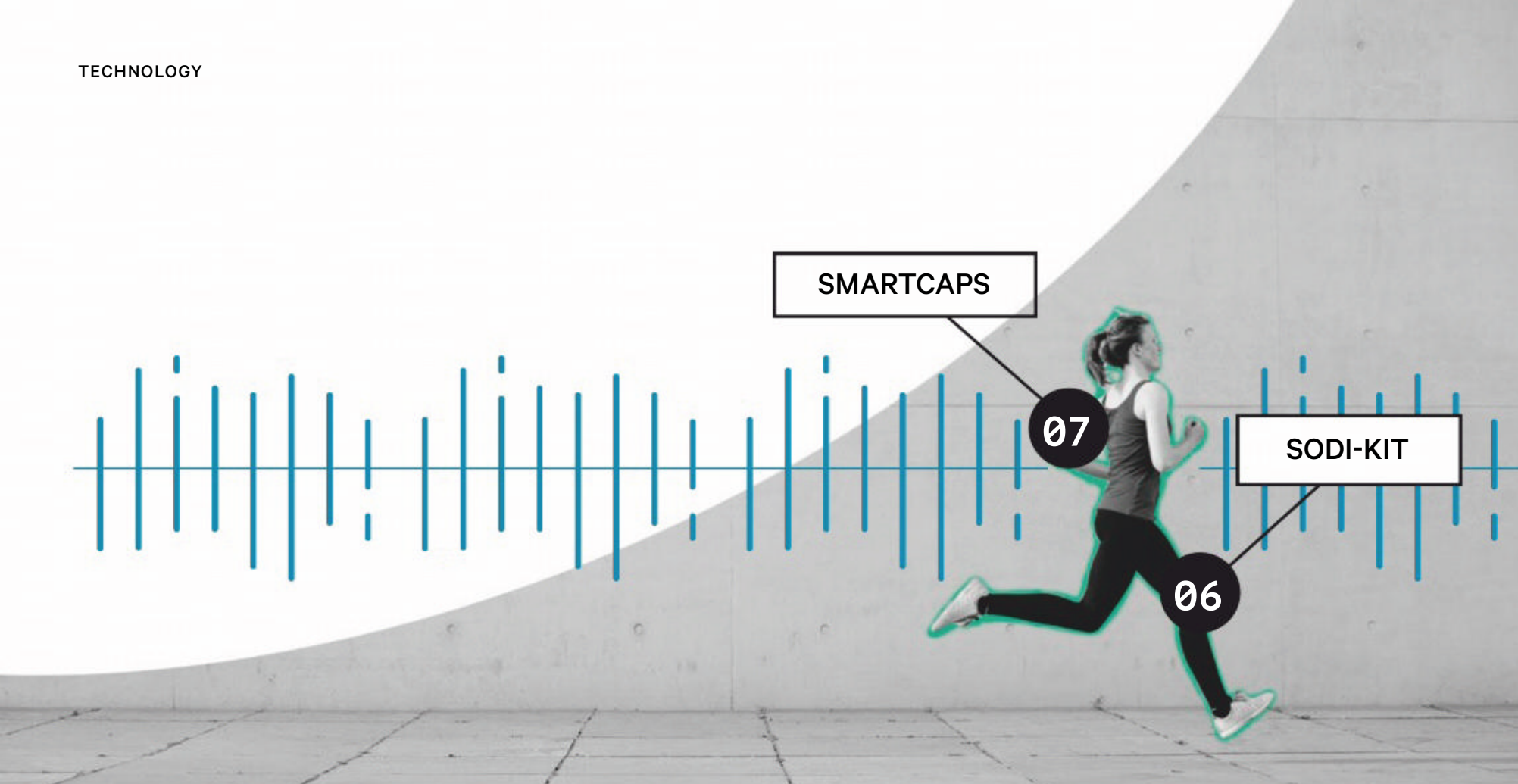
Story by DREW TURNEY

Graphics by CHRISTER DE SILVA

FISC

04

A few Tuesdays from now, you get out of bed early and blearily pull on your clothes for your morning exercise. You head for the kitchen to grab a snack. In the fruit bowl, each item's Forever Fresh sticker registers its ripeness and nutritional value, and you take the fruit with the highest content. >



As you pop your Respiratory Calorimeter Pellet (RCP) into your mouth and head out the door to jog down the street, your T-shirt's SmartHeart loads up, logging information about your heart rate.

When you start to push up the neighbourhood hill about a kilometre in, your phone changes the music to slow your rate. You make it to the top without getting last week's warning to stop for a break and victoriously run the rest of the route with music that matches the tempo of your improving heart rate.

Back at home, the RCP (which measured the chemical content of your inhaled and exhaled breaths) shows that the run burned 2,035kJ – not bad for an hour round the neighbourhood.

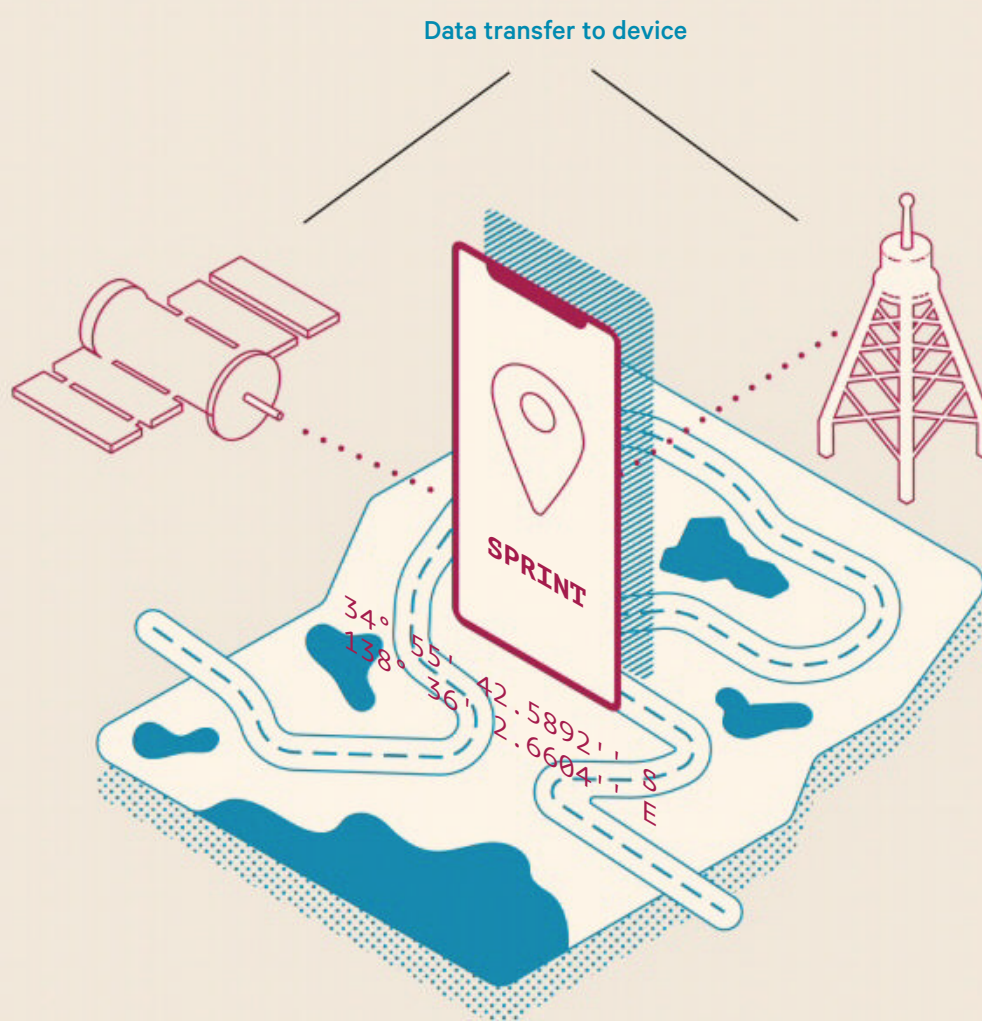
You shower, stick your Sodi-Kit strip to your calf, and head out into the day.

YOU'VE HEARD OF the Internet of Things (IoT), where a sensor is put into every tool, device, computer or machine from a mobile right up to a factory? Billions of readings from millions of microchips report on the performance of computers, planes, server farms, fridges, energy plants, lamps and everything in between. According to market intelligence firm IHS Markit, the number of IoT devices will balloon to over 125 billion by 2030.

The last boundary of data collection is from non-silicon-based systems like clothes, food, the environment or even our own bodies. Welcome to the Internet of Disposable Things (IoDT), where temporary or ultra-cheap sensors are embedded or affixed to any number of inexpensive media that aren't computer-based.

Pretty much everything in the world has a

01 PATHFINDER



A more traditional IoT sensor, your phone's GPS knows where you are and can plan your most efficient workout according to the path ahead. Say there's a long, straight stretch coming up. Because your Pathfinder app has access to both the local geography and the SmartHeart app tracking your fitness regimen, it suggests a sprint, knowing that the best time for a harder rep.

container or wrapper around it (even we do, in the form of garments) – and now the technology to manufacture and embed low-powered, single-use sensors into disposable materials means you can be your very own Internet of Things.

While you might think current IoT is pretty varied (sensors recording the temperature in a house for your smart home app, movement in an electric toothbrush to make sure the kids are brushing properly, or the wear on your brake pads so you know when to replace them), they're all essentially based on electronics.

The IoDT is based on anything and everything else as long as it meets one single criteria – it's produced cheaply enough to be discarded, which makes substrates like paper, plastic or fabric its ideal home.

BUILDING BLOCKS

WHILE IOT DEVICES RELY on a microchip, transmitter and a battery to keep them going, the inexpensive IoDT device can't afford all (in some cases any) of those elements as we know them. Nevertheless, the building blocks will be the same: sensors, telemetry to record and transmit readings, and a power source.

INPUT SENSORS

Where IoT inputs are digital data, those of the IoDT could be almost anything – changes to the ambient light, temperature, pressure, mass, acceleration, humidity, chemical make-up, force and more.

One of the critical advances ushering in the disposable sensor world is microelectromechanical systems, or MEMS. Most MEMS sensors are made on silicon wafers, just like computer chips, but use tiny mechanical structures that respond to some physical stimulus like pressure, movement, light, temperature and more. Only a few millimetres in size, they can express readings as electrical signals and – when attached to an equally tiny radio antenna – send data to a nearby receiver.

Silicon electronic sensors cost between 10 and 50 US cents and are suitable for use in consumer products worth \$100 and up, such as phones and fitness trackers.

Alissa Fitzgerald, founder of MEMS manufacturer AM Fitzgerald, estimates that disposable sensors will need to be made for less than one cent if they're used for items costing around \$10 in the medical, food, fitness, package tracking or garment fields. That means the market rate for silicon would need to be about a fifth of what it is today (fat chance).

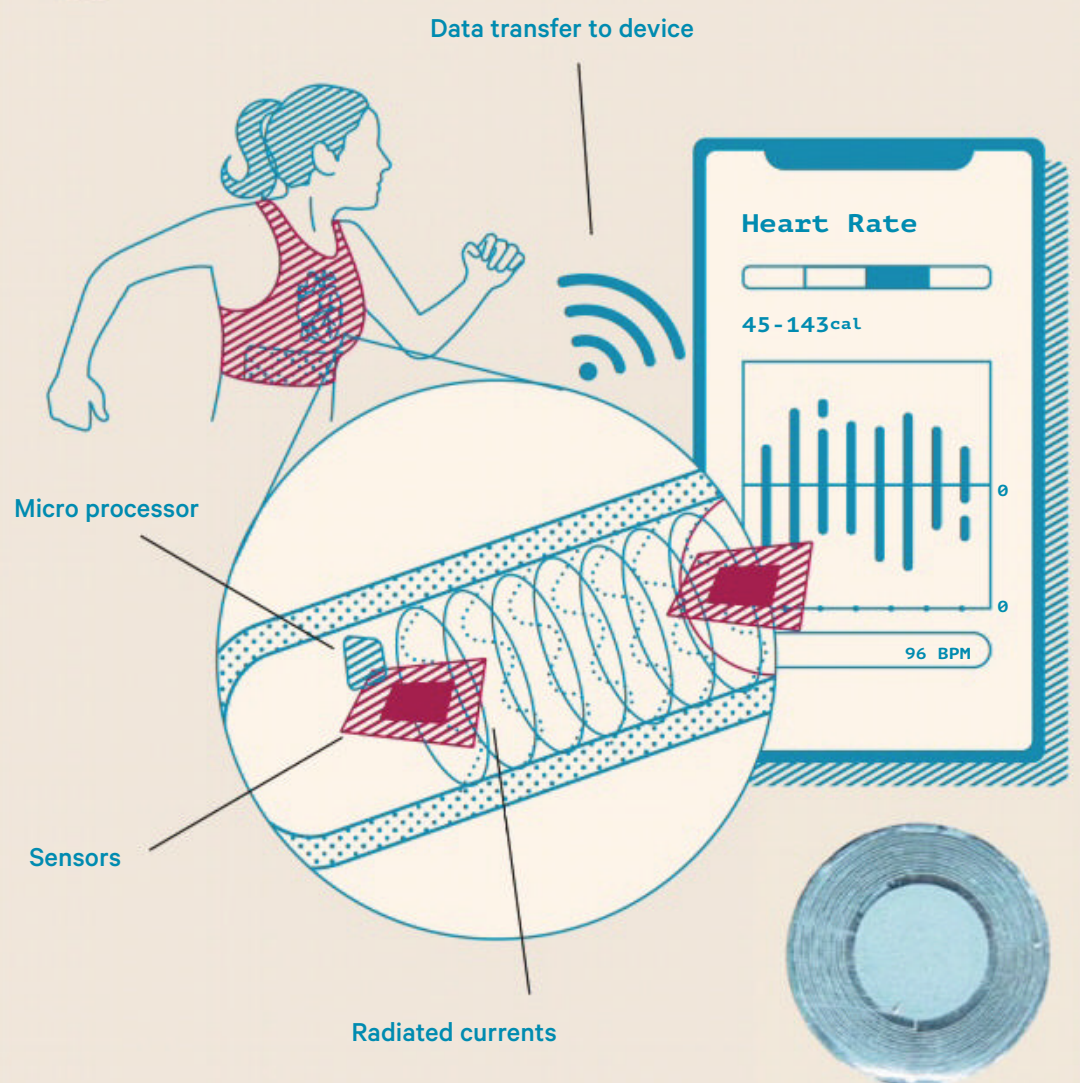


**Welcome to the IoDT,
where temporary or
ultra-cheap sensors are
embedded or affixed to
any number of media that
aren't computer-based.**



02

SMARTHEART



Your SmartHeart's sensor is based on technology that already exists. A stent placed inside the heart contains a membrane of quartz with an antenna inside, forming a capacitor. When blood pressure squeezes down on the membrane it changes the capacitance and therefore the resonant frequency of the circuit. An external reader embedded in your shirt interrogates the antenna with an RF signal of known frequency, then compares it with the altered frequency of the return signal.

In 2017, Belgian researchers built a printed plastic near-field communication (NFC) chip out of indium, gallium, zinc and oxygen. Essential for contactless payment systems and other proximity-based technologies, the researchers aim to make their chips refined enough for high-volume manufacturing that they can be produced to the tune of around 1¢ per square centimetre.

As similar research to manufacture IoDT devices using inexpensive materials continues, it will further drive the price down and make sensors available for ever cheaper uses (and using safer, more benign materials) – from T-shirts and bananas to skin and body parts.

TELEMETRY

Getting the data is half the job; reporting it to a computer or app that can make sense of it is the other. Your ubiquitous mobile or tablet is an obvious candidate to receive and synthesise all the new IoDT data, but mobile phones understand GSM, UMTS and LTE cellular signals, Wi-Fi, Bluetooth and a handful of others.

What if your telemetry is a simple electrical charge, a chemical reaction, a shift in air pressure or a subtle temperature variation? Of course, we have tools that can speak all those languages – a voltmeter, blood sugar monitor, barometer and thermometer respectively – but they’re not found in the average smartphone (yet).

Until they are, designers have to resort to new tools to listen in. One of the most popular is the passive coil, which transmits by induction rather than by active signalling. It sounds like double Dutch, but in fact you’ve already used it – it’s the basis for radio frequency ID (RFID) and NFC systems we’ve had for many years in retail anti-theft, self-checkout and tap-to-pay.

POWER

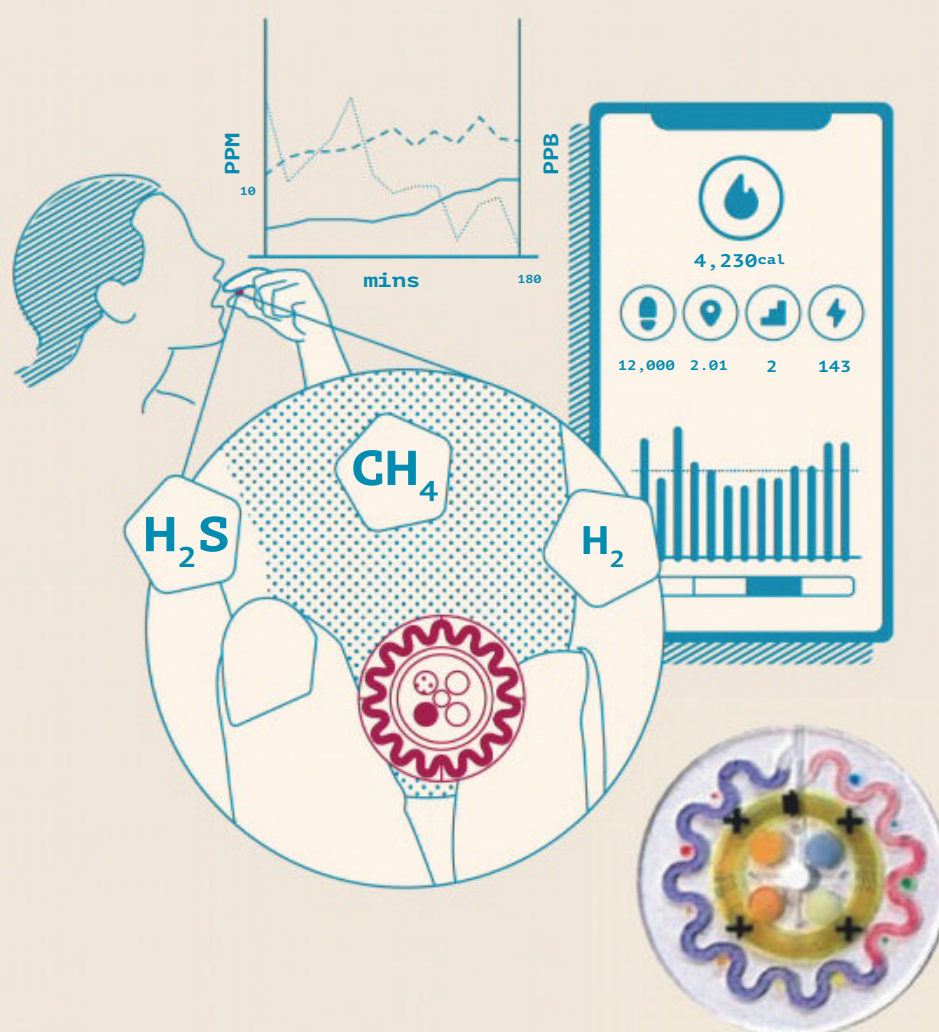
Putting a \$1 battery on a supermarket shrink wrap that costs less than a cent won’t just drive the price of goods and handling unfeasibly high, it’ll be an environmental nightmare.

In the absence of power sources that cost a fraction of packaging, clothes or medical devices (think of blood glucose test strips), we need to look elsewhere – and the most likely solution at the moment seems to be passive power.

Just as an RFID tag only comes to life when it’s in the presence of a reader, many IoDT devices need to extract power from their environment to work when they’re called for and not before. And there’s no lack of sources, from the movement of blood in a vein to the release of gas from food, orientation to gravity and everything in between.

03

RCP (RESPIRATORY CALORIMETER PELLET)



Measuring calories burned during exercise is usually a matter of averages. Take your weight, age, sex, etc and multiply according to the duration and intensity of exercise – also called “indirect calorimetry”. But since the mid ’60s there’s been a way of measuring the chemical content of inhaled and exhaled breaths. There’s a lot of arcane chemistry involved, and a 2017 study found the technique “not sufficiently accurate” to compete with indirect calorimetry, but technology has shown us nothing if not a tendency to overcome such hurdles.

Since the natural home of many disposable sensors will be the human body, it makes perfect sense to use our heat, movement and chemistry inside – and out – to power them. Blood pulsing past a sensor could act like a waterfall over a turbine, and the movement of air in and out of our lungs would nicely replicate the operations of a mini wind farm.

A recent device developed by scientists at France’s National Centre for Scientific Research and the University of California, San Diego, is worn on the skin. It flexes and stretches as the wearer moves, producing electrical energy by oxidising the lactate in sweat. At the moment it produces only enough power for a single LED light, but work is being done to amplify the voltage to power larger devices.

Then there’s 4D printing – think 3D printing, but where the printed matter reacts further upon

04

FISC (FIDELITY IN SUPPLY CHAIN)



Is that single vineyard olive oil really sourced from the Italian hill town it claims? The inexpensive FISC tag or sensor attached to the bottle (or pair of shoes, or expensive fountain pen, etc) contains and transmits information about the entire trip from grove to supermarket shelf to prove product authenticity.

“

Since the natural home of many disposable sensors will be the human body, it makes perfect sense to use our heat, movement and chemistry to power them.

”

contact with certain conditions. 3D printed cells, for example, can start to divide, fold and interact when they come into contact with other cells or in the body. A microscopic chemical turbine could fire up when it reaches body temperature, and as any physicist will tell you, movement equals energy.

When biomedicine does move beyond lithium or cell batteries it will open the field exponentially. A group at the University of Pennsylvania has developed an electrochemical battery made of paper where polymers are incorporated in a network of cellulose fibres, performing the oxygen-blocking and proton-exchange properties of organic decomposition.

And in June this year, Seokheun Choi, Associate Professor of Electrical and Computer Engineering at Binghamton University, New York, led his team to develop a biobattery made from organic microbial fuel cells where bacteria in the device is used to disintegrate the device itself at the end its useful life.

“One of the critical challenges to make the Internet of Disposable Things is a power source,” says Choi. “It has to be disposable, eco-friendly and inexpensive.”

To that end, his research group embarked down two pathways – disposable paper-based batteries and long-term microbial fuel cells – then found themselves meeting in the middle.

“The biobattery was a combined technique of those two,” says Choi.

“We enhanced the power duration by using solid-state compartments – but the device is still a form of a battery without complicated energy-intensive fluidic feeding systems that typical microbial fuel cells need.”

It's been so busy through the first part of the work day that you've forgotten lunch, until your phone vibrates with a notification from the Sodi-Kit strip's data, which is showing that your blood sugar and sodium are low enough to be a drag.

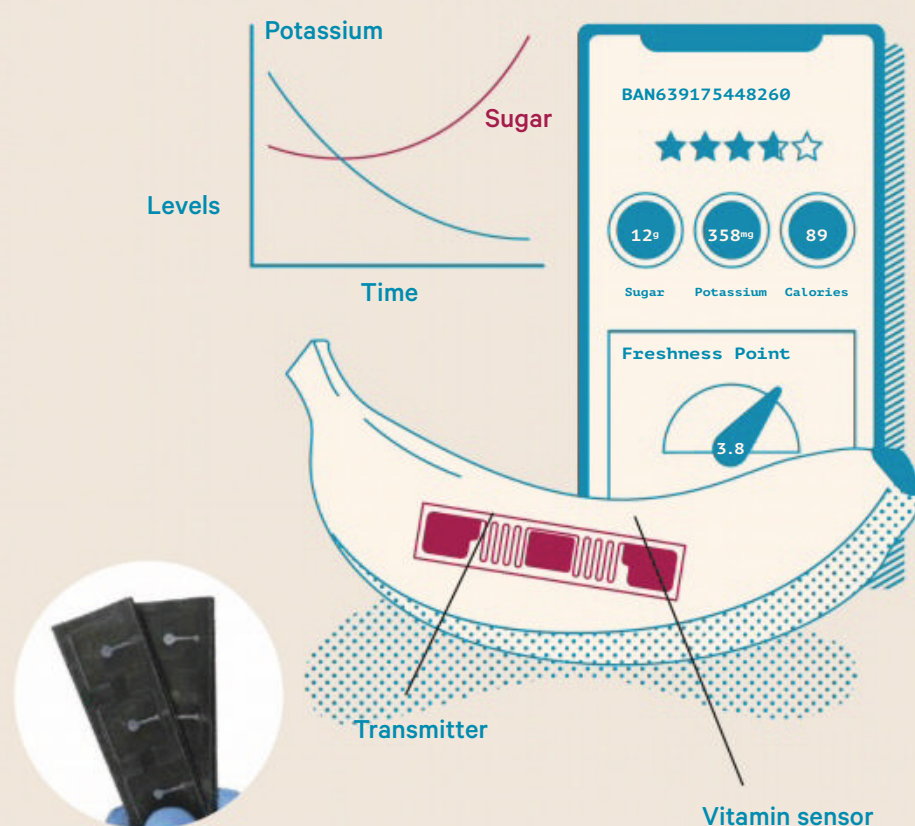
While you're eating lunch, you get a call from your GP's office asking you to make an appointment to come in soon. You're on blood-thinning medication following a recent heart arrhythmia event, and the SmartCaps pill that you took this morning has alerted your doctor that your metabolism is absorbing the drug faster than expected.

GETTING DOWN TO BUSINESS

THERE'S A NASCENT COMMERCIAL field sprouting up around the IoDT, including AM Fitzgerald, which has specialised in MEMS since 2003. Most of its market so far has been high-performance silicon sensors in

05

FOREVER FRESH



Eat a banana too early and it can affect your ability to digest complex carbs, too late and it contains fewer nutrients and more sugar. Work at New York's Clarkson University has created a paper sensor that can detect food spoilage from the supermarket packaging or even the skin of the fruit itself. Embedded nanostructures change colour (like litmus paper or a home pregnancy test) in response to the gases released by decomposition, so a visual sensor could read the colours and report the result digitally. A lab at Harvard University is also adapting a paper-based diagnostic test strip sensor to transmit data by radio.

implantable medical devices, scientific instruments, aircraft, spacecraft – things Alissa Fitzgerald says you can't find just anywhere.

But she told me on the phone from her office south of San Francisco that she's recently seen a change. "About five or six years ago I started to see this trend where more of the university research was in developing sensors on flexible – or even just cheaper – substrates like paper or fabric."

Today, thanks to the work done in labs and universities, a lot of the theory and many aspects of the practice are in place. The only bottleneck remaining is the manufacturing infrastructure.

"Companies that make printing presses, and textile manufacturers which already have equipment, will probably be best positioned to take this on," says Fitzgerald. "If you want to buy a shirt that already has sensors embedded in it, where's that going to be done? It's going to be at a textile company."

Such businesses have the large-scale means to merge electronics manufacturing with that of making paper, fabric or other flexible materials by producing it on huge rolls – a merger that hasn't occurred at the industrial level yet.

Notable by its absence in Fitzgerald's imagined future is the semiconductor industry.

Household names in the industry – such as Intel and AMD – have designed and built almost every other electronic sensor in your home and workplace today thanks to their command of the computer and smartphone markets.

"A semiconductor factory is essentially a giant clean room," Fitzgerald says, referring to the high threshold for process fidelity and the purity of the parts and processes needed. These are markers not required at a factory making exercise books or \$5 shirts.

Then there's the precedent of "fabless" (as in, fabrication-free) chip-making. Small semiconductor companies in the 1980s drove an explosion of innovation by designing inhouse but outsourcing actual fabrication to established third-party foundries and manufacturers, thus avoiding the huge capital outlays and risk that come with equipment, plants and staffing.

Today it's the natural home of some of the biggest names in the information and communications technology (ICT) industry. Among the top five companies by sales, using fabless manufacturing in 2017 were semiconductor giant Qualcomm, graphics and gaming specialists nVidia and, of course, Apple.

In fact, some work in hybridising manufacture has already been done – and from a surprising quarter. University of Illinois chemical and biomolecular



Today, thanks to the work done in labs and universities, a lot of the theory and many aspects of the practice are in place. The only bottleneck remaining is the manufacturing infrastructure.



WHAT IS AVAXHOME?

AVAXHOME-

the biggest Internet portal,
providing you various content:
brand new books, trending movies,
fresh magazines, hot games,
recent software, latest music releases.

Unlimited satisfaction one low price

Cheap constant access to piping hot media

Protect your downloadings from Big brother

Safer, than torrent-trackers

18 years of seamless operation and our users' satisfaction

All languages

Brand new content

One site



AVXLIVE:ICU

AvaxHome - Your End Place

We have everything for all of your needs. Just open <https://avxlive.icu>

engineering professor Ying Diao was working with a molecule that was studied as a cancer treatment by inserting itself into DNA to prevent replication.

After it failed in the test phase as an effective cancer treatment, Diao – who happened to be working in the disparate fields of pharmaceutical engineering and printable electronics – noticed that “their molecular structures looked much like the organic semiconductors we were working with in the rest of my group... This convergence of my two research areas was totally unexpected”.

Composed of stacked columns of electrically conductive rings connected with hydrogen, the molecules can pass charges across the columns, forming a bridge that behaves like a semiconductor. They interact with biological material using very

specific markers and measures, which makes them ideal biosensors. Better yet, they can be produced from a printer, so they’re able to be affixed to flexible substrates.

It’s bedtime. You’ve elected to spend your last minutes of consciousness old-school, catching up on the day’s events through news sites on your phone. And then – darn.

The report bings in on your day’s stats: an analysed combination of RCP, SmartHeart, SmartCaps, Sodi-Kit and several others. The recommendations for tomorrow include an extra 10 minutes of exercise, a fair bit less coffee and a delectable array of legumes for dinner. Plus a reminder to confirm your appointment with the doc about the warfarin.

Sensing both trouble and the need to head it off at the pass, your phone automatically offers your favourite musical soporific: an endless loop of the humming bit from “Don’t Worry Be Happy”.

INFORMATION OVERLOAD

IN TODAY’S DATA-DRIVEN WORLD, is it possible to make too much information? In 2017, IT platform provider Domo.com released research that estimated we collectively produced 2.5 quintillion bytes of data every day. That’s 2,500,000,000,000,000,000 bytes – or two-and-a-half million terabytes.

Late in 2019, market intelligence provider IDC said IoT data would continue to balloon, reaching 79.4 zettabytes (79,400,000,000,000,000,000 bytes), a jump of over 31,000 times.

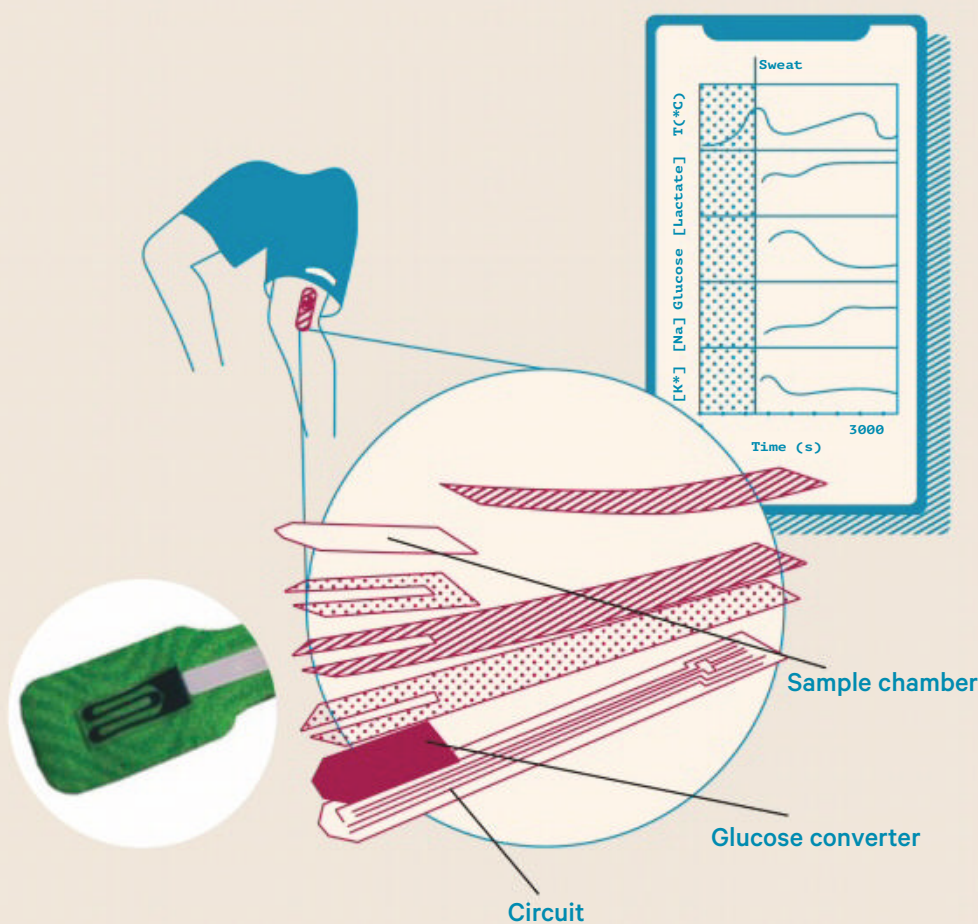
Now imagine what happens if we factor in communications between every sock, jogging shoe, bucket of fried chicken, bottle of soft drink and headache pill. “Big” won’t come close to doing justice to such a deluge.

The possibilities for learning are just as vast. As data scientist and machine learning engineer Luciano Strika points out, studies like whether apples make you live longer, or a vegan diet protects against heart attack, are based on “30 to 150 people – usually young white male university students”.

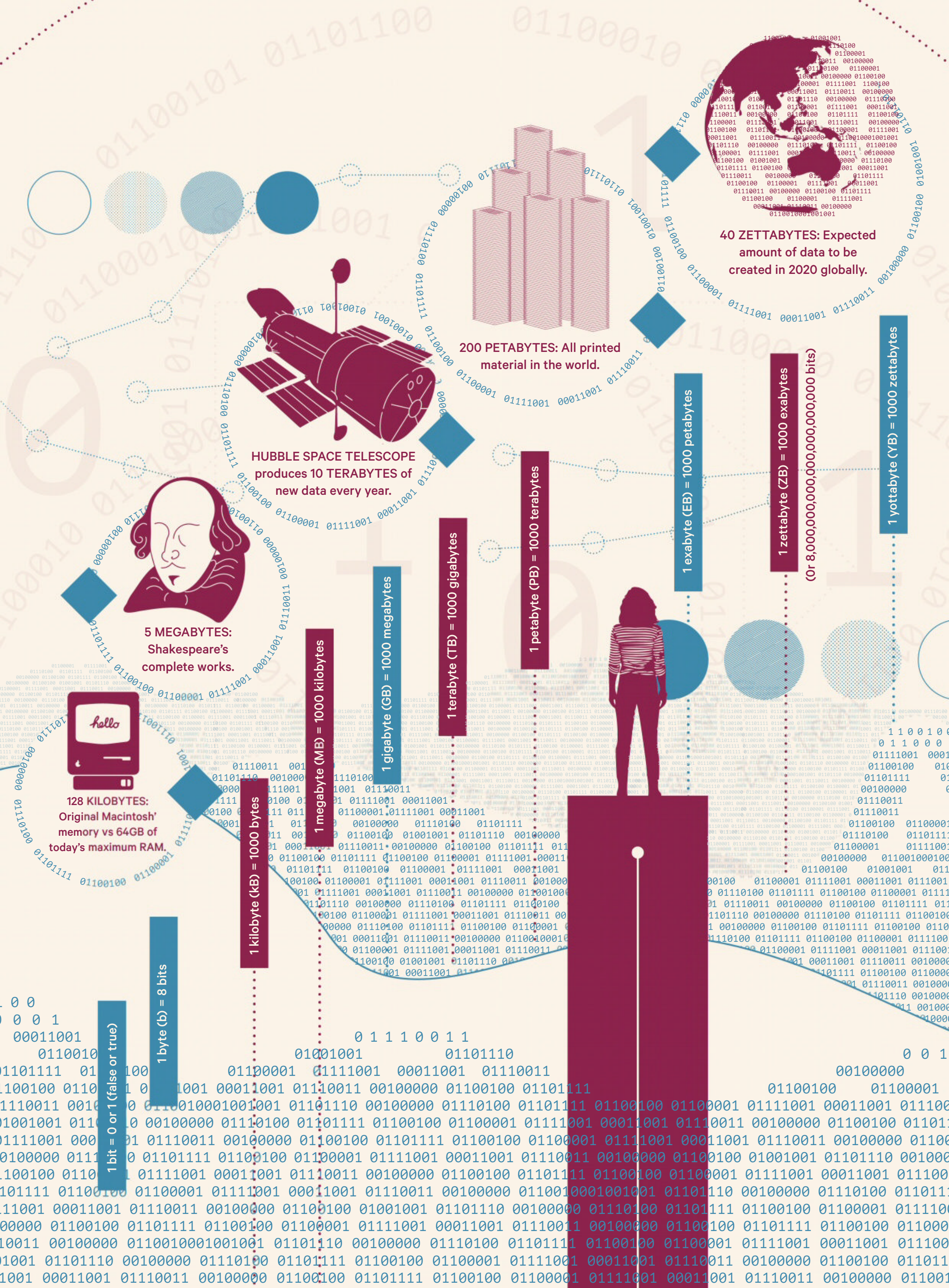
“Imagine conducting those same studies with a population of a thousand or a million,” he says. “And it’s a more random set with people of many ethnicities, age groups, etc. Suddenly you’ll find more granular results – maybe apples plus oranges plus being female helps prevent a certain type of heart disease.”

Strika also thinks it will prompt a new breed of intelligence. “What may really amaze us is emergent

06 SODI-KIT



If you know any diabetics, you’re familiar with the disposable strips that read the glucose in a blood sample. Blood deposited on the strip prompts a chemical reaction which sends a specific electrical current to the meter depending on the mix. The salt (sodium) content of blood is also important – particularly in relation to fitness – so similar technology could be embedded into a small strip of tape and applied to your skin, albeit with a smaller, less permanent reader than an everyday glucose monitor. Biodegradable electrochemical sensors already exist that use the salt content in the body to provide power through electrolytes, so your Sodi-Kit can read your salt content and draw power from it at the same time.



1 bit = 0 or 1 (false or true)

1 byte (b) = 8 bits

1 kilobyte (kB) = 1000 bytes

1 megabyte (MB) = 1000 kilobytes

1 gigabyte (GB) = 1000 megabytes

1 terabyte (TB) = 1000 gigabytes

1 petabyte (PB) = 1000 terabytes

1 exabyte (EB) = 1000 petabytes

1 zettabyte (ZB) = 1000 exabytes

(Or 8,000,000,000,000,000,000 bits)

1 yottabyte (YB) = 1000 zettabytes

40 ZETTABYTES: Expected amount of data to be created in 2020 globally.

200 PETABYTES: All printed material in the world.

HUBBLE SPACE TELESCOPE produces 10 TERABYTES of new data every year.

5 MEGABYTES: Shakespeare's complete works.

128 KILOBYTES: Original Macintosh' memory vs 64GB of today's maximum RAM.

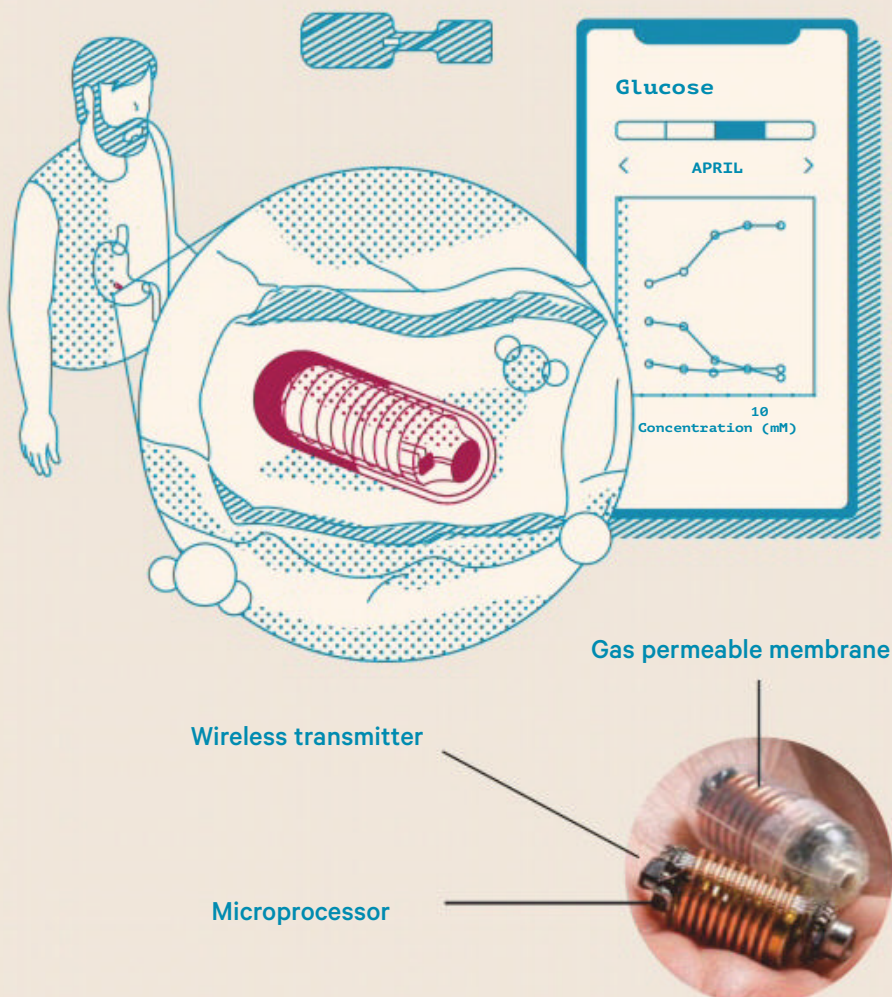
“

The biggest question of the IoT age will be data sovereignty and our rights when so much more about us is being recorded and transmitted.

”

07

SMARTCAPS



Your prescription drugs could be delivered in a pill that – after your stomach acids have broken it down and left only the microscopic magnesium and copper sensor – react with it to activate it chemically. Signals about the volume and efficacy of the drug in your system are sent to the bandaid-like patch on your skin that collects the readings, sending them to your phone for you or your doctor. Ingestible sensors have been commercially available for at least five years.

behaviour – if we’re tracking heart rates, deliveries and food quality, the interaction between these data points might provide us with very interesting results.”

In fact, the IoT age might comprise such a surge in data collection, transmission and storage that it entirely changes the way the world computes. Rohit Dewani, an engineer with Mumbai-based industrial IoT systems provider CraneSCADA, says that to analyse and generate value out of such volume will require a paradigm shift.

“[It] will require a complete overhaul of our servers, hard discs and deep learning capabilities,” he says. “Current generation [hardware] will need to be drastically optimised due to the amount of data, and algorithms will need to become even more robust.”

But with bigger data will come bigger privacy concerns, says Monica Eaton-Cardone, founder and COO of US financial services company Chargebacks911. “Interestingly, it could very well be that our fear of data breaches triggers a demand for disposable IoT devices,” she says.

“Something that only temporarily tracks your personal data might be perceived as less risky than a device used over many years.”

Paris-based author and strategist Rahaf Harfoush, who honed her expertise about technology and innovation at the World Economic Forum, thinks the biggest question of the IoT age will be data sovereignty and our rights when so much more about us is being recorded and transmitted.

“We’re shifting from an age of data abundance to integrative data,” she says. “It’s the difference between someone Googling about weight-loss tips and being targeted by advertisers versus their smart fridge sharing information about their weight and the food they buy via obscure and overly-legal agreements. It becomes even more true as datasets are integrated with each other to form more complex and accurate profiles of us.”

But while there are certainly data storage and security concerns that need to be addressed if this is all going to enjoy mass economic and consumer adoption, the benefits will far outweigh the risks.

By applying other methodologies like machine learning to the flood of information the world around us will generate, it’s possible that we’ll be able to connect dots we never knew existed to further improve society.

Not only will trains, planes and factory equipment work for us better, the Internet of Disposable Things will see to it that food, medicine and product packaging do so too. ©

DREW TURNEY is a technology writer based in Perth.

མཁའ་རྒྱལ་གྱི་
thought energy

ཡེ་ཤེས་ཀྱི་
wisdom energy

སྐྱེ་བུ་ཀྱི་
compassion energy



རྒྱུ་རྒྱུ་གྱི་
Stretching energy

ཐག་ཆད་ཀྱི་
Collision energy $K? S?$
 $H?$

G = gravity - རྒྱུ་རྒྱུ་གྱི་ - if you are above the earth

H = heat - རྒྱུ་རྒྱུ་གྱི་

M = muscle - རྒྱུ་རྒྱུ་གྱི་

K = motion - kinetic རྒྱུ་རྒྱུ་གྱི་

S = sound - can hear it

f = energy

མཁའ་རྒྱལ་གྱི་
laughter S, M, K



TEACHING PHYSICS TO MONKS

In south-western India, inside 600-year-old Gaden monastery, visiting academics ILYA MANDEL and LESLIE ATKINS ELLIOTT sought to enlighten a group of young monks. The transfer of knowledge wasn't all one way.

Leslie Atkins Elliott: My plan was to organise instruction around a series of questions – a thought experiment or a brief observation – hoping for discussion among the monks (that I may or may not be able to understand), and then a mini-lecture that says “So here is how Western science answers that question...”.

For example, when water disappears (in evaporation, or into plants), where does it go? Is it still water? Under what conditions can we say it is still water? It's an idea that explores atoms, molecules, conservation, chemical changes, physical changes.

Some of these questions come from curricula I've taught; most are from conversations I've had over the years as a teacher. I loved these questions already: What exists? Under what conditions? Will it always? Why might we believe answers to these questions? – but as I read about Tibetan Buddhism, I thought they might be good in this setting, too.

In my classes, I often talk about conservation laws as “there are things I have but cannot give (a dream,

the right of way); and there are things I give but cannot have (a kiss, a high five); and there are things I can give and have (money, food, bricks etc)”. And things like forces are more like high-fives; energy is more like bricks (it's more like bricks than *bricks!*). But so much of this depends on language games. I don't think the translation works.

Ilya Mandel: *The monks are very clever and have a tremendous background in logic and debate, but they don't have formal math skills. We quickly gave up on equations when we realised that mathematics was a challenge. The only place we really did any mathematics was in discussing distance scales, just to provide a sense of the size of the microscopic world and the cosmos, and the many realms of physics.*

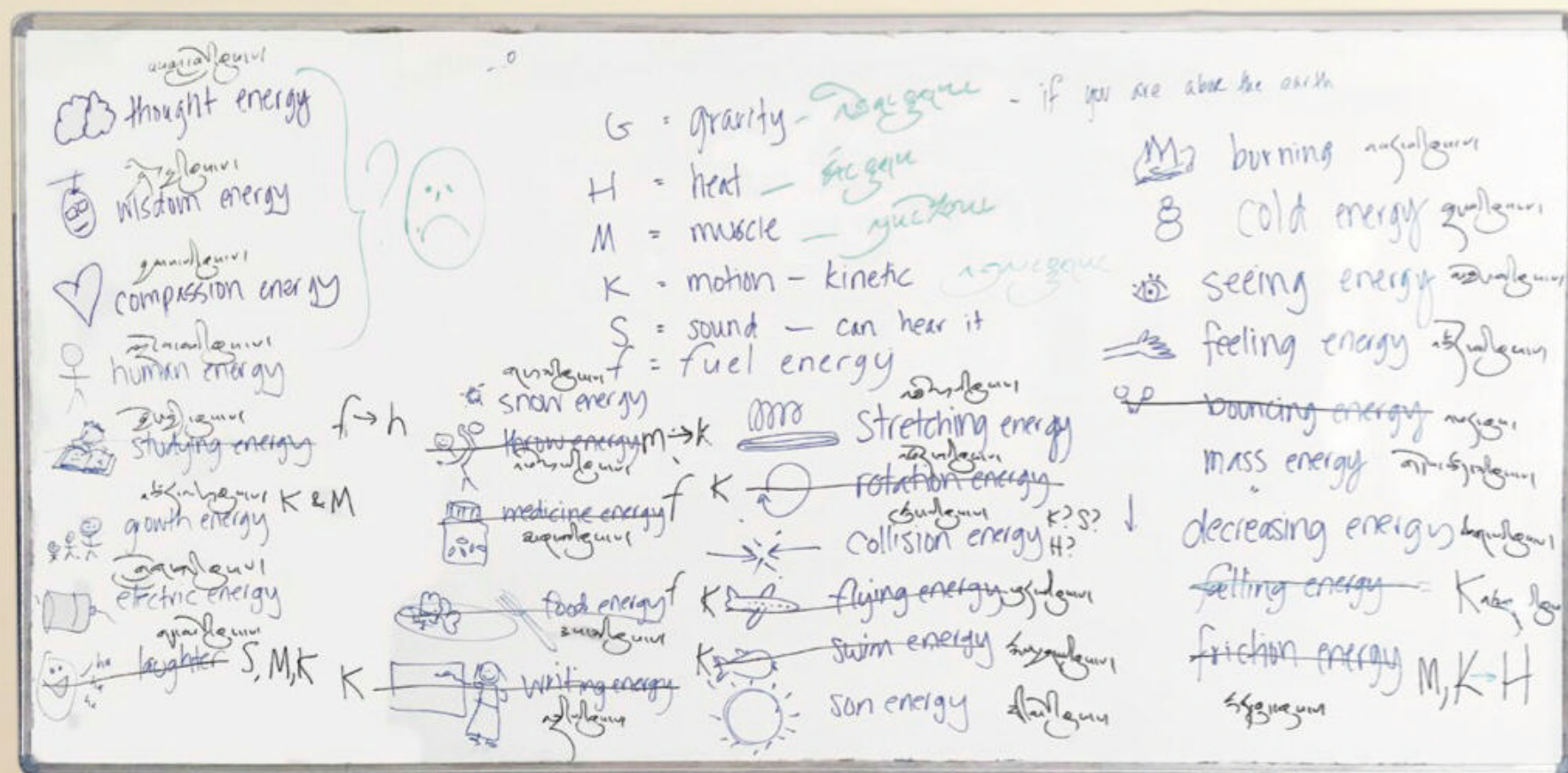
LAE: We started by thinking about the fact that atoms exist, which was a new idea for many but wasn't earth shattering. But what I think surprised them the most was Ilya's pendulum experiment.



LESLIE ATKINS ELLIOTT
Professor in Curriculum,
Instruction and
Foundational Studies,
Boise State University,
Idaho, US



ILYA MANDEL
Professor, School of
Physics and Astronomy,
Monash University,
Victoria



IM: It was very improvised: a roll of duct tape on a string that I held in my hand. I tried to hang it off a switched-off ceiling fan, but the fan started swinging as well, so this turned into a rather complicated double pendulum...

LAE: You had us count how long it took to do 10 swings – and then halved the string and asked them to predict the period. And then you predicted it (accurately, of course). And they were impressed; like, audible gasps of amazement. If I had to teach it over again, I might start with the pendulum, and with that kind of predictive power. Not because the prediction is the “thing” I’m most interested in, but because it suggests that our models and ideas are in conversation with data. It orients people to a particular kind of game we’re playing and what it buys you. If I could characterise the biggest difference between teaching the monks and teaching undergraduates in America, it is that the monks didn’t feel compelled to agree with me. Every idea we offered was considered food for thought. So, for example, when I noted that warm air is simply air that has faster moving particles, one of the monks politely rejected this idea: “Madam, in Tibet when it is windy it is colder.” I have taught kinetic theory of gases dozens of times, and no one has ever mentioned this. Ditto for the forms of energy.

IM: I think the most important part of this particular rejoinder is the implicit acceptance of the paradigm of physics as an empirical science. The objection does not come from Buddhist/Aristotelian reasoning from first principles, which was the initial approach of the monks, but from an apparent disagreement between theory and empirical observations. So, while it shows clever analysis on the part of this particular student, it also shows that we succeeded!

LAE: In our initial dive into forms of energy we had some typical ideas like “light energy” and “heat

energy” but the monks added “compassion energy” to that list. And we told them that, to a physicist, there is no unique form of energy related to compassion. I will admit to feeling like a caricature of the overly rational scientist as we told them this.

IM: They seemed initially unimpressed, but in a later discussion one monk said to another something like, “You are thinking like a Buddhist, but we should be thinking about this as scientists” – so the general message of adopting a different viewing angle seemed to resonate.

LAE: It’s tempting to hear this story and decide that “compassion energy” is a uniquely Buddhist notion and represents a cultural barrier that makes it hard to teach physics – but I suspect that this idea is actually pretty common. My undergraduate students might not refer to compassion energy, but I would not be surprised if they maintain narratives of cause and effect that are inconsistent with physics, and closer to ideas that the monks hold in terms of, say, our thoughts as having a particular kind of physical agency.

IM: Though our Buddhist students’ point that compassion energy and thought energy were more important than mere physical forms of energy may have been more uniquely Buddhist...

LAE: It’s like you never lived in California! I maintain that even this point is not uniquely Buddhist (c.f., *Star Wars*).

There is a style of Buddhist debate the monks engage in (usually in pairs), with a “defender” and “challenger”. The challenger, standing, poses a series of questions that the defender, sitting, can agree or disagree with. This took place in the courtyard our first night there (it does not happen every night but is common) and we got to watch. It all takes place in

East meets West on a whiteboard: Buddhist ideas of energy get a sad face from empirical science.



Q: You have a cup of water and pour half of it out. Then you pour out half of what’s left. And again. Can you keep doing this forever? Is there a smallest piece of water?

Tibetan, of course – our translator noted that one pair was debating why they wear the red robes; others were debating implications of the science they are learning (“since my hand is made of atoms, my hand does not exist” was the translation). It’s incredibly animated and they look like they’re having a blast.

We asked our translators to help us choose a good debate topic (not everything is debate-worthy) and chose to ask the monks to endorse or refute the claim that everyone ate some of Newton’s apple at lunch one day. In the ensuing – and quite intense – debate, the refuters’ main claim was “the past is not on your plate”. (A physics interpretation of this idea might be construed as “all carbon-12 atoms are the same and indistinguishable” or “carbon has no memory”.) I don’t think of this as a particularly empirical claim on their part. (The dissenting monks accused this monk of arguing from Buddhist philosophy and not scientific philosophy.)

IM: Buddhist monks were convinced that objects naturally come to rest when no forces are acting on them (and I am not sure we convinced all of them otherwise). The monks would have fit perfectly into Aristotle’s Lyceum – or, rather, Aristotle would have felt very much at home in the monastery!

LAE: There’s a commitment in Buddhism to the idea of impermanence. There’s a commitment in physics to conservation laws – which, of course, is a commitment to the idea of permanence. It’s interesting to think about trying to learn physics while holding that lens.

IM: I learned a lot about teaching physics from Leslie. My natural reaction would have been to opt for old-school lecturing, especially when faced with the relative

lack of preparation in the audience. Surely this is the time to teach from the pulpit, rather than waste time on letting the audience express their ignorance. And yet spending an hour asking them for what they thought of as possible forms of energy [shown on the whiteboard opposite] was clearly a useful strategy in discussing the domain of physics. I tried to incorporate this when asking for predictions for the pendulum. Less algebra, more of a sense of what empirical science is about.

LAE: As a teacher I’ve aimed to develop courses in which students start to ask really great questions. They don’t just take what you say and spit it back to you, but really make sense of it and question it. With undergraduates, this is a heavy lift. With the monks, it was trivial. They questioned things in deep, physical ways. It makes me wonder if there’s an aspect of their training that supports this stance towards science or if it actually says something damning about our educational system that stops students from asking these questions. I feel like we could learn something about learning from the monks. ☺

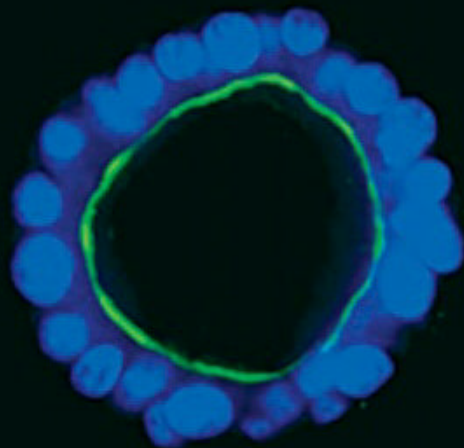
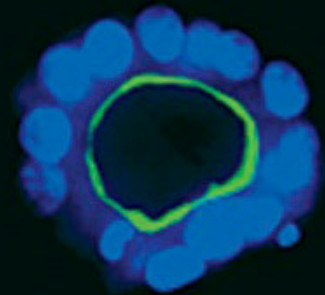
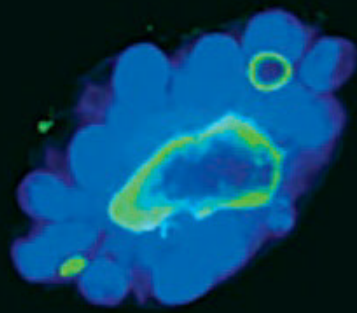
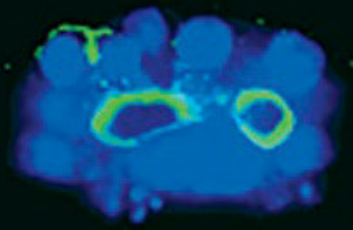
THE EMORY-TIBET SCIENCE initiative was conceived in 2006 through a partnership between His Holiness the Dalai Lama and Emory University, in Atlanta, US. Designed to introduce modern science for use in Buddhist monasteries in India, the curriculum has been presented as a series of courses in the philosophy of science, neuroscience, biology and physics to more than 1500 monks at three monasteries.

Mandel and Elliott taught 25 monks, most in their mid-20s, a two-week broad-survey course covering topics ranging from Newton’s laws to energy to astronomy, introducing key themes that will be taught in greater depth in subsequent courses.

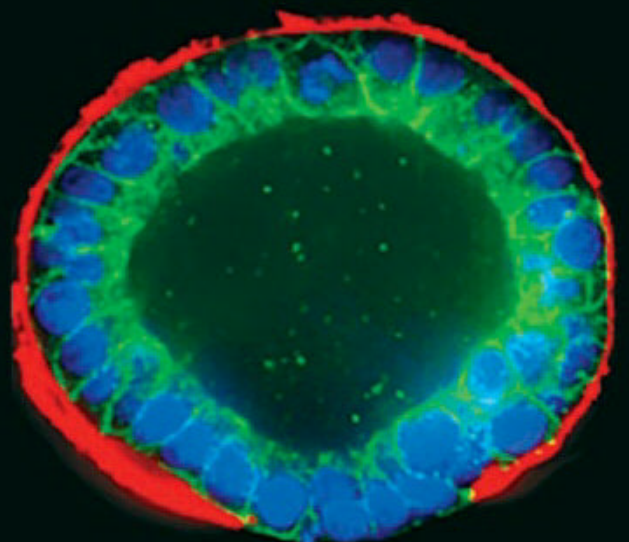
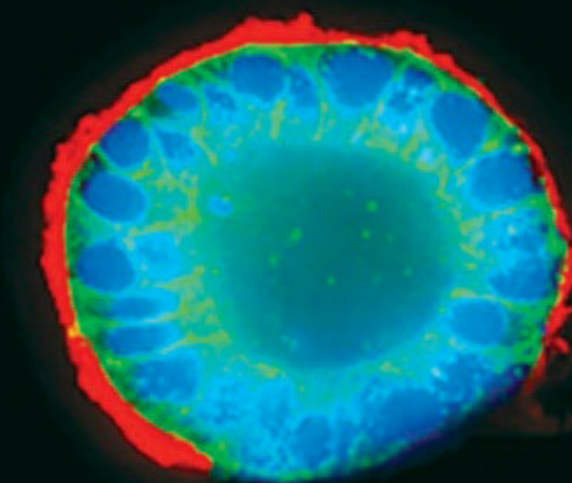
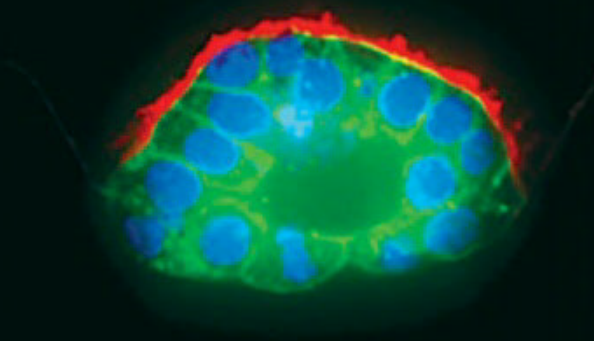
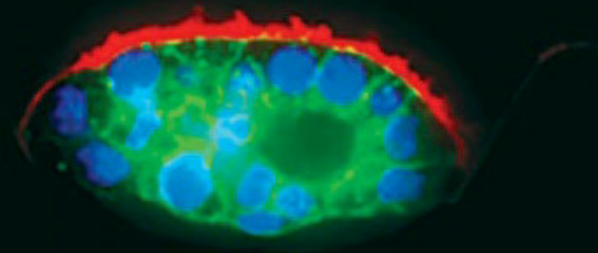
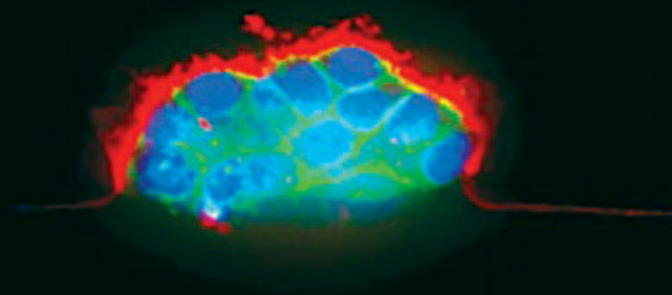
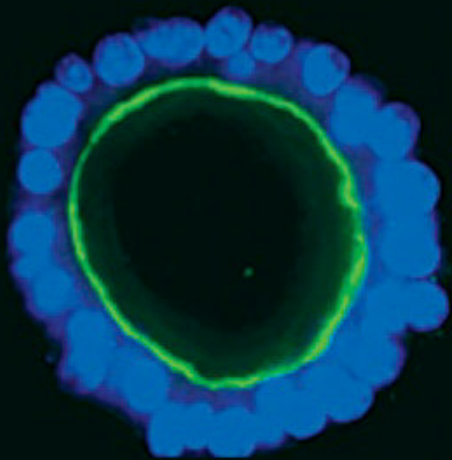
Q: Light from the sun reaches the Earth – then what happens? Does the light cease to exist? Does it turn into something else?

Smiles all round: The monks with translators and teachers at the completion of the course.





INSIDE BIOLOGY'S BLACK BOX



A new device for bioengineering embryo-like structures is shedding fresh light on those earliest, most mysterious – and largely unobservable – moments of human development. Great leaps forward in safe, successful pregnancies and congenital defect prevention await, but so do a host of ethical questions. PAUL BIEGLER reports.

COUNT SIX LITTLE ziggurats side by side, stolid and squat and obviously man-made. They are not going anywhere, but in between them things are on the move.

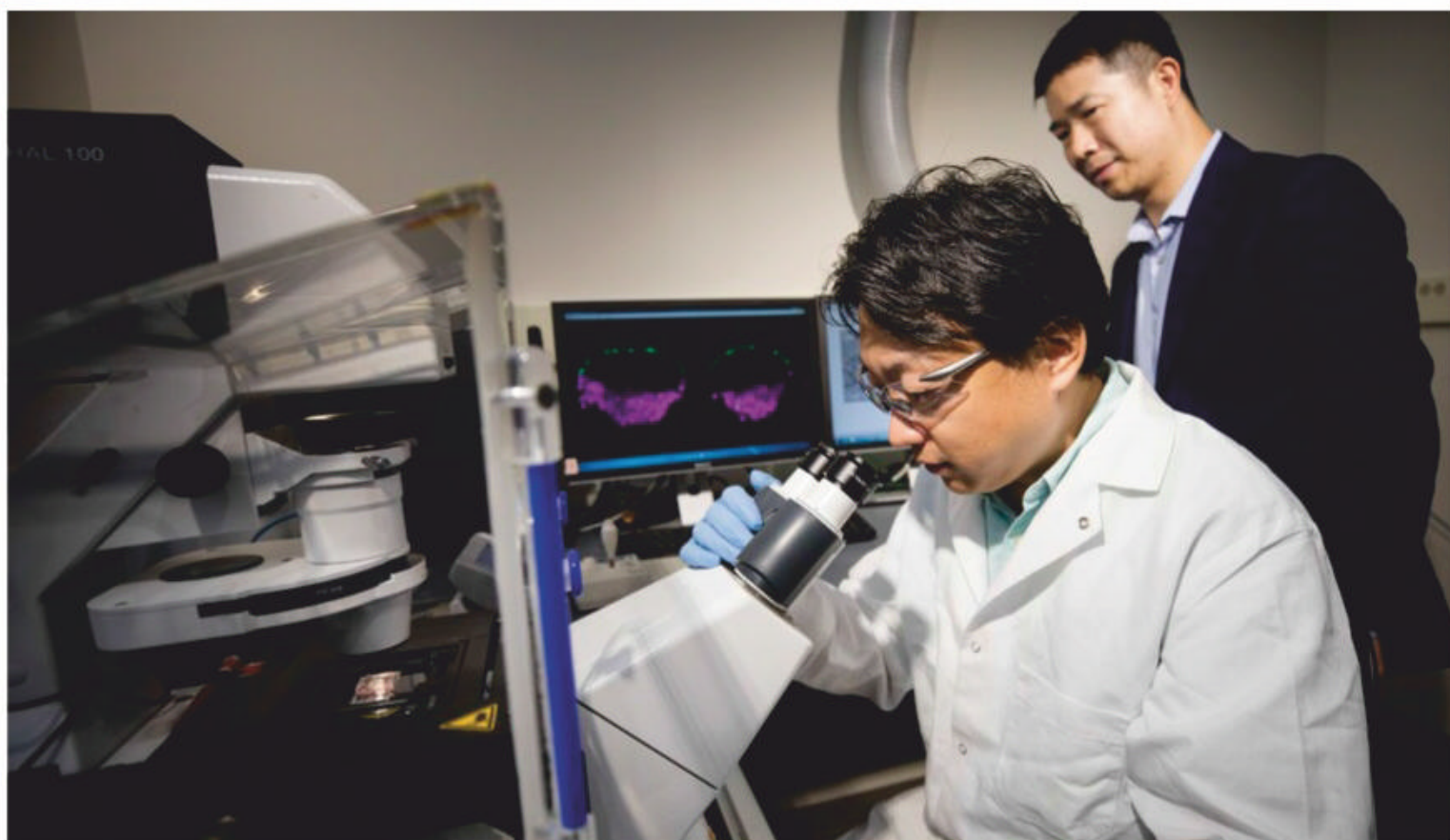
Circles of dots have begun to roil and rotate, angry blimps rising up among the static trapezoids, their contents swirling in a frenzy of disorder. Then, in each one, a ring solidifies and grows in the chaos. It's fleeting, and the jiggling hoop is soon churned back into the mass as the riot spreads unchecked.

These dots are human cells and their acrobatics are the beginnings of human life, though not as we know it. There is no womb, no pulsing maternal heart. Instead, the cells are born in an elaborate plastic chamber under constant video surveillance, and I am witness to their first two days of existence, compressed into a sparse 18 seconds by the wonders of time-lapse video.

The architect of this dazzling piece of cellular music hall is bioengineer Jianping Fu, whose field of expertise – mechanobiology – tries to understand how living cells change in response to physical forces.

Working from his University of Michigan lab on the outskirts of industrial Detroit, Fu is bringing the measured mindset of the machine-builder to the

Jianping Fu looks on as postdoctoral fellow Yi Zheng examines stained stem cells. At left, the development of two stem cell groupings at 6 hour increments, from 0 – 36 hours.



EXPLAINER

HUMAN EMBRYO DEVELOPMENT



DAY 0
Sperm and egg nuclei fuse, forming a fertilised egg – zygote – and rapid division begins.



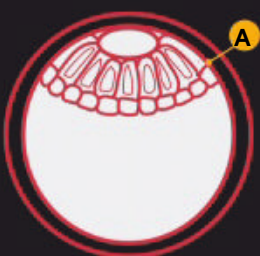
DAY 4
Morula has formed from 16-32 blastomeres, with fluid filled cavity inside morula.



DAY 6
Blastocyst forms, with an inner cell mass (ICM) and outer layer – the trophoblast.



DAY 7
The ICM – which will become embryonic stem cells, develops.



DAY 8
The ICM separates into epiblast and hypoblast cells.



DAY 8
Implantation occurs; cells start to differentiate.



WEEK TWO
Embryonic disc separates yolk and amniotic sacs.



WEEK TWO
Gastrulation; the primitive streak forms.



WEEK TWO
Cells in different regions differentiate.

A

EPIBLAST & HYPOBLAST CELLS
These cells form the divide that allows the amniotic cavity to develop.

B

EMBRYONIC DISC
The two layers of cells that will become the embryo.

C

PRIMITIVE STREAK
Defines the axes of asymmetry that will define differences in the embryo's left and right; front and back; and top and bottom.

D

CELL DIFFERENTIATION
Epiblast cells become endoderm, ectoderm and mesoderm (see page 75).

job of constructing life. He is one of an elite cohort of scientists trying to build a replica of the human embryo from the ground up to try to understand just how we are made – and where it can all go horribly wrong.

This area of science aims to alleviate the gamut of reproductive misery, from the anguish of infertility and miscarriage to gathering information about drugs like Thalidomide, which seem innocuous but have grave consequences if taken during pregnancy.

Fu’s bundles of cells, dubbed embryoids, could be used to screen drugs for toxicity in the womb. They might also unravel the mystery of why two out of every five pregnancies fail before 20 weeks. But these scientists, tinkering at the dawn of life, don’t know how far the cells can develop. There is talk their creations could one day provide a source of organs for transplant. The spectre of a baby in a dish looms ominously in the public imagination.

Which is why Fu’s bit of kit, written up in *Nature* in September and described by leading embryologist Ali Brivanlou as “a major advance in the knowledge of early human development”, is also an invitation for humanity to do some circle time on what it means to build a human.

THE INVENTION THAT’S CREATED this excitement is a simple-looking chamber with three channels. In one, Fu places pluripotent stem cells, blue-sky building blocks that can become almost any human cell. They are immortal and can be frozen and thawed, forming a renewable resource that can be used for years.

Some of these are embryonic stem cells, originally derived from human IVF embryos. Fu also uses “induced pluripotent stem cells” – iPS cells for short – that come from adult skin cells re-programmed back to a primal state.

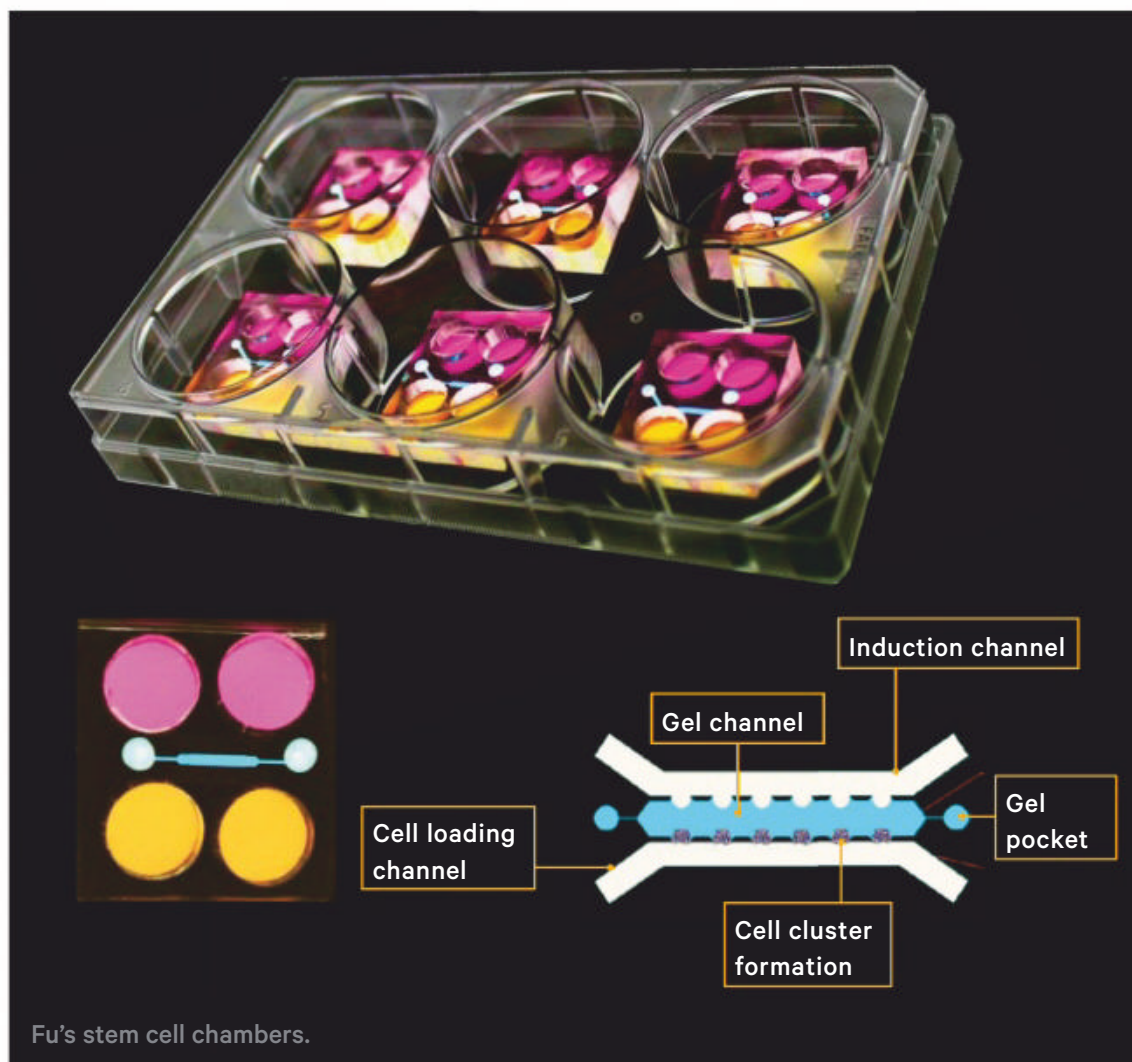
In the second channel Fu pours a liquid containing morphogens, the fertilisers that hurry stem cells on with the job of remaking themselves over and over. In the third, he lays a gel to support the growing masses, each one hived into its own mini-domain by evenly spaced support posts – the ziggurats.

In many respects there’s nothing novel about this. Researchers the world over are growing stem cells into structures that mimic the early embryo, before getting them to switch course in the first few weeks and become heart, brain or kidney cells.

These grow to make mini organs or “organoids”, about the size of a stunted chickpea, that are used to model diseases on the lab bench and test if drugs or gene tweaks might be a cure.

But Fu is aiming to make the whole shebang. There’s no diverting cells off into hearts and brains – rather, he wants them to run their course and become something that resembles the early human embryo.

Fu has pushed these embryoids as far as anyone’s



been yet and, true to his engineering pedigree, he's done much of it by inventing a new 3D world for the stem cell colonies to grow in.

"Most excitingly... in this first set of experiments, is the fact that in a subset of those colonies we start to see some asymmetric tissues, asymmetric embryonic structures," he tells me by phone.

Embryologists tend to get breathless about symmetry, or lack of it. After natural conception, when the sperm fuses with the egg to form the single-celled zygote, there follows a cascade of dividing, with new cells budding outwards in a uniform ball which, at day three, becomes the 16-cell morula – Latin for mulberry, which it resembles.

But around day six there is a major break from the order of symmetry, as the front-to-back, belly-to-spine axis appears. Anyone aiming to make a human embryo needs to nail this. Fu didn't just meet the milestone; he also produced the cells that become the amniotic sac – the fluid-filled bag in which the foetus floats.

"These asymmetric structures, basically they resemble the core of the peri-implantation human embryo," he says.

Implantation. It strikes at the heart of this project. Somewhere between six and 12 days after conception, the human embryo nestles into the fleshy wall of the uterus. This is essential if the pregnancy is to continue. But when it goes wrong, it's disastrous. Nearly three quarters of all pregnancies that miscarry by 20 weeks are a failure to implant. And the two months after implantation are when the embryo is

most vulnerable to the effects of drugs or maternal infections that cause birth defects.

Given the gravity of these issues, you'd think an avalanche of research would have shed light on them. In fact, we know so little about the period it's called the 'black box' of embryology.

The implanted embryo, key to the enigma of early life, is mostly invisible to science. The first reason is structural: the embryo is sequestered in a uterus beyond our gaze. The second is ethical: scientists have grown human IVF embryos for 13 days in the lab, but no one has gone beyond two weeks.

Endorsed by the UK's Warnock Committee in 1984 and then by the US National Institutes of Health's Human Embryo Research Panel in 1994, the 14-day rule bans lab research on embryos beyond that point.

It is around this time that a groove called the primitive streak appears in the embryo: among other things this marks a cut-off beyond which twinning is impossible. This is the defining line of the individual human which, some believe, is morally significant. The 14-day rule is enforced by legislation in at least 12 countries.

The reasoning is clear, but the effect is to keep the black box in shadow; science hasn't had a way to illuminate it.

NOW THE SPOTLIGHT FALLS on Fu's plastic channels, properly called microfluidic devices. In Fu's earlier experiments, only around 5-10% of his embryoids reached that asymmetry waypoint. But in his lab just a short drive from the factory where Henry Ford christened the first of his Model Ts, Fu has rewritten the rules of embryoid production.

"With this microfluidic system, now we can generate such human embryo-like structures with very high efficiency, up to about 95%," he says.

Fu's system isn't just meeting quality benchmarks, and this is where the parallels with Motor City's early denizens become a little more pronounced. "It is a scalable system," he says. "I would even say that now... it becomes a manufacturing system, depending on the needs, right? Depending on how many you need."

Fu's tone is measured, matter of fact. But on this moonshot to the dark side of our collective beginning he carries the interests of Everyman, so be reassured that he tells his tale with deep concern for our wellbeing.

When he says the system "will be very useful for high throughput screening", that clinical parlance describes the potentially vast benefits to real embryos of testing hundreds of drugs on embryoids first. His work could also show why so many pregnancies miscarry – and improve our measly IVF success rate of 20%.

THALIDOMIDE



One of the new wave of sedative drugs introduced through the 1950s, this over-the-counter cure for insomnia and morning sickness was launched in West Germany in 1956. In Australia it was marketed as Distaval or Tensival: "Safe sedation and sounder sleep". By its withdrawal in 1961, an estimated 2000 children had died, with serious birth defects identified in 10,000 more across 47 countries. Thalidomide is now used to alleviate conditions associated with leprosy and HIV.



MEGAN MUNSIE
Deputy Director,
Centre for Stem Cell Systems,
University of Melbourne

Indeed, his precision-tooled temperament may be a prerequisite for the kind of slog needed here, to get an embryoid to trace the footsteps of a real human embryo, in something the scientists call recapitulation. It is only by mimicking the true-life course that a dish-bound doppelganger can give test results that are valid.

And that is a big ask, not least because there is no gold standard; the ‘black box’ means there is no definitive embryo library to provide reference points for the journey. Then there are the endless variables in embryoid research: the physical layout of the device, when to add morphogens and chemical signals, and countless other tiny details.

Which is where Fu took his Enterprise into deep space. His embryoids reached the early phase of another critical developmental stage called gastrulation. When the furrow-like primitive streak appears at 14 days, it signals that the cells below, a little like the settling of ploughed earth, are falling into three layers: the ectoderm, mesoderm and endoderm, respective precursors of skin and brain,

the substrate has to repeat faithfully across each test. One example, of course, stands out.

“Thalidomide, who was expecting that? What if we could develop a screening mechanism, that is an adjunct to pharmaceutical development, that enabled us to provide a safeguard for a new drug?” asks Munsie.

BARELY A KILOMETRE FROM Munsie’s office, across Melbourne’s verdant and expansive Royal Park, Andrew Elefanty is using stem cells to try to make bespoke blood for people whose bone marrow has failed, or is in overdrive making blood cells that don’t work properly – the leukaemias.

It is the kind of medicine that shows just how personalised the embryoid project could become.

In order to create the customised blood, Elefanty’s team at the Murdoch Children’s Research Institute takes blood samples from volunteers. The immature red cells are removed and, with the help of genes delivered in a virus, programmed back to a pluripotent state – they become iPS cells.

In crimson culture fluid in blue-capped flasks, these iPS cells are then urged by the team towards the embryoid stage. But, unlike Fu, the team halts development at the point of gastrulation, directing

the cells to become mesoderm alone.

Why? Because it is that layer, as Elefanty shows me in a stunning photo, that fashions the seminal version of our biggest blood vessel, the aorta, in whose walls, at this rudimentary time, the red blood cells are made.

Duplicate Elefanty’s process with the blood of someone with leukaemia and the hope is that, one day, you could make healthy blood for them that’s a perfect match.

But I’m confused about something.

Since stem cells were first coaxed into tiny 3D brain-like structures in 2008, scientists have produced a cornucopia of organoids. All of these – mini brains, hearts, kidneys and even blood cells – can be made directly from pluripotent stem cells. Why, then, would you want to push them through the embryoid pathway first, which seems to be taking the long way round?

“The way that works the best, if you like, is if you try to direct them via a trajectory where you do actually try to replicate some of the steps during embryonic differentiation,” says Elefanty. “That’s the road map that you’re following.”

The whole process is artificial, but there’s something of a “nature knows best” adage at its

“What if we could develop a screening mechanism, that’s an adjunct to pharmaceutical development, that enabled us to provide a safeguard for a new drug?”

muscle, and internal organs. Their emergence heralds the laying down of the body plan.

But Fu’s embryoids also showed something else undeniably human. Budding off from those furiously dividing balls were the barely discernible outlines of germ cells. These define the male and female sex – they are the cells that go on to produce sperm or eggs.

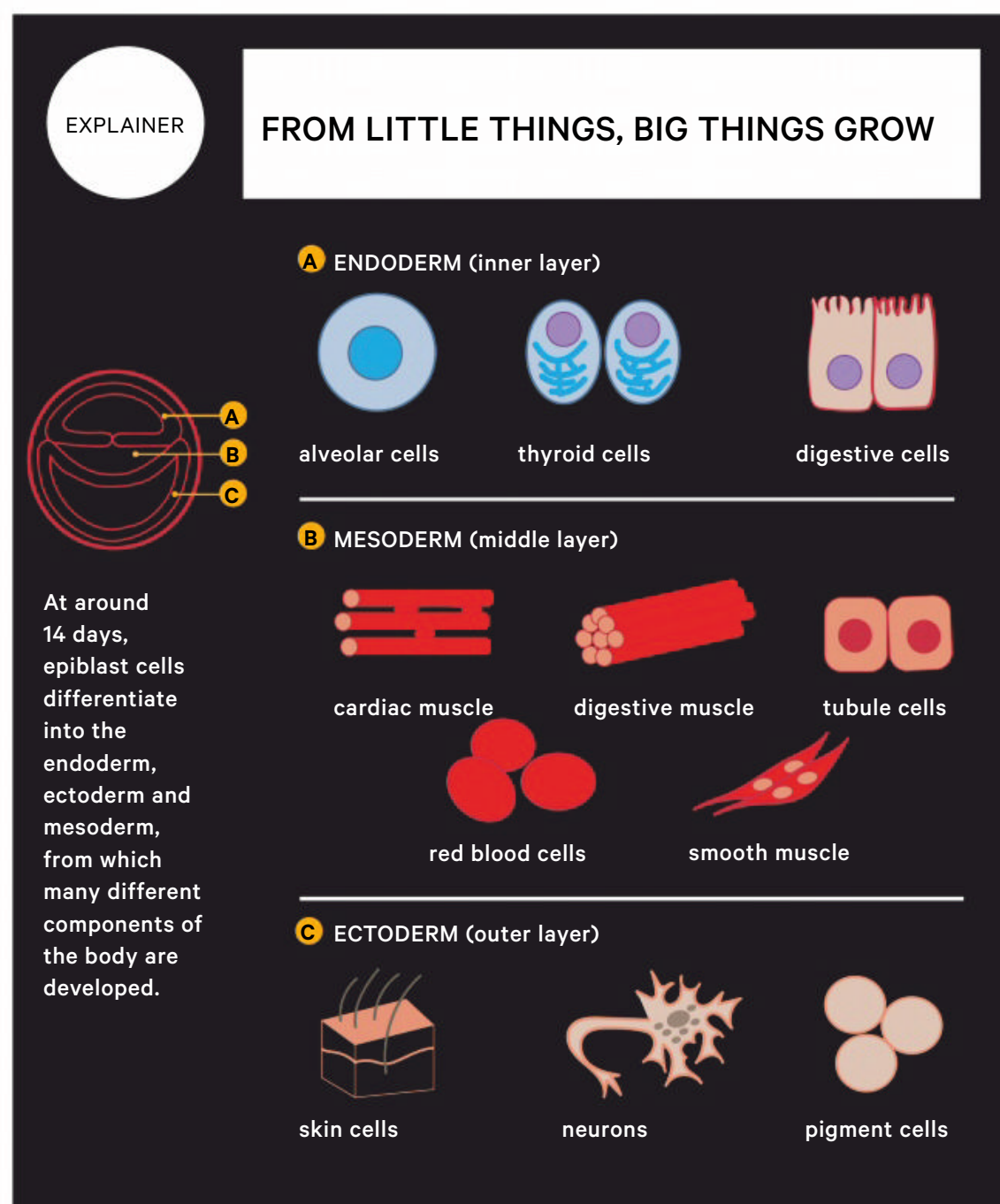
Megan Munsie is Deputy Director of the Centre for Stem Cell Systems at the University of Melbourne and has been entangled with the stem cell story for two decades, first as a researcher and now as an expert on policy and ethics. The appearance of these sex cells left a deep impression.

“This is a part of human development that we just really can’t follow,” she says. “The start of the germ lineage I think is absolutely fascinating.”

Nor was it the only aspect of Fu’s achievement that gave her pause.

“When we looked across his images I found them quite extraordinary,” she says. “In almost all the clusters in the wells the patterning was consistent, and as you can imagine in this area of biology there is often quite a lot of inconsistency.”

That cookie cutter reliability is essential if you want to screen a bunch of drugs for harmful effects;



heart. Elefanty is leveraging nature's navigational toolbox, whose items have been checked off by the rigorous oversight of evolution, to make a better blood cell.

THE EMBRYOID PATHWAY could also be a way forward for organ replacement.

Writing in *Nature* in 2018, stem cell pioneer Martin Pera and colleagues noted that mini brains, livers and kidneys made from stem cells are pretty basic, and that maybe we can do better.

"Initiating organ development in an environment as similar as possible to the developing embryo might... generate structures that more closely resemble mature, functional organs, for drug screens or even for transplantation," they write.

Usable organs, however, both in terms of sophistication and size, would need the embryoid to be pushed much further along the developmental path than it has been. Elefanty points out two largish hurdles to that ever happening.

"If you don't have the right cell type you can't make a whole embryo. And secondly, what people can't underestimate is the difficulty in reproducing

the environment that is the same as the implanted embryo," he says.

Here's the rub. Fu's whirling cell clusters are the right ones to make the headline act of the embryo, but are missing the supporting entourage: the trophoblasts that become the placenta, and the hypoblasts that go on to make the yolk sac, needed to nourish the early embryo.

These are critical kit in their own right, but they also play a key role in what is called patterning, which plots the layout of the body – for example, getting your liver and spleen in the right spot or crystallising the geography of the brain's bumps and folds.

Here, however, the incoming breakers of science seem relentless.

In 2018, Japanese researchers cultured human trophoblast stem cells for the first time, raising the prospect of an artificially grown placenta. Another announcement last June, however, may have leapfrogged that altogether.

A group led by Xuefei Gao from the University of Hong Kong created something called "expanded potential stem cells". With some clever chemical coaxing they heightened the potency of human embryonic stem cells and iPS cells – stem cells on steroids if you like. Crucially, expanded potential stem cells can make those missing bits – the placenta and yolk sac.

The final step would be replicating implantation, and in October 2019 the Salk Institute's Juan Carlos Izpisua Belmonte led a team that created expanded potential stem cells from mice, some by reprogramming cells from the critters' ears, to make what they say "could potentially be... fully functional synthetic embryos in vitro".

Equipped with placenta and yolk sac, these are primed to become fully fledged foetuses – and Belmonte successfully implanted the structures in a mouse uterus. Only 7% took and, after a week, they were badly malformed. But it is early days.

AS THE SCIENCE RUSHES ONWARDS it is hard enough to understand it, let alone pass judgment on how far it should all be allowed to go. There are ground rules in place. The 14-day rule is as bedrock as ethics gets, exerting global influence. But, for the purposes of regulation, is an embryoid an embryo?

In Australia it probably is, even though no one is pushing the experimental agenda at anywhere near Fu's level.

Dianne Nicol is Chair of Australia's Embryo Research Licensing Committee, which would make any such adjudication should the question arise. It hasn't – yet. She originally trained as a developmental biologist and is now a Professor of Law at the University of Tasmania.

Nicol directs me to *The Research Involving Human Embryos Act 2002*, which defines a human embryo as something made by fertilisation of a human egg by a sperm. But it goes beyond that, to things with a human nuclear genome that have “the potential to develop up to, or beyond, the stage at which the primitive streak appears”.

“That does seem to me to include these embryoids that have a capacity to develop to the primitive streak. And if that’s the case then we have a regulatory environment to deal with them,” she says, careful to stress she’s speaking in her capacity as legal academic, not Committee chair. Should the Committee decide similarly, research like Fu’s in Australia would require a licence.

The Act specifies that any research on human embryos must be done under a licence issued by the Committee, a second layer of scrutiny after review by an institutional ethics committee. The decision whether or not to grant such a licence would, almost certainly, take cues from philosophers who specialise in stem cell ethics.

One job for those professional thinkers is to look

Adding to the regulatory imbroglio are the tectonic shifts we’ve seen in the ways of concocting human life, from test tube babies to reproductive cloning.

In 1996, biology superstar Dolly the sheep was the first mammal to be cloned from an adult cell. Fashioned by putting DNA from a sheep’s udder cell into a sheep embryo – a process called somatic cell nuclear transfer – Dolly was proof of concept for reproductive cloning, which remains universally banned in humans.

Along with those reproductive advances, Hyun tells me, the laws that define embryos have shifted focus. “You’re seeing embryo definitions in legislation that have less and less to do with how it was created and more and more to do with what they can become,” he says.

Which suggests, he adds, that the lawmakers are preoccupied with one big issue when it comes to reproductive technology: “Does the thing in question have the power to make a baby if transferred into the womb?”

When the moral rightness of something hinges on what it could become, you have what philosophers

call an “argument from potential”. But such arguments, says Hyun, can get hoisted on their own petard as science advances.

What would happen if, following Belmonte’s work, you could program a

human skin cell into an expanded potential stem cell that could ultimately make a baby under the right conditions? In that brave new world, would a flake of dandruff meet a requirement for moral protection?

And what of social potential? If regulation itself prohibits transfer of research embryos into a womb, should that allay concerns about what they might become?

Good ethics, of course, starts with good facts, and Elefanty reminds me that our capabilities are limited.

“There is still a considerable degree of concern over making embryos in a dish which will make viable organisms and so forth because that’s still got a degree of playing God associated with it,” he says.

“I think it is partly moot because I think the technology is nowhere near there.”

Elefanty could well be right. And no one is even remotely suggesting we could, or should, grow a baby in a lab. But the science is moving at speed, and so it may be prudent to get our ethical ducks in a row sooner rather than later.

Just in case. ☺

PAUL BIEGLER is a Teaching Associate at the Monash Bioethics Centre in Melbourne.

“You’re seeing embryo definitions in legislation that have less and less to do with how it was created and more and more to do with what they can become.”



INSOO HYUN

Professor of Bioethics and
Philosophy, Case Western
Reserve University

at why the primitive streak is a moral line in the sand, beyond the question of individuation.

The standard answer is that it heralds the arrival of ectoderm, which prefigures the nervous system, which transmits pain that will, way on down the track, be perceived by a conscious brain. So the primitive streak seems to mark a point beyond which harm could be inflicted.

I asked Insoo Hyun, a Professor of Bioethics and Philosophy at Case Western Reserve University in the US, if the moral weight attached to the primitive streak is justified.

“I think, from a secular point of view, it is very hard to defend that, because we’re not even at the point where we’ve got functioning neurons or any kind of capacity for experience or pain,” he says.

Hyun also notes that many versions of the 14-day rule are nuanced, specifying that culture of embryos cannot go beyond 14 days or the appearance of the primitive streak, whichever comes first.

That points to 14 days being relevant only because it coincides with primitive streak formation. But the whole embryoid project could rejig the developmental order – scientists could, theoretically, make the primitive streak happen earlier or later.

THE COURSE OF CURIOSITY

From fruit flies to human organoids,
ELIZABETH FINKEL reflects on the
circuitous path of medical advances.

DID NOT BECOME a scientist to cure cancer.

I was one of those types who are curiosity-driven; give me the blue-sky mystery and I'll leap into it. So when in June 2019 Megan Donnell told me she was using research I'd participated in 30 years ago to find a cure for her two sick children, it hit me with the force of revelation: blue sky research really *does* pay off.

It may be an article of faith inked into your grant proposals, but when you spend your days with fruit flies, as I did in the mid-1980s at the University of California San Francisco, it can be a little hard to believe.

Though I had no medical problem in mind, I was trying to answer a rather profound question: how does the mush of an embryo sculpt itself into a body? At my lab and others around the world, we found the answer lay with a set of so-called 'pattern-forming' genes. In the same way that a tailor draws a pattern on a sheet of fabric to guide the cutting and sewing of the garment, these genes lay down a pattern on the newly-laid fly egg to instruct the construction of its body. My gene of interest went by the name engrailed. A few hours after a fruit fly egg is fertilised, engrailed lays down a pattern of 15 stripes along the developing embryo, which provide the pattern to start constructing the 15 segments of the fly grub.

What was so thrilling was that these pattern-forming genes weren't just involved in the construction of fruit flies; other researchers found the same pattern-forming genes at work instructing the embryos of frogs, mice and humans. While later researchers delved deeper and deeper to unravel the details of just how pattern-forming genes guide the development of embryos, one stream of this research took a turn that was quite beyond my imagination.

From the early 2000s, researchers began using pattern-forming genes to instruct human embryonic cells to make tissues for patients. Today, advanced clinical trials are offering patients made-to-order grafts for skin, pancreas and retina. Even more startling, the pattern-forming genes are being put to work to make small replicas of human brains in a dish, dubbed brain organoids.

It was Megan who made me realise that this science fiction technology had well and truly arrived. We first met at a conference in September 2018, discussing genetic testing for prospective parents. Members of inbred communities, including Ashkenazi Jews (like myself), have long availed themselves of genetic tests to ensure they are not carriers of afflictions such as Tay-Sachs – a fatal neurodegenerative disease from which infants typically die by the age of four. But members of the wider community are not immune; any couple can wake to the living nightmare of discovering they have passed on a fatal genetic disease to their offspring.

That was Megan's cautionary tale. A tall, attractive, dynamic woman, her children Isla and Jude appeared normal at birth. But by the time Isla was two, there were concerns. Unlike most toddlers she was not putting words into sentences. Jude was born soon after, and he too had drawn the genetic short straw.

The Donnells were unaffected – and unknowing – carriers of the Sanfilippo gene. Its function is to clear away heparan sulfate, a sugar that holds proteins together in the matrix between cells. Absent a functioning copy of the gene, the sugar levels build up and start poisoning the brain.

Megan and her husband Allan each carried one gene that functioned and one that didn't. There

Soon after fertilisation, the gene called engrailed quickly lays down the fruit fly grub's pattern of 15 body segments. Organoids developed utilising similar pattern-forming techniques may offer a solution for Sanfilippo sufferers such as Megan Donnell's children Isla and Jude (opposite).



was only a one-in-four chance their offspring would inherit both bad copies. Tragically, that was the case – twice over. They were told Isla and Jude would live only to their teens and die paralysed, unable to talk or eat.

The advice the Donnells got from doctors was “have no false hope”. Megan didn’t listen. She did her research and discovered gene therapy.

IT’S A WONDERFULLY SIMPLE idea. For all the profound consequences of a disease like Sanfilippo, its cause is simple: a single gene is faulty. If you could ferry the missing gene to the organ that most needs it, typically using a virus that infects the cells of that organ, you might be able to fix the disease. Megan

discovered Abeona, an American start-up spun out of Nationwide Children’s Hospital in Ohio, which was planning clinical trials of gene therapy for Sanfilippo children. A savvy IT business manager, Megan founded the Sanfilippo Children’s Foundation and raised a million dollars. She invested that money in Abeona on the proviso it would carry out clinical trials in Australia.

Megan’s story blew me away. Even though I was editor of *Cosmos* magazine at the time, we had completely missed the arrival of gene therapy. I suspect we thought of it as a failed technology.

Certainly, there had been disasters such as the death of US teenager Jesse Gelsinger in 1999, when his immune system went into meltdown from the sudden infusion of trillions of virus particles bearing the therapeutic gene. In 2003 tragedy struck again when five children developed leukaemia after receiving gene therapy.

Today’s shining example of the success of gene therapy is a

Though I had no medical problem in mind, I was trying to answer a rather profound question: how does the mush of an embryo sculpt itself into a body?



MEGAN P. DONNELL

treatment for children born with spinal muscular atrophy (SMA). Until a couple of years ago, there was no hope for babies born with this condition; they became paralysed and died by the age of two. But babies treated with the gene therapy Zolgensma, marketed by Novartis, have reached the age of four – with many of them walking and some dancing. At a cost of more than US\$2 million per treatment, it is the most expensive drug in history.

Spectacular results have also been seen for children suffering from a form of retinal blindness that begins months after birth. A gene therapy called Luxturna, marketed by Roche at a cost of US\$850,000 per patient, has restored sight to blind children.

With the lame walking and the blind seeing, paediatrician researcher Ian Alexander at Children’s Medical Research Institute in Westmead, Sydney, has dubbed these “biblical results”. And for the first time that I can recall, medical researchers are using a four-letter word: *cure*.

Governments and health insurers around the world are now confronted with the dilemma of how to pay these exorbitant prices. Gene therapy advocates argue that one-shot cures end up saving money because most genetic diseases incur costs of tens of millions of dollars through ongoing treatment and hospitalisation. But that calculation depends on whether or not single shot cures such as Zolgensma do indeed last a lifetime, which remains to be seen.

Novartis is offering US insurers pay-as-you-go plans, as well as refunds if the treatments stop working.

But while medical miracles are taking place because of gene therapy, that hasn’t been the case for the Donnell children. In part because they are too old; Abeona trials show that children are most likely to benefit from gene therapy if it is administered in infancy. Once brain damage has begun, it’s difficult to reverse.

Furthermore, in order to qualify for gene therapy trials, children have to be free of antibodies to the viruses that act as ferries for the gene – and one of the Donnell children did carry antibodies.

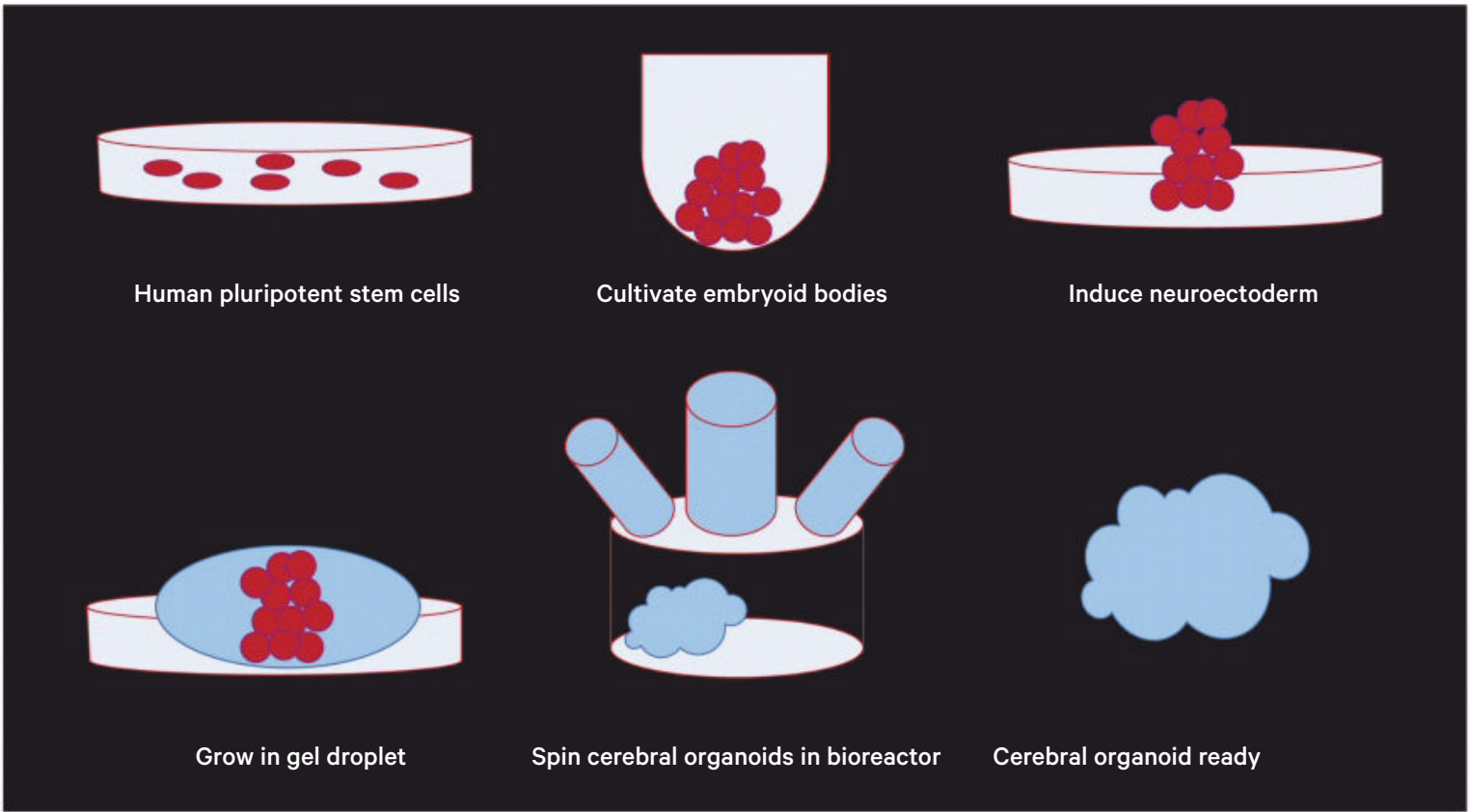
When I caught up with Megan in September 2019, nine-year-old Isla was back to nappies and Megan was sporting a black eye from her frustrated daughter. But she was far, far from beaten. The Sanfilippo Children’s Foundation is moving ahead on multiple fronts. And once again, I was stunned by what she had to tell me. She was funding a research scientist who was making organoids of her children’s brains in order to test drugs that could slow the progress of their disease.

BRAIN ORGANOIDS proved their value during the 2015 Zika virus outbreak in Brazil. Babies were being born with abnormally small heads, a condition known as microcephaly. But there was debate as to whether the virus was responsible. Researchers used human brain organoids to show that the virus infected and delayed the development of certain types of brain cells.

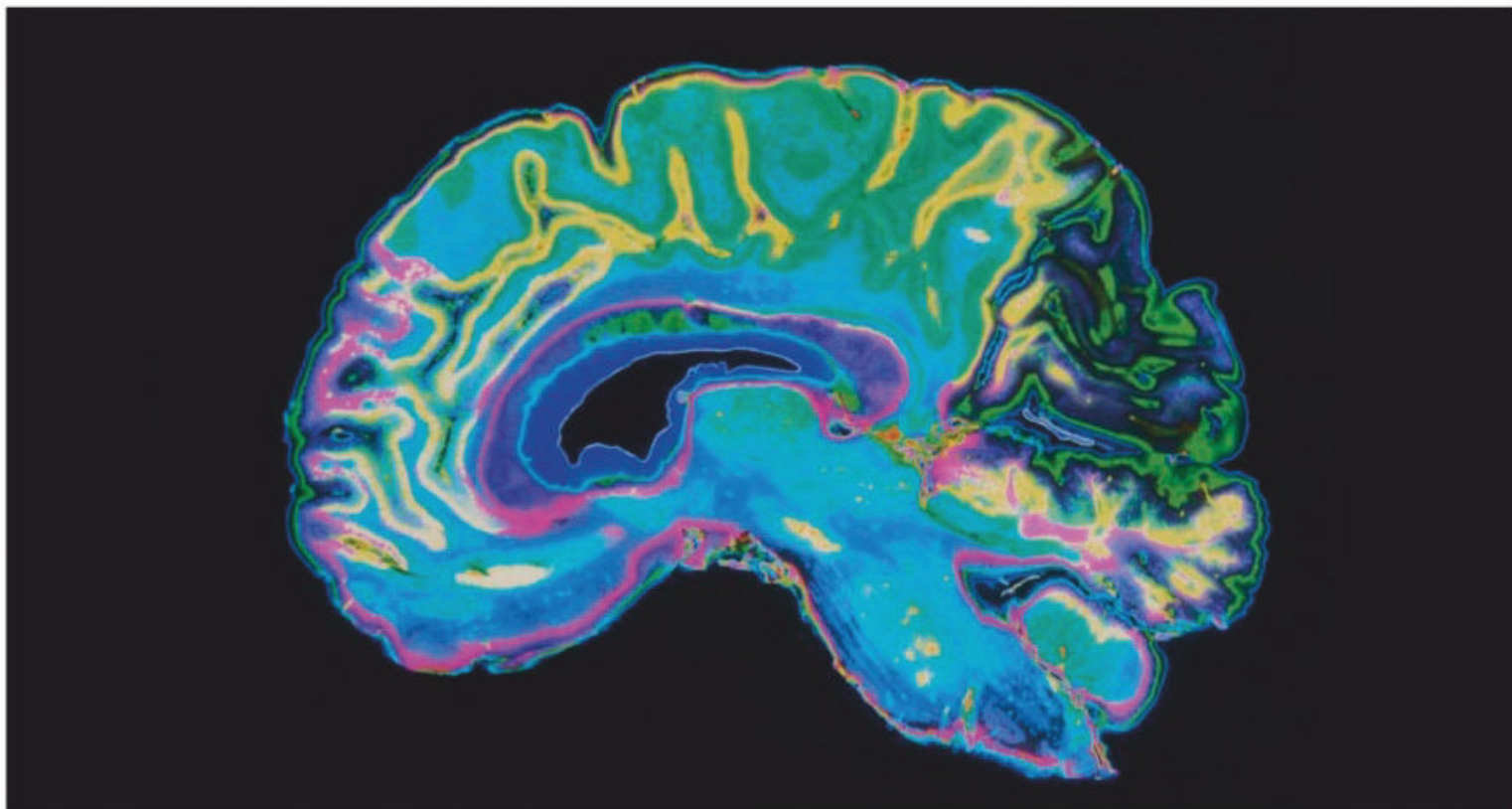
Megan was now commandeering this technology to make brain

The remarkable ability to make a facsimile of a person’s brain to study their disease relies on the braiding together of two streams of epic research.

Brain organoids are artificially grown organs which can mimic brain structure (opposite). To make an organoid, start with a patient’s skin cells and transform them into induced pluripotent stem cells. Culture them in a brew that includes pattern-forming genes to induce them to become progenitors of brain tissue – neuroectoderm. Then grow them in a gel droplet and rotate them in a bioreactor.



KEVAL TILVA



organoids for her children. And that, I realised, had been made possible by the convergence of two streams of epic research – both of which I had a connection to.

The first stream delivered pluripotent human stem cells – cells bequeathed with the potential to form any type of body tissue. I had written a book on stem cell development – *Stem Cells: Controversy at the frontier of science* – in 2005. James Thomson from the University of Wisconsin first learned to make embryonic stem cells in 1998; Alan Trounson's team in Australia wasn't far behind. These embryonic stem cells were highly controversial because their source was leftover human embryos from IVF clinics. These embryos were destroyed in order to harvest the stem cells.

Then things got a whole lot more controversial.

Dolly the sheep was cloned from a single cell of an adult sheep in 1996. In theory the same technique could deliver cloned human babies. Not that anyone wanted to clone babies; what medical researchers had in mind was cloned embryos. Why? Let's imagine researchers took one of my skin cells and made an embryo clone of me. They could harvest embryonic stem cells from my 14-day-old clone, which would be perfectly matched to my tissue type.

If, for example, I was diabetic and needed a graft of pancreas tissue, my cloned embryonic stem cells could deliver one – no anti-rejection drugs required. By contrast, if stem cells were sourced from a foreign embryo, I would need to take those drugs for the rest of my life, just as I would for any foreign tissue. Controversial as it was, Australia passed legislation to permit this so-called therapeutic cloning (aka somatic cell nuclear transfer) in 2007.

The explosive debate over human therapeutic cloning was diffused by a single discovery. In 2006,

Japanese researcher Shinya Yamanaka found a magic cocktail – made from just four factors – that reprogrammed skin cells directly into stem cells, no embryo required. These stem cells were given the innocuous descriptor: induced pluripotent stem cells (iPS). As Paul Biegler's article describes (see page 70), iPS cells are now being made into many different types of tissues, including brain organoids.

But to make those tissues from iPS cells required a second stream of research: the pattern-forming genes I worked on. With a sheet of iPS cells, researchers can now deploy a combination of pattern-forming genes to direct cells towards the formation of any body part, including the brain.

Over the past few years, I've read about these developments with great interest. But it was all academic to me till Megan Donnell told me that a researcher was making brain organoids from her children's skin cells.

In a moment of revelation, I suddenly saw the streams of research converging over the decades. Beginning from those of us propelled by sheer wonder, our research on fruit fly genes trickled down, joining with rivulets emanating from the work of embryo researchers, cloning researchers, and then the torrent flowing from the discovery of the Yamanaka's factors.

And here sitting in front of me sipping her coffee, was Megan, waiting at the spigot for what this braided stream of research could offer her children.

If I could go back to 1985 and reveal to my younger self – bent over the microscope, peering at fly embryos – just what fruits her research could deliver, I'm not sure she'd believe it. ©

Elizabeth Finkel is *Cosmos's* Editor at large and a regular contributor.

Hook, Line & Thinker

On a remote Pacific atoll, science has blended with tradition to save a species of fish and the islanders that thrive on it.

NATALIE PARLETTA reports.



WITHIN THE DAZZLING turquoise waters of an atoll called Anaa in the South Pacific swims the roundjaw bonefish (*Albula glossodonta*), a species that thrives in the coral-fringed lagoon's shallow waters. But like many fish populations globally, its numbers are dwindling, threatening the island's economy and food security. Unlike many regions around the world, a unique blend of science, children's voices, community cohesion and a return to tradition has set the bonefish on a sustainable trajectory.

It all started with a dynamic Tahitian, Hinano Bagnis. Passionate about helping residents of the surrounding islands, Bagnis studied law, but her interests led to a role as the executive director of an NGO helping island communities. She then became frustrated with ventures that failed to address the complex environmental and economic challenges faced by these communities, and wanted to help them become more self-sufficient and manage their resources more sustainably.

She had befriended Sir Douglas Myers, a multi-millionaire who had fly-fished the atoll Teti'aroa with a company run by Mathew McHugh. Myers agreed that something could and should be done, saying, "Okay, pick an island and redefine your project".

So, with funding from Myers, the Anaa Atoll Project was born in 2016. Nestled in the Tuamotu

archipelago, 350 kilometres west of Tahiti, 38 square kilometre Anaa was chosen by Bagnis and McHugh as a pilot site because of its declining population of about 500 people with limited education and employment prospects, which also held promise for fly-fishing tourism. In 2018 they created the Island Initiative charity to generate more funds, and identified the island's popular bonefish as a potential economic driver for other income sources for residents, such as accommodation and locally made souvenirs.

Known to locals as Kiokio, Anaa's bonefish appears to fly across the island's lagoons, its shimmering silvery skin tinged with blues and greens. A member of the ray-finned Albulidae family, its speed, eagerness to feed and visibility make it a popular game fish in the warm shallow waters of many tropical regions, including Florida, the Caribbean, Seychelles and French Polynesia.

In Anaa, the locals rely on *A. glossodonta* for trade – and it's also one of their favourite food staples. This is unusual, because, well, it's full of bones. But the fish tastes better at Anaa.

"It's one of the few islands where bonefish is a big resource as far as eating it," says marine biologist Alex Filous from the University of Massachusetts Amherst in the US, "but here it's considered like the best eating fish on the island – and it is really good."

According to Filous, that's because of the worms, crabs and clams the bonefish feed on, all of which thrive in the lagoon's uniquely shallow waters. With an average depth of just 1.5 to 3.5 metres – compared with 20 to 30 metres in other atolls – sunlight is able to freely reach the bottom.

"They're well fed and well nourished, so they have a distinct flavour that's different than other bonefish, and their flesh is softer," he explains.

When Bagnis and McHugh formed the Anaa Atoll Project, they invited Filous to investigate the viability of a fly-fishing venture. After identifying the bonefish as the atoll's most abundant species, and therefore critical for the islanders' food security, Filous decided to study it for his PhD research.

From 2016 to 2018 he tracked and tagged bonefish to estimate their age, size and growth, reproduction, fertility and natural mortality. He used underwater computers that detect acoustic transmissions from electronic tags within 500 metres. Filous surgically inserted the tags, about the size of a small phone battery, each with a unique beeping sound, inside the body cavities of 40 fish. This enabled him to track and correlate their movements with spawning and lunar cycles. He did encounter a slight hitch: at some point virtually every islander caught one of his tagged fish, which meant retrieving and cleaning the tag, before capturing another fish to track.

With the help of local fishermen, he also attached ID tags to around 2500 other fish to gather information on growth between captures, the timing of their capture and the timing of spawning with seasons and moon cycles.

To estimate the species' natural longevity, in 2014 they had collected comparison samples from nearby Teti'aroa, which had no permanent inhabitants – and hence an unexploited fish population – and a similar predator profile to Anaa.

From the data collected, Filous calculated a spawning potential ratio (SPR) to evaluate the stock's health. The SPR calculates the theoretical number of

eggs a female could produce in a given population, divided by the number of eggs it could produce over its lifetime in an unfished population.

The figure is based on fish size, which in a general sense correlates with egg production. A five-year-old, 50-centimetre-long female, for instance, can produce around 300,000 eggs. If she's allowed to grow to 60 centimetres (perhaps seven years and older), she can produce more than a million eggs, so longer-lived females are essential to maintaining a sustainable fishing stock.

An SPR ratio of 100%, Filous explains, "means that this population is producing eggs at a rate that would be like it's virgin stock that has never been touched by fishermen. And 0% means there's no egg production."

The data showed that the average age of the roundjaw bonefish in the waters around Anaa was well below the species' 20-year longevity, with males surviving to eight years and females to 10. The SPR metric hovered between 7% and 20%, a finding Filous published in the *Journal of Fish Biology* in 2019. So, as many Anaans had already noticed, the numbers weren't just dwindling, they were unsustainably low.

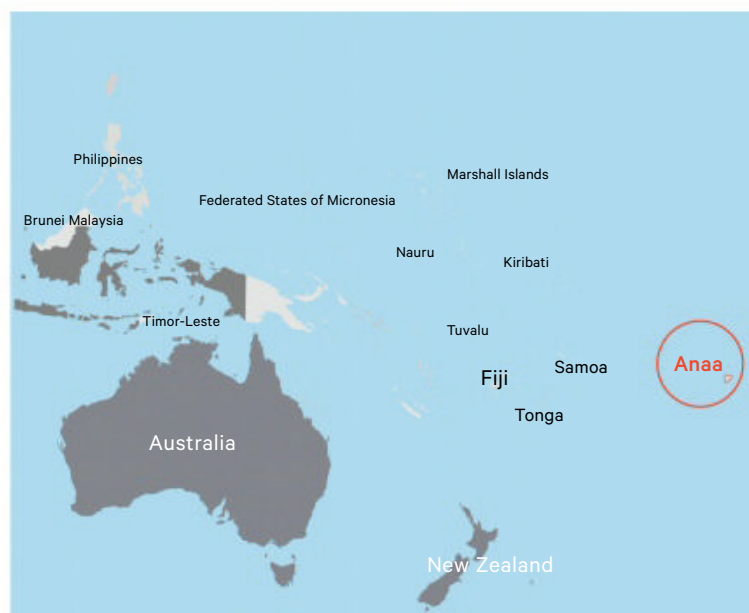
To address the problem, the Island Initiative isn't talking about not fishing, says Bagnis, but about leaving enough fish to repopulate. "It's really man and nature working together."

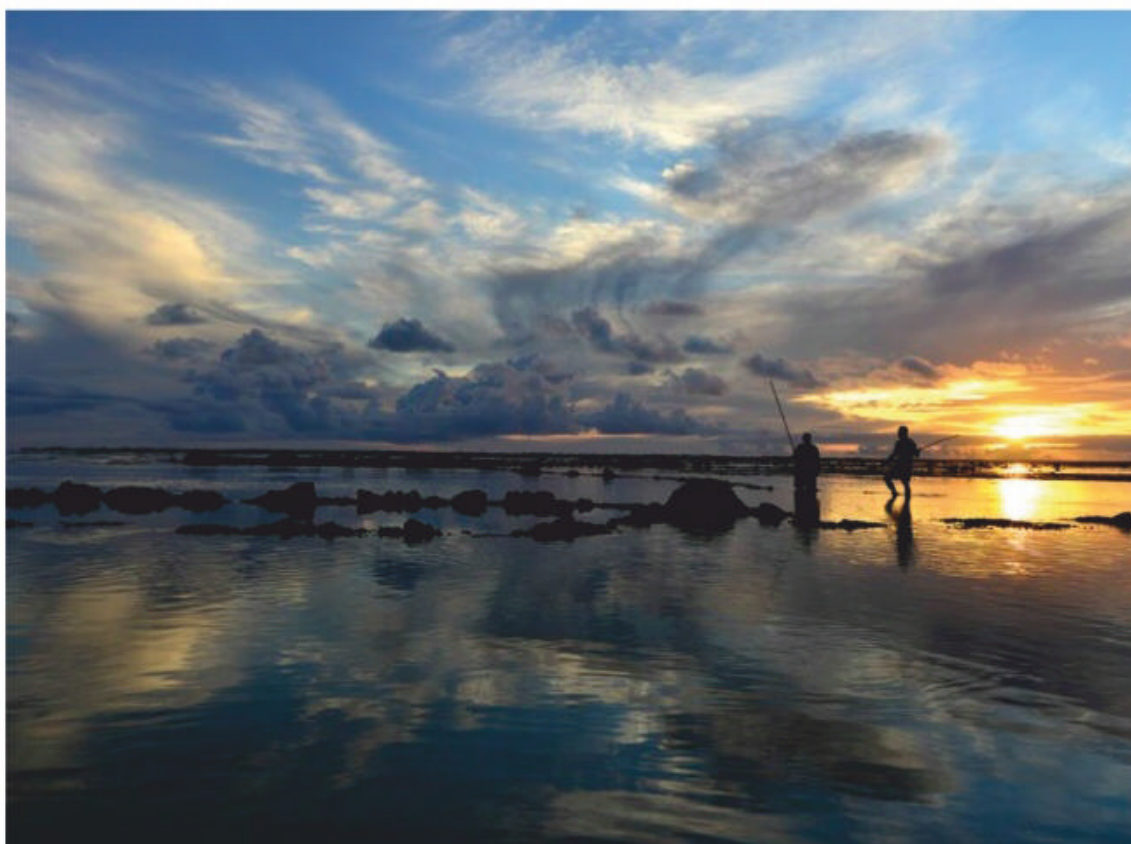
The goal is to maintain a threshold above 20%, ideally 30-40%. "The other way to think about 20%," says Filous, "is that means you can kill 80% of the population's egg production and still fish." But it's a red alert if you dip below that. "My data supported that it was pretty overexploited, and something should be done."

Filous delivered his findings to Bagnis, who asked, "If we had the full support of the population, what do you think should be done?"

As a rule, reef fish search for safe areas to spawn, Filous explains. The upper section of the atoll is ideal, because it has a deeper water passageway for them

Opposite. Marine biologist Alex Filous has been collecting data on Anaa atoll (below) for his PhD. His topic is "fisheries science to support conservation of bonefish (*Albula glossodonta*) through traditional community base management".





Although the roundjaw bonefish (top left) is – as its name suggests – bony, it’s a dietary staple on Anaa. Use of traditional fishing traps (top right) resulted in the islanders over-exploiting the species. The Anaa Atoll Project recovery program includes creating a new economic driver – a sustainable tourism industry based around catch-and-release fly-fishing (above left). Islanders (above) still use stone traps to fish, but on a schedule informed by science and culture. Left, Anaa schoolchildren – with, from left, mayor Calixte Yip, marine biologist Alex Filous and school principal Jean Pierre Beaury – wrote and distributed a petition that was instrumental in gaining island-wide commitment to the fishing changes.

to exit to the ocean but the swell comes from the southwest – so it’s like a rock in a stream that leaves gyres behind it. Fish have easy access because it’s deep, and the gyre helps the spawn to intermingle.

Albula are broadcast spawners, releasing eggs and sperm into the water in a big cloud. “Because they’re just basically squirting their eggs and sperm into the water, there needs to be a lot of fish to make sure the gametes meet,” says Filous. “So, what they do is, every fish from every corner of this entire atoll, after the full moon, swims right out here, forms a big, big, big-ass school, thousands of fish. And then it’s like, too-to-too-tooooo, charge! They just rush through this corridor” and out to sea.

Those gametes that get lucky develop into plankton-like eels – leptocephalus – while the current disperses them. Finally, at about two months old, the leptocephalus metamorphose into juvenile fish.

From the sex ratios of catches throughout the season, Filous worked out that the bulk of the female population moved through the migratory corridors to spawn between March and May, at which time they were being heavily exploited by an ingenious trapping method.

The traps, locally known as *kaua*, are weirs made from dead coral and rocks that the fishermen drag across the ocean bottom and pile into heart shapes. “It’s like a perfect work of art,” Filous says admiringly of the technique. “I don’t know how they did it.”

Filous knew the best way to allow the bonefish population to recover to above 20% would be to close the fish traps from March to May and shift the fishing towards the end of the season when the proportion of males was greater, and females had completed their breeding. But he also was certain that there was no way the fishermen – who were among the many people he had befriended on the island – would take the traps down.

Bagnis said to Filous at the time: “Well, you have done what we asked you to do. Now it’s my turn to negotiate with those people and hopefully find a solution.” To which Filous replied, “They’re going to kill me if you say that.”

“He was really freaking out,” recalls Bagnis. “Because it was like asking those people to lose a bigger part of their income.”

Bagnis asked Filous to create a poster to help people understand the life cycle of the fish and to explain the problems with current fishing practices.

Enter eccentric, singing school principal Jean Pierre Beaury, an enthusiastic student of the island’s historical songs and traditions, and passionate advocate for the children’s future. When Filous sought his help to translate the poster into the local languages

(French and Tuamotu), Beaury recognised how important it was to address the issue. He had applied to the French government to create an educational marine area where the students could learn about environmental management and conservation – and he saw the migration corridor as the perfect location.

The students also understood the importance of conserving the fish, saying “this is our island too, this is our future”, says Bagnis. The students decided to explain to their community what was at stake, and went door-knocking to gather signatures for a petition to reinstate an ancient Eastern Polynesian tradition – *rahūi* – which would pull down the traps for three months each year.

“It’s like a gentlemen’s agreement,” says Hagnis. “We are respecting this area and we are all agreeing that during three months there will be no traps.”

Although it can’t be legally enforced, she adds,

“In the ancient time, if you were not respecting it, they were cutting off your head. So they were very serious about that, because the *rahūi* is meant to preserve the resource

“We don’t expect to have *rahūi* and then for all the fish to fall from the sky”

for the whole population.”

Filous was so worried when the children went out to gather signatures that he wedged a bed against his door. But of the 300 people the students spoke to, 297 signed the petition to pull down the public traps, with fishermen who sold their catch accepting compensation from the Island Initiative for lost income, using profits from the newly established fly-fishing enterprise.

In 2019, the traps came down for the first time, in tandem with the reinstatement of a *marae* – a temple made from rocks – by the children in the area, accompanied by a traditional ceremony and music.

The *rahūi*’s success will be monitored over the next five years by the islanders, with Filous visiting each year.

“We don’t expect to have *rahūi* and then for all the fish to fall from the sky,” he says. But they expect the fish born now will grow, and 50 centimetre fish will be bigger, so the SPR ratio should increase.

“So, the past and the future met, the science and the traditional too, so it was quite amazing to get it that way,” says Bagnis. “I was very proud because it really embodied the meaning of what we were trying to create with our organisation, you know. It started out with a Tahitian girl knowing some issues and willing to do something and now it’s not about a Tahitian girl anymore.

“It’s really about the island taking over and proposing a way to manage their resources.”

NATALIE PARLETTA is a freelance science writer based in South Australia.



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BORN IN CHINA, TAUGHT BY AI

In recent years, China has rushed to pursue “intelligent education”. Now, it’s exporting it to the rest of the world. But do we know what we’re buying into? KAREN HAO reports.

ZHOU YI WAS TERRIBLE at math – he risked never getting into college. Then a company called Squirrel AI came to his middle school in Hangzhou, China, promising personalised tutoring. He had tried tutoring services before, but this one was different: instead of a human teacher, an AI algorithm would curate his lessons. The 13-year-old decided to give it a try. By the end of the semester, his test scores had risen from 50% to 62.5%. Two years later, he scored an 85% on his final middle school exam. “I used to think math was terrifying,” he says. “But through tutoring, I realised it really isn’t that hard. It helped me take the first step down a different path.”

Experts agree AI will be important in 21st century education, but how? While academics have puzzled over best practices, China hasn’t waited around. In the last few years, the country’s investment in AI-enabled teaching and learning has exploded. Tech

giants, start-ups, and education incumbents have all jumped in. Tens of millions of students now use some form of AI to learn, whether through extracurricular tutoring programs like Squirrel’s, through digital learning platforms like 17ZuoYe, or even in their main classrooms. It’s the world’s biggest experiment on AI in education, and no one can predict the outcome.

Silicon Valley is also keenly interested. In a report in March, the Chan Zuckerberg Initiative and the Bill and Melinda Gates Foundation identified AI as an educational tool worthy of investment. In his 2018 book *Rewiring Education*, John Couch, Apple’s vice president of education, lauded Squirrel AI. (A Chinese version of the book is co-authored by Squirrel’s founder, Derek Li.) Squirrel also opened a joint research lab with Carnegie Mellon University last year to study personalised learning at scale, and then export it globally.

But experts worry about the direction this rush to AI in education is taking. At best, they say, AI can help teachers foster their students' interests and strengths. At worst, it could further entrench a global trend toward standardised learning and testing, leaving the next generation ill-prepared to adapt in a rapidly changing world of work.

As one of the largest AI education companies in China, Squirrel highlights this tension. And as one of the best poised to spread overseas, it offers a window into how China's experiments could shape the rest of the world.

The learning centre that Zhou attends, one of the first that Squirrel opened, occupies the second floor of an unassuming building on a busy commercial road in Hangzhou, a second-tier city in Zhejiang province. Company awards line the walls in the stairwell. Further in, large photographs of at least a dozen men are on display: half of them are Squirrel AI's executives and the others are master teachers, a title bestowed on the best teachers in China, who help develop the company's curriculum.

The school's interior decorations are modest. The foyer is small and colourful, with lime green accents. Photos of smiling students hang along the corridor between six or so classrooms. Inside, faded decals of trees and simple mottos like "Be humble" enliven the walls. There are no whiteboards, projectors, or other equipment, just one table per room, meant for six to eight people.

The vehicle of instruction is the laptop. Students and teachers alike stare intently at screens. In one room, two students wear headsets, engrossed in an English tutoring session. In another, three students, including Zhou, take three separate math classes. They work out practice problems on pieces of paper before submitting their answers online. In each room, a teacher monitors the students through a real time dashboard.

At different points, both teachers notice something on their screen that prompts them to walk over and kneel by a student's chair. They speak in hushed tones, presumably to answer a question the tutoring system can't resolve. Though I'm just feet away, I can't distinguish their words above the soft hum of traffic on the street below.

"It's so quiet," I whisper to the small gang of school and company staff assembled for my tour. The Hangzhou regional director smiles with what I interpret as a hint of pride: "There are no sounds of teachers lecturing."

Three things have fuelled China's AI education boom. The first is tax breaks and other incentives for AI ventures that improve anything from student learning to teacher training to school management. This makes them good bets for venture capitalists. According to one estimate, China led the way in over \$US1 billion invested globally last year in AI education.

Second, academic competition in China is fierce. Ten million students a year take the college entrance exam, the *gaokao*. Your score determines whether and where you can study for a degree, and it's seen as the biggest determinant of success for the rest of your life. Parents willingly pay for tutoring or anything else that helps their children get ahead.

Finally, Chinese entrepreneurs have masses of data at their disposal to train and refine their algorithms. The population is vast, people's views on data privacy are much more lax than in the West, and parents are big believers in the potential of technology, having seen how much it has transformed the country in just a few decades.

Squirrel focuses on helping students score better on annual standardised tests, which taps straight into national *gaokao* anxiety; more than 80% of its students return

year after year, it says. It also designed its system to capture ever more data from the beginning, which has made possible all kinds of personalisation and prediction experiments. It heavily markets its technical capabilities through academic publications, international collaborations, and awards, which has made it a darling of the Shanghai local government.

The strategy has fuelled mind-boggling growth. In the five years since it was founded, the company has opened 2000 learning centres in 200 cities and registered over a million students. It plans to expand to 2000 more centres domestically within a year. To date, the company has also raised over \$180 million in funding. At the end of 2018, it gained unicorn status, surpassing \$US1 billion in valuation.

Squirrel isn't the first company to pursue the concept of an AI tutor. The earliest efforts to "replicate" teachers date back to the 1970s, when computers first started being used in education. Then, between 1982 and 1984, several studies in the US showed that students who received one-on-one human tutoring performed far better than students who didn't.

This set off a new wave of efforts to re-create that kind of individual attention in a machine. The result

"It's so quiet," I whisper to the staff assembled for my tour. The Hangzhou regional director smiles. "There are no sounds of teachers lecturing."

Derek Li's education tech company, Squirrel AI, is valued at \$US1 billion. "When AI education prevails," he says, "human teachers will be like a pilot."



was adaptive learning systems, which can now be found everywhere from kindergartens to workplace training centres.

Squirrel's innovation is in its granularity and scale. For every course it offers, its engineering team works with a group of master teachers to subdivide the subject into the smallest possible conceptual pieces. Middle school math, for example, is broken into over 10,000 atomic elements, or "knowledge points", such as rational numbers, the properties of a triangle, and the Pythagorean theorem. The goal is to diagnose a student's gaps in understanding as precisely as possible.

By comparison, a textbook might divide the same subject into 3000 points; ALEKS, an adaptive learning platform developed by US based McGraw Hill, which inspired Squirrel's, divides it into roughly 1000. Once the knowledge points are set, they are paired with video lectures, notes, worked examples, and practice problems. Their relationships, how they build on each other and overlap, are encoded in a "knowledge graph", also based on the master teachers' experience.

A STUDENT BEGINS A COURSE of study with a short diagnostic test to assess how well she understands key concepts. If she correctly answers an early question, the system will assume she knows related concepts and skip ahead. Within 10 questions, the system has a rough sketch of what she needs to work on, and uses it to build a curriculum. As she studies, the system updates its model of her understanding and adjusts the curriculum accordingly. As more students use the system, it spots previously unrealised connections between concepts. The machine learning algorithms then update the relationships in the knowledge graph to take these

new connections into account. While ALEKS does some of this as well, Squirrel claims that ALEKS's machine learning optimisations are more limited, making it, in theory, less effective.

The students I speak to at the learning centre have high praise for the tutoring program. All are finishing middle school and have been coming to the centre for more than a year. One girl, Fu Weiye, tells me she's improved far faster than when she got individual tutoring from a human teacher. "Here, I have a teacher both on and offline," she says. "Plus, the instruction is very targeted; the system can directly identify the gaps in my understanding." Another student echoes the sentiment: "With the system, you don't have to do tonnes of exercises, but it's still effective. It really saves time."

While I have to take their words with a grain of salt – the students are hand-picked and give their testimonials under intense supervision – I'm still touched by their relief that they've found a formula that works to ameliorate the often brutal academic environment. Zhou Yi's story, perhaps not coincidentally, also neatly illustrates how Squirrel can help struggling students.

For Squirrel's founder Li, this vision doesn't stop at tutoring. He has ambitions to break out of the confines of after-school programming and integrate his curriculum directly into the main classroom. Squirrel is already in discussion with several schools in China to make its system the primary method of instruction.

I try to imagine what this world might be like, and whether we might be better off for it. I ask the students one last question: Is there anything that Squirrel could improve? A long pause. "I wish we had more interaction with our human teachers," Fu says.

Every educational expert I spoke to for this story began by making the same point: to understand how AI could improve teaching and learning, you need to think about how it is reshaping the nature of work. As machines become better at rote tasks, humans will need to focus on the skills that remain unique to them: creativity, collaboration, communication, and problem solving. They will also need to adapt quickly as more and more skills fall prey to automation. This means the 21st century classroom should bring out the strengths and interests of each person, rather than impart a canonical set of knowledge more suited for the industrial age.

AI, in theory, could make this easier. It could take over certain rote tasks in the classroom, freeing teachers up to pay more attention to each student.

Squirrel's approach may yield great results on traditional education, but it doesn't prepare students to be flexible in a changing world, the experts I spoke to say. "There's a difference between adaptive

learning and personalised learning,” says Chris Dede, a professor at Harvard University in the Technology, Innovation, and Education Program. Squirrel is doing adaptive learning, which is about “understanding exactly what students know and don’t know”. But it pays no attention to what they want to know or how they learn best. Personalised learning takes their interests and needs into account to “orchestrate the motivation and time for each student so they are able to make progress”.

Jutta Treviranus, a professor at the Ontario College of Art and Design University who pioneered personalised learning to improve inclusivity in education, breaks it down further. “Personalised learning has a number of levels,” she says: she calls them pace, path, and destination.

If the pace of learning is personalised, students with different abilities are allowed different amounts of time to learn the same material. If the path is personalised, students might be given different motivations to reach the same objectives (“Here’s why statistics is relevant to your love of baseball”) and offered the material in different formats (e.g., video versus text). If the destination is personalised, students can choose, for instance, whether to learn with a vocational school or a university in mind.

“We need students to understand their own learning. We need them to determine what they want to learn, and we need them to learn to learn,” Treviranus says. “Squirrel AI doesn’t address those things at all. It only makes it more efficient to bring all of the students to the same standardised place.”

LI, SQUIRREL’S FOUNDER, is tall and lanky and has severe cheekbones. When he speaks English, he punctuates every few sentences with “Right?” – eyebrows raised – to make sure you’re on the same page. When he speaks Mandarin, his words tumble out twice as fast.

A week after my visit to the learning centre, I meet him at Squirrel’s headquarters in Shanghai. In the style of an understated showman, he gives me the grand tour. The modesty of the learning centre stands in sharp contrast to the office décor here: each wall boasts of different details about the company and milestones it has reached. Here’s one with all its media mentions. Here’s another with all its awards. And here are some examples of students who were deemed “hopeless” and then saved. I run into another tour before I’ve finished my own.

A few steps past the first door, Li points out a screen to my immediate left playing a TV clip on repeat. It’s a game show featuring a showdown between Squirrel’s tutoring system and a human teacher – one of the best in China, he says. Three of the teacher’s students, whom he has taught for three years, stand alongside him on stage solving problems.

The system and the teacher compete to predict which ones they will get right.

Li doesn’t wait for the clip to end to reveal the punchline: “In three hours we understand students more than the three years spent by the best teachers.” On screen, the teacher looks increasingly crestfallen and humiliated. “He looks so sad,” I say. “You noticed!” Li laughs.

Much of Squirrel’s philosophy stems from Li’s own experiences as a child. When he was young, he didn’t have very good emotional intelligence, he says, and reading books on the subject didn’t help. So he spent half a year dividing the skill into 27 different components and trained himself on each one.

He trained himself to be more observant, for example, and to be an interesting conversationalist (“I spent a lot of time finding 100 topics, so I have a lot of material to talk with others,” he says). He even trained himself to keep smiling when others criticised him. (“After that, in my life, I do not have any enemies.”) The method gave him the results he wanted – along with the firm belief that anything can be taught this way.

Li uses an analogy to lay out his ultimate vision. “When AI education prevails,” he says, “human teachers will be like a pilot.” They will monitor the readouts while the algorithm flies the plane, and for the most part they will play a passive role. But every so often, when there’s an alert and a passenger panics (say, a student gets bullied), they can step in to calm things down. “Human teachers will focus on emotional communication,” he says.

Squirrel is already exporting its technology abroad. It has cultivated its international reputation by appearing at some of the largest AI conferences around the world and bringing on reputable collaborators affiliated with MIT, Harvard, and other research institutes. Li has also recruited several Americans to serve on his executive team, with the intent of pushing into the US and Europe in the next two years. One of them is Tom Mitchell, professor of computer science at Carnegie Mellon; another is Dan Bindman, who led the user experience and editorial teams at ALEKS.

Treviranus worries that Squirrel’s educational philosophy is representative of a broader flaw in China’s pursuit of intelligent education: its emphasis on standardised learning and testing. “The tragedy of the China experiments is that they’re taking the country to a point of education that any progressive pedagogue or education system is moving away from,” she says.

But she believes that China also has one of the best opportunities to reinvent a more teacher-friendly, learner-focused classroom environment. It is less entrenched than the West in older models of education and much more willing to try new ideas.

“China needs to look at a completely different form of AI,” she says. The question is: What does that mean?

The answer may lie a dozen miles west of Squirrel’s headquarters, across Shanghai’s Huangpu River. There, Pan Pengkai, a children’s educational expert, is conducting experiments of a different nature.

Pan has been thinking about how to use AI in education for nearly two decades. Fifteen years ago, he founded his first ed tech company in China after getting his PhD from the MIT Media Lab. Inspired by his experience in grad school, he focused on building tools for learning English. “Innovation comes from difference,” he says. “That’s exactly what China lacks. If you are able to speak multiple languages, you are able to talk to different people; you are able to communicate different ideas.”

Pan now runs Alo7, a K–12 ed tech company with the same mission of teaching English. Unlike many other firms, it seeks to move away from test-oriented learning and instead foster creativity, leadership, and other soft skills. The company offers products and services for both physical and digital classrooms. It has an online learning platform paired with a collection of textbooks that help students learn and practise their language skills.

It also has a service that connects up to three pupils via video with English tutors abroad for regular group lessons. To date, it has served some 15 million students and teachers and partnered with 1500 institutions nationally.

Pan’s ultimate vision for AI in education is to get rid of standardised tests entirely. “Why do we test people for two or three hours to determine if they are good or bad?” he asks. He thinks AI will eventually create flexible learning environments that are as good for sensitive and creative students as for precise and analytical ones.

In 2018, Alo7 began to experiment more. It added face and voice analysis to its video tutoring sessions to produce summary reports of each lesson. Algorithms measure the amount of time the students spoke English in class, the accuracy of their English pronunciation, and basic indicators of their engagement and joy, such as the number of times they opened their mouth to speak and laugh.

Last year, the company created several physical classrooms equipped with cameras and microphones to produce similar analyses. Teachers get reports on their own performance, too.

I go see one of Alo7’s intelligent classrooms for myself. It’s small but bursting with colour. The walls are illustrated with the company’s mascots, five cartoon companions with distinct personalities, which appear throughout the company’s educational materials. There are neither tables nor chairs, just a bench that runs along the back wall. At the front are a whiteboard and two TVs for displaying the day’s curriculum.

There are no classes in session, but a company employee plays me some short clips of elementary school classes. In one, six students sit on a bench and practise saying the names of different animals. “Bird, bird, bird!” they chant with their teacher as she flaps her arms like wings. “Turtle, turtle, turtle!” they continue as the screen changes its display to a cartoon turtle. The teacher-student interactions take the fore ground; the AI purposely fades, unnoticed, into the back.

Dede says the kind of data generated in an intelligent classroom could be useful, but he cautions that cameras and other sensors could also be misused to judge a student’s emotions or state of mind, applications that have little grounding in science

and could lead to over-surveillance. Pan agrees that it’s important to be careful: “That’s why we provide the data mainly for teachers and not students, because we haven’t yet run scientific tests.” He has begun to see a shift in the national conversation. As government leaders have sought new ways to stimulate innovation,

the idea of a “quality-oriented education” – one that emphasises creativity and the liberal arts – has gained momentum.

In 2018, China’s education ministry passed a series of reforms, including stricter licensing for tutors, aimed at reducing the obsession with testing. Last year, the government also unveiled a set of guidelines to focus more on physical, moral, and artistic education, and less on exams. Though critics point out it still hasn’t eliminated the *gaokao*, Pan is optimistic about its intent to change.

“We want to change the future of Chinese education with technology,” he says. China’s current mass experiment in AI education, and the choices it must make, might also change education for the world. ☺

Karen Hao is the artificial-intelligence reporter for *MIT Technology Review*. This story appeared in its Jan/Feb 2020 edition.

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COLOUR OF LIFE

The word “green” describes a vast range of hues, and as **ASHLEY HAY** explains on page 96, its mysteries run deep within language and nature.

Ode to green

Stifle envy, set aside jealousy and rise for a moment above greed. For right now, when we need it so badly, green most definitely means grow. By Ashley Hay.

AFTER A SUMMER of heat, drought and devastating fires, it's a poignant time to think about green – the colour most often associated with life, with nature, with renewal. Green stands for jealousy – Othello's "green-eyed monster" – and for envy and for greed. But green for growth, and green for go now, too.

This hasn't always been the case. The first standard lights chosen by railways in the 1830s used red for stop – picking up on its long associations with danger – but white for go. Green, originally, was chosen to signify caution. Problems occurred if the coloured lenses fell out of any of the warning lights, leaving the white light source exposed... and giving an apparent signal to proceed. Problems occurred, too, if bright white signals were mistaken for stars – or stars themselves were mistaken for those early "go" lights. And so the system was recast.

THROUGH THE WINDOW above my desk, I can see dozens of greens. There are seven or eight different tints on the closest stem alone: different colours for different stages of growth. So many tones scooped in by this one word, the vastness of hues and tints and tones contained in it.

Our eyes can discern more greens and more reds than any other chromas – we "prioritise" distinction of these colours. One explanation for this is that it's an evolutionary constraint: the red and the green cones in our eyes "largely overlap", perhaps because the gene that codes for our green receptor and the gene that codes for red were almost identical and haven't yet evolved enough to differentiate.

Another is the evolutionary advantage of being able to gauge the difference in ripening fruit. Humans are trichromatics (organisms with three separate channels for distinguishing colour) who eat a lot of fruit (like other New World monkeys), which makes the importance of choosing which fruit to eat a "plausible selection pressure".

"How many colours are there in a field of grass to the crawling baby unaware of green?" asks the American experimental filmmaker Stan Brakhage. As they crawl through smaragd, through prasine, through chrysopraxe, through viridescence – and that's only imagining their journey in lesser-used English. The Himba, an indigenous tribe of around 50,000 in northern Namibia, have the colour system most distinct from any Euro-American systems: it's divided into language for dark, very light, dry desert colours, and then vivid green and blue, between which last two they make no distinction – they register

a circle with 11 green squares and one blue as a circle with 12 *buru* squares.

CHLOROPHYLL, one of the fundamental ingredients for photosynthesis, is what gives a plant its green. This nourishing process converts light into sustenance for vegetation – it's one of the fundamental mechanisms of life, of growth.

As early as 1704, Isaac Newton suspected a link between light and growth in his *Optiks*, suggesting that “gross Bodies and light [were] convertible into one another”. He meant this in a more alchemical than biological sense: that magical thinking that would give us the power to transform one material into another. But work by researchers in the subsequent years of the 18th century – including Joseph Priestley and Antoine Lavoisier – led to Jean Senebier's 1782 deduction that green plants “breathe in” carbon dioxide from the air and “breathe out” oxygen, all through their interactions with sunlight.

The “basic equation” of photosynthesis, a process by which “a green plant illuminated by sunlight takes in carbon dioxide and water and converts them into organic material and oxygen”, was confirmed by work published by Nicolas de Saussure in 1804.

An alchemy all of its own.

Perhaps one of the most beautifully symbiotic uses of chlorophyll comes from the small green sea slug *Elysia chlorotica* – a marine opisthobranch gastropod known not only “for kidnapping the photosynthesising organelles and some genes from algae” but for retaining these in working order for the slug's year-long lifespan.

In 2010, this slug was found to have “acquired enough stolen goods” to generate the complete “plant chemical-machine pathway work inside an animal body”, according to researchers at the University of South Florida in Tampa. It raised the possibility, in the words of one zoologist, of “branch tips touching” in the tree of life. And in a poetic twist, the slug itself resembles a delicate green leaf – as if it is embodying the plants whose mechanisms it now mimics.

It was also found that “once a young slug has slurped its first chloroplast meal from one of its few favoured species of *Vaucheria*

algae, the slug does not have to eat again for the rest of its life. All it has to do is sunbathe”.

By 2018, populations of this slug in the wild had shrunk to the point where they were becoming “too rare to research”.

But green pigments are surprisingly rare in the animal world. Even among birds, only a handful sport features of a true green – most green feathers arise through a combination of blue structural colouration and yellow carotenoids. One exception is turacoverdin, a unique copper pigment that generates bright green plumage in several birds from the *Musophagidae* family, most notably the turaco. The birds accumulate copper through the fruits, flowers, buds and other plants of their diet. It's not known if turacos have especially copper-rich diets, or are better at extracting copper from their foods.

Some of the greens outside my window come from casuarina, dianella, dietes, *Alpinia caerulea*. Since the rupture of this continent's landscape after 1788, many of these plants have worn names that speak more of the northern hemisphere – she-oaks, lillies, ginger, iris – the linguistic component of what the historian, geographer and biologist Alfred W Crosby has described as the attempted creation here of a “neo-Europe”. The “foreign aspects of Australia's nature and ecology caused many Europeans to react by imposing their own plants and animals in order to ‘improve’ the land,” writes Lucinda Janson in her account of imperial settlement and expansion in early colonial NSW. Theirs was often a “confused and defensive reaction to an ecology and a way of living in a land very different from their own”. To homesick British colonials such as Barron Field, this country's colour



The sacoglossan sea slug *Elysia chlorotica*, above, eats algae and incorporates its ability to photosynthesise; in a different kind of absorption, a turaco, below, displays its copper-toned sheen.

“How many colours are there in a field of grass to the crawling baby unaware of green?”



could be dismissed as “one cold olive”, monotonous and harsh.

It’s hard to think of anything less monotonous than the greens in my front yard, particularly after the relief of much needed rain – including 130 millimetres on a single day. The plants perk up; enriched. It’s an almost instantaneous reaction in this one tiny plot of a continent’s space. It makes me wonder about the different greens of plants that might be absent – or present – across more than 18 million hectares of the rest of the continent that’s burned out in recent weeks. Photographs document tiny bursts of colour in the blackened space – always so sudden; always so relieving – while scientists begin to estimate the number of extinctions that may be under way.

THREE QUARTERS OF AUSTRALIA’S threatened species are plants, often with restricted range; a single fire could spell the end for species’ entire populations.

After previous fire seasons, the first sprouts of new growth – clusters of grass, new shoots on trees – have shimmered like dot points of hope. In the first weeks of 2020, scientists write that with the frequency and ferocity of these last fires, entire ecosystems can be pushed “beyond their limits of resilience”. They write, instead, of ecosystem collapse.

In the 1990s, the Danish-Icelandic artist Olafur Eliasson discovered he could dye rivers a safe but startling and incandescent green using uranin, the disodium salt form of fluorescein. He’s

since performed this artistic intervention a half-dozen times, in rivers in cities throughout Norway, Iceland, Germany and the US – always unannounced. In Los Angeles, “nobody cared, nobody stopped, nobody looked”, he has reported, while in other cities people reacted “with fear and distress”.

All these cataclysmic transformations, these great changes we can wreak. It’s a time the world’s greens should feel so much more rare and precious, whatever names they go by, as chlorophyll continues to transform sunlight into life.

ASHLEY HAY is a novelist and editor of *The Griffith Review*. Her most recent book is *A Hundred Small Lessons*.

Photographs document bursts of colour in this or that blackened space while scientists begin to estimate the number of extinctions that may be underway.

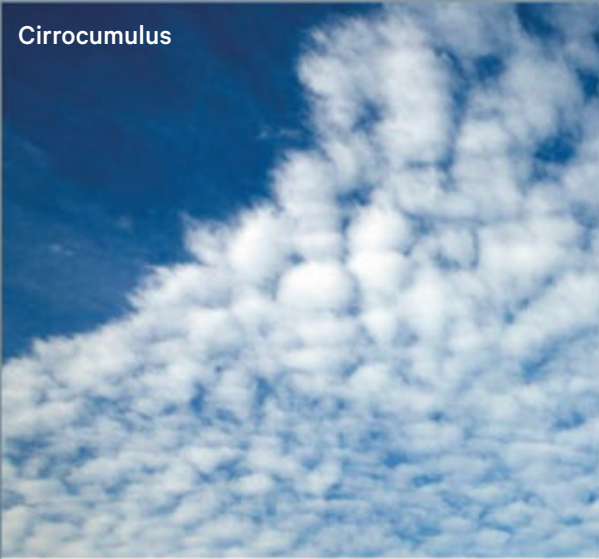
Head in the clouds

You've heard of Cloud Nine – but what about clouds one through 10? Looking to the heavens, weather presenter and meteorologist **Nate Byrne** handcuffs thunder, throws lightning in jail, and even comes up with an entirely new word for “fog”.

WHEN YOU LOOK UP at the sky and spot an interesting cloud, you may see a bunny, a hippo or a cake chasing a lollypop. When meteorologists see a cloud, it's hard for them to do anything other than try to figure out how to classify it.

We all appreciate the importance of classification when it comes to animals – it helps us figure out relationships, relatedness and where creatures fit in the complex ecological web. Classification provides a similar function for clouds, but it can also tell us about what we might expect on the ground – either from that specific cloud, or from a synoptic system that helped to generate it.

Echoing the techniques used by our biologist cousins, meteorologists have organised clouds into genera, species and varieties. Unlike the animal kingdom, though, clouds can move between types, they can grow extra features or lose them, and two different people looking at the exact same cloud from different vantage points can have wildly different ideas about what they are seeing.



Cirrocumulus

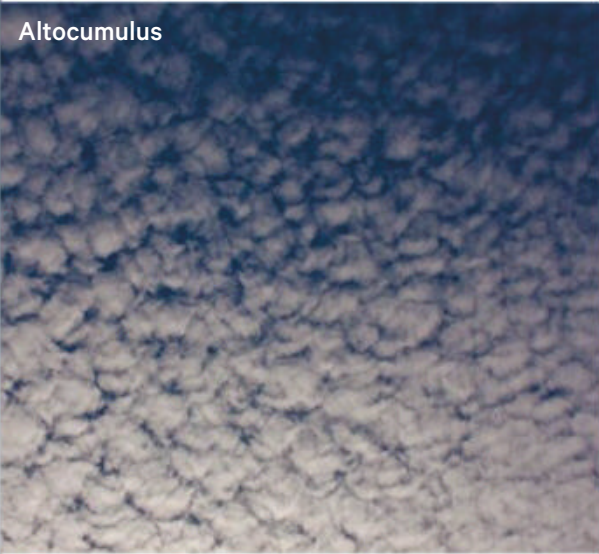


Cirrus



Cirrostratus

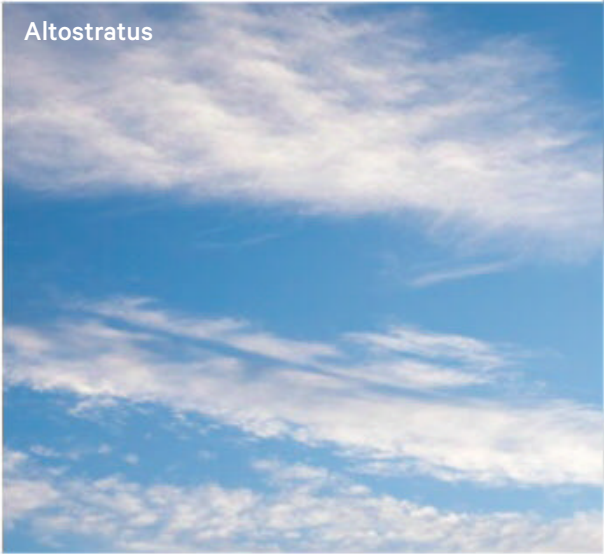
High level (8+ km): Cirro-



Altostratus

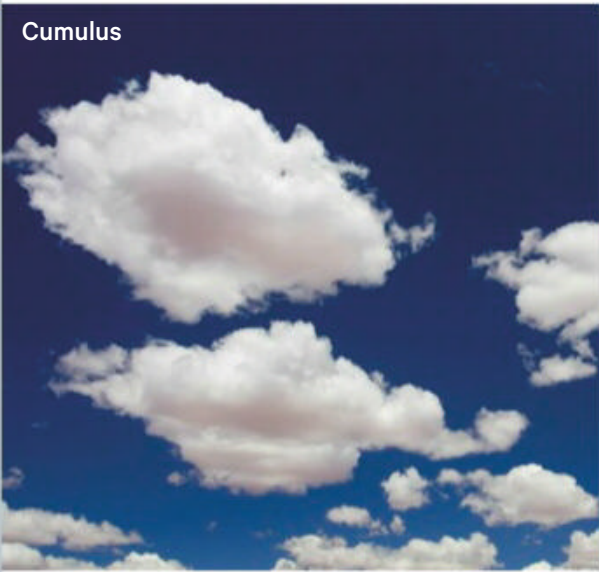
CLOUD ATLAS

The words may sound confusing, but giving a name to your cloud is as easy as knowing its level and its shape. Missing from this classifier are the multi-levelled nimbo- clouds: endless grey nimbostratus (behind) and the majestic thunderstorm cloud cumulonimbus (right).



Altostratus

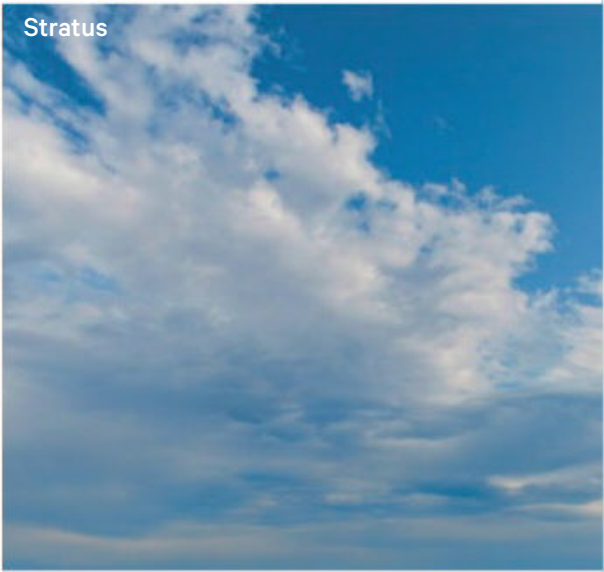
Mid-level (2-8 km): Alto-



Cumulus



Stratocumulus



Stratus

Lower Level (0-2km)

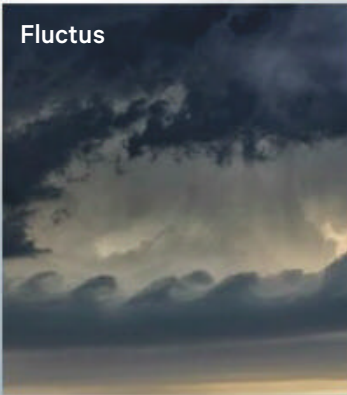
Lumpy (cumulus)

Lumpy & layered

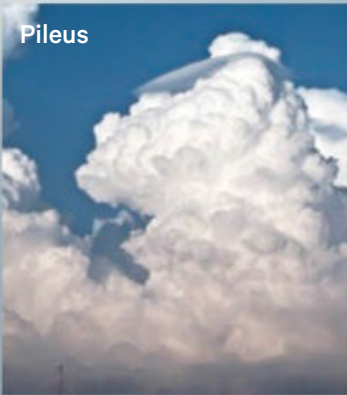
Layered (stratus)



Mamma



Fluctus



Pileus



Homogenitus



Flammagenitus

Nimbostratus

Cumulonimbus

Nate's Fab Five

Choosing a favourite cloud is as hard as picking a favourite child, but here are a few stand outs:

MAMMA

Often called mammatus clouds, these are ominous, pendulous lobes that can be found hanging underneath a cumulonimbus in the right circumstances. They often indicate a severe storm cell.

FLUCTUS

An accessory cloud that gets physicists excited. Curled wave formations called Kelvin-Helmholtz waves are caused when an airmass interacts with another above it that's moving at a different speed or in a different direction. Nothing significant weather-wise, but a rare delight to spot.

PILEUS

When a rising airmass is creating a cloud, it can force a layer of air above it to rise, creating a small stratus above the upwelling cumulus, like a cloud with a whimsical hat.

HOMOGENITUS

Clouds created by human activity, like cumulus forming above a smokestack or cirrus left behind a jet in a contrail (ice particles formed in the wake of the jet by a pressure disturbance).

FLAMMAGENITUS

Clouds formed by the heat rising from a fire. The one you'll hear about most is commonly called pyrocumulonimbus, but its official designation is cumulonimbus flammagenitus. These clouds are incredibly difficult to forecast and can cause widespread havoc with sudden changes of wind direction and lightning.

Everyone has their favourite, and you may already know its name – cumulonimbus or cirrus – but knowing why it's called that can tell you a bit about what caused it, and what it might go on to do. There are a few basic guidelines and several methods of attack when trying to tie your cloud down.

WHAT CLOUD IS THAT?

Clouds are the weather we can see, and they can tell us a lot about what's happening in the atmosphere. Where clouds form, air is (almost always) moving upwards. That's something air doesn't generally like to do – sideways is relatively easy, but up and down are much more difficult, because you're either fighting gravity or trying to push towards an area of higher pressure. When you do get the air to move upwards, though, you bump into the good old combined gas law: $P_1 V_1 / T_1 = P_2 V_2 / T_2$.

Higher in the atmosphere the pressure is lower, so any air that pushes up there expands and the temperature drops. Air holds water vapour, and when you drop the pressure or the temperature, the saturation point also drops. When it's high enough (or cool enough), the air reaches 100% humidity and excess water vapour condenses into water droplets. That's the start of a cloud.

There are two ways you can get air to move upwards – either give it a sharp kick from an external force, or gently sweep it. This informs what kind of cloud you end up with, and that's how I like to start my classification, with the age-old question: Is it lumpy or layered?

LUMPY: When air gets pushed upwards explosively – perhaps by heating it or by forcing it up a mountain range like a skateboarder on a ramp going for some epic air – eddies and currents around the airmass cause the cloud particles to take on structure. It can look lumpy or fluffy like a scoop of ice-cream or cotton wool. It's all kind of piled up, hence their name: cumuliform.

LAYERED: If your cloud is created gently by cooling it down to saturation, or by slowly pushing it up in the atmosphere, it takes on a much more uniform appearance. Those days when clouds look flat and stripy – that's when you're dealing with stratiform clouds.

LUMPY AND LAYERED: Sometimes it's really hard to tell exactly what's going on – you've got something that looks like a layered cloud, but there are some features, or maybe your cumuliform clouds are spreading out and joining; that's when to just mix the two and call it stratocumulus.

Next, think about how high your cloud is. This can be tricky, because the depth of the troposphere (the lower levels of the atmosphere where almost all of the weather happens) changes depending on where you are on the planet. At the poles the atmosphere is significantly smaller than at the equator, largely because warm air takes up more space.

Clouds in the lower regions – from the surface to about two kilometres – are generally made of liquid water, and get the straight names: cumulus and stratus.

Mid-level clouds are a mix of liquid water (often supercooled below 0°C) and ice crystals. These get the prefix “alto” – so altostratus and altocumulus.

In the high levels, it's all ice, which makes for a much more wispy appearance. To our meteorological forebears these clouds looked like mares' tails, which may explain their Latin hair-curl-inspired name “cirrus”. They are often difficult to clearly define, so cirrus is a cloud in its own right, along with cirrostratus and cirrocumulus.

Sometimes clouds extend through several layers – “nimbus”. Nimbostratus is a wall of featureless cloud that heralds a very wet day, while cumulonimbus is the cloud most people tell me they love – a thunderstorm.

Put all that together and we've got the 10 genera that all clouds fit into. But there's a whole range of other features that can give the species in the classification. Is it towering, are there waves or lobes? If you want to explore the cornucopia, the World Meteorological Organisation's International Cloud Atlas is your one-stop-shop.

Now that you can name your nearest cloud, I hope you're wondering: What can it actually do?

RAIN DANCES

When it comes to rain, size matters. While a fairly small cloud can hold large amounts of water, a good, average-sized small cumulus can easily yield a volume in the cubic kilometre range. The liquid water density of a fair-weather cumulus (a fluffy white cottonball that won't rain) is around 0.5 grams per cubic metre (g/m^3), and that represents roughly 500 tonnes of water in the air. In a cumulonimbus, the density can be as much as six times that, with the cells reaching potentially 20 kilometres into the atmosphere with a footprint many kilometres across. The amount of water these clouds hold can be incredible – one of 20km^3 could hold 9600 Olympic swimming pools of water.

Tiny cloud droplets have a fair distribution, measuring anywhere from one to 100 microns in size, and are easily kept aloft like motes of dust. In fact, every raindrop starts as a mote of dust, or a grain of salt, a particle of pollution, a bacterium, a fungal spore or some other similarly sized particle in the atmosphere. Water doesn't like to condense out of clean air; it prefers a surface of some sort, which is why you can have misty windows in a clear car.

The droplets bump into each other on air currents, combining as they collide. Like a steamy bathroom mirror, they remain suspended until they get large enough that gravity forces them downwards, 100 to 1000 times larger than when they formed.

Once a drop leaves the cloud, it finds itself surrounded by air with relative humidity less than 100%, so it starts to evaporate. If you've ever noticed a raincloud with a shaggy underside, you're seeing a cloud that has formed as the rain

raises the humidity of the air below its parent cloud. If the rain evaporates before it hits the ground, it leaves visible streaks that slowly vanish called "virga".

Cumulus clouds tend to cause showers – on-again-off-again rain that reflects the cellular nature of the clouds, but with heavy raindrops because of the strength of the updrafts that create them. Stratus clouds' individual drops are usually smaller, since there aren't turbulent winds to make them collide, but they usually cause steady falls that last a long time, which can result in large totals on the ground.

Inside a cumulonimbus cell, huge updrafts keep the drops in the air for a long time, allowing them to grow very large, often taking them above freezing altitude to create hail. (This is a different process to the formation of snow, which is usually driven by water vapour attaching to pre-existing ice crystals, growing until they are too heavy to be kept aloft.)

When these large raindrops finally fall and start to evaporate, they cool the air around them – much like sweat cools you when a breeze is applied – and this can have dangerous implications. If the air is cooled sufficiently it can become much less buoyant than its surroundings and crash rapidly to earth, causing microbursts with erratic winds blowing hundreds of kilometres an hour.

CLOUD. ON. GROUND

On a foggy morning, when you step out the front door, you are walking into a cloud. Fog is just cloud on the ground (which makes me want to rename it "cog" – if there's a petition, let me know). To create "cog", the ingredients need to be just right.

First of all, you want the air to have some moisture – the more the better, because it will take less effort to get it to saturation. Next, you want the air to cool down. A clear, cloudless night is usually the easiest way (surface-level high-pressure systems are best for this, because they help push air downwards, clearing out any clouds). Lastly, you want the faintest of breezes (more on that in a moment). From there it's fairly straightforward – cool the air near the ground to saturation, cloud droplets form. Voila, fog.

But there's a problem. The atmosphere heats and cools from the bottom up, and liquid water in the air acts as a great insulator. Air is fairly translucent to much of the sun's radiation (certainly the wavelengths that provide the bulk of the heating), which is good for those of us who want to see. This means that heating in the atmosphere primarily works by sunlight getting absorbed by the Earth's surface, then slowly passed to the air immediately above it. Air has a lot of thermal inertia (and water has even more), so it too cools slowly,

and also from the bottom when the surface is no longer heated by the Sun's rays.

With all this in mind, when fog first starts to form right next to the ground, it creates a really good insulation layer, preventing the air above it from losing its heat as efficiently and cooling to saturation. If there's a small breeze, mixing can loft the fog layer and replace it with the air from above, allowing that to cool and form fog, which grows up from the ground.

Usually.

If you're up a mountain, fog can happen just because a normal cloud bumps into you. It still counts as fog, even though the process for making it is entirely different (seriously, it should be "cog"). Fog can also be blown around – or advected – from place to place, so you can still end up with a fog even if the conditions aren't quite right.

SOUND & LIGHT SHOW

Only cumulonimbus can make thunder and lightning, because the phenomenon requires specific processes that only occur in the explosive updrafts associated with the cloud. (Exploding volcanoes can also create lightning, but that's one for the vulcanologists to explain.)

Lightning is a wildly scaled-up static shock such as you might get after rubbing your shoes on carpet. That's dealing with puny charges in the order of 20,000 volts, whereas lightning can deal out a potential one billion volts per bolt. Electrons are stripped from their molecules by some sort of collision, and when you have great updrafts keeping things in the air for a long time, collisions are a given – particularly in the middle levels of the cloud where you can have a mix of supercooled water, ice crystals

and hail. Typically, lighter raindrops and small ice particles are lifted upwards and encounter heavier, falling hail. That's where things get a little hazy (forgive the forecaster's pun), as meteorologists aren't yet entirely convinced on a single method by which those charges form and gather. But the result is well known: charge separation across the cloud, with a positive charge at the top and negative at the bottom.

That negative charge in the underside of the cloud also induces a positive charge on the ground, and that's when the fun starts. Air is a great insulator, and it takes a lot of charge build-up to overcome the resistance. Once the charge is large enough, a catastrophic discharge of electrons occurs to try to equalise the charge differential (because nature doesn't only abhor a vacuum, but also a sufficiently strong gradient), with a massive current heating the air into plasma as it passes through.

The charge equalisation can happen either between the top and the bottom of clouds (cloud-to-cloud or intra-cloud strike), the bottom of the cloud and the Earth's surface (cloud-to-ground strike), and occasionally between the positively charged cloud-top and a distant negatively charged area of ground (also cloud-to-ground, but called positive lightning – the amount of charge needed to overcome the air's resistance is so huge that these bolts are particularly dangerous and can travel many kilometres away from a storm cell).

Thunder is a side effect of the heat of the energy ripping through the air. The air expansion along the bolt's path is so fast that it breaks the sound barrier: thunder. When the electricity is turned off, the air cools rapidly, causing more reverberations. Bounce that sound around a bit, plus allow for the several strikes that actually make up one complete bolt of lightning, and you end up with a roll of thunder.

There's also a wide array of lightning we don't get to see from the ground but which has been observed by pilots and people in orbit. They have some great names – sprites, blue jets and tortured ELVES (Emission of Light and Very Low Frequency perturbations due to Electromagnetic Pulse Sources) among them – but little is known of these phenomena.

Some wish for clouds to go away, many of us wish for more – but either way, it's hard to deny that these enormous, heavy and complicated structures are fascinating, despite often passing overhead completely unnoticed. And after all of that, we've barely scratched the surface, which if you were ever to try to do, would show even more cloud underneath. It's kind of the nature of the beast. ☺

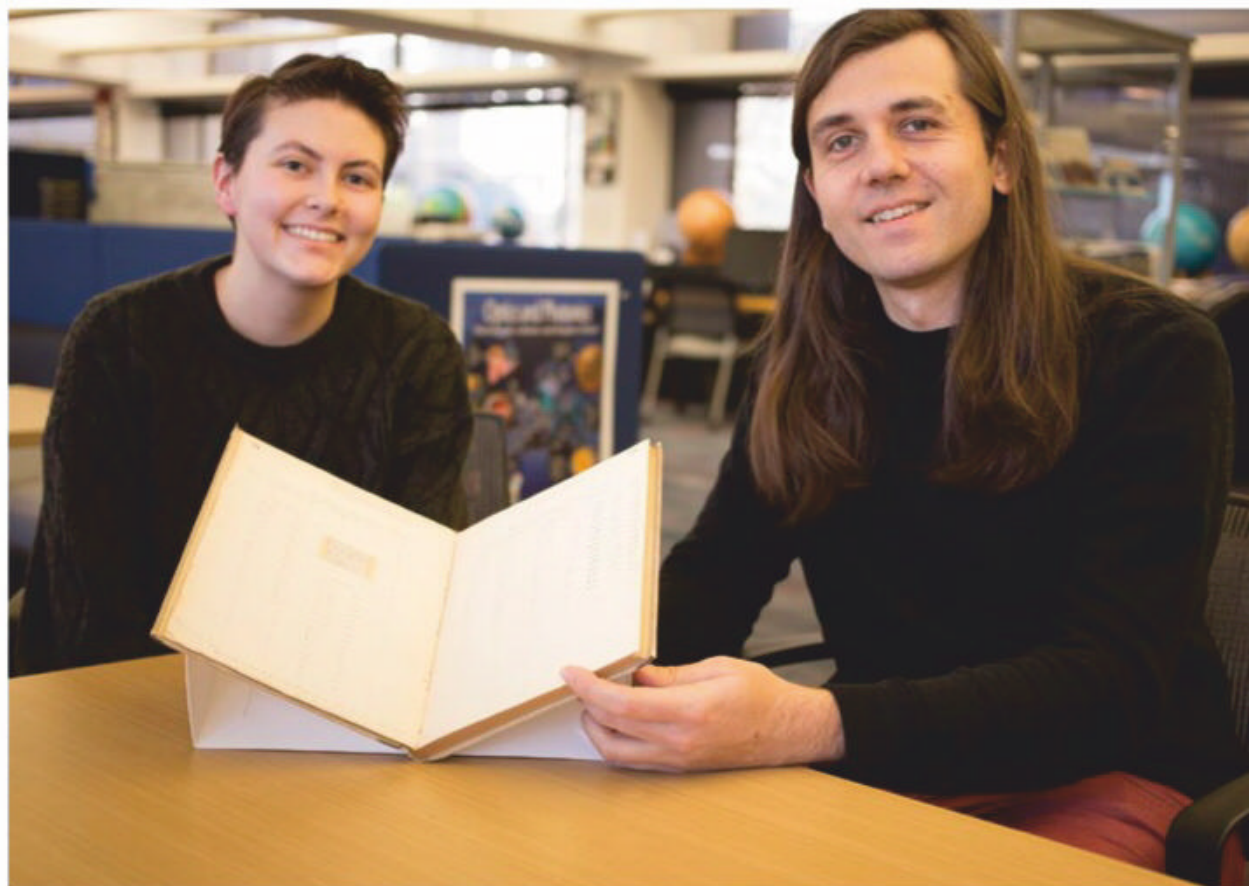
NATE BYRNE is a meteorologist, oceanographer, ABC presenter and all-round science nerd.





The glass universe noted

Join a global effort to match Harvard computers' observations to the collection of glass-plate photographs of the northern hemisphere night skies.



Harvard's librarian for collaborative programs, Nico Carver (above, at right) and assistant community coordinator Sam Correia hope to identify the mainly anonymous women who logged the heavens in a rediscovered collection of notebooks. The books – part of the Astrographic catalogue – hold records of star exposures like the plate (opposite) of the Small Magellanic Cloud.

INSIDE A BUILDING as, old and vast as the Harvard-Smithsonian Center for Astrophysics (CfA), you can only imagine the volume of research hidden away in boxes.

A marriage of the 1839 Harvard College and 1890 Smithsonian Astrophysical observatories, at Harvard University, the centre is home to a collection of around 500,000 astronomical glass-plate photographs. Taken over the century between the 1880s and 1989, the plates are accompanied by hundreds of thousands of hand-written observations by women who became the project's Computers.

When Nico Carver and colleagues from the CfA came across those observations in 2653 notebooks, they set to work digitising the pages and slides.

"So, we found these notebooks – they were actually a re-discovery, because they'd initially been catalogued," Carver admits. The notebooks extend all the way back to very early sketches of Jupiter and observations done with Harvard's renowned Great Refractor telescope – the largest in North America between 1847 and 1867.

Now, faced with the task of matching the observations to one of the 500,000 glass slides, Carver and his team knew they'd need help, and a lot of it.

"The notebooks extend back to very early sketches of Jupiter and observations done with Harvard's Great Refractor telescope"

"We realised very early on that we would need citizen science efforts to do this, because it's an incredible amount of material," he says. "It's hundreds of thousands of pages related to 500,000 glass plate photographs.

"I think if I was just doing it eight hours a day, it would take me a lifetime to get through it!"

Thus, the citizen science project Star Notes was born. The goal is to link the notebooks to their original glass-plate photograph through the unique plate number.

"This project is a little more fun than just straight transcription, where you just have to write down literally everything," Carver says. "People need to do a little hunting on the page, try to find the plate

number and then once you find it, it's easy to type it out and move onto the next page."

All you need to do to participate is go online, choose an astronomer and get hunting (see Getting started on Star Notes, page 107).

The project is important in preserving the work of early 20th century Harvard Computers, many of whom made great strides in both astronomy and gender equality.

Towards the end of the 19th century, the Harvard College Observatory brought dozens of women on board to process astronomical data, paying them much less than their male counterparts. Like the "hidden women" of Australian astronomy (see page 34), their work often involved measuring the brightness, position and colour of stars. Then, they would classify the stars by comparing the photographs to known catalogues.

The Harvard Computers' work led to many discoveries, including the Horsehead Nebula, as well as the creation of the Harvard Classification Scheme, which is still used by astronomers today. While their work might be known, those who carried it out aren't.

"A major impetus of Star Notes is to better recognise the work of the women... at

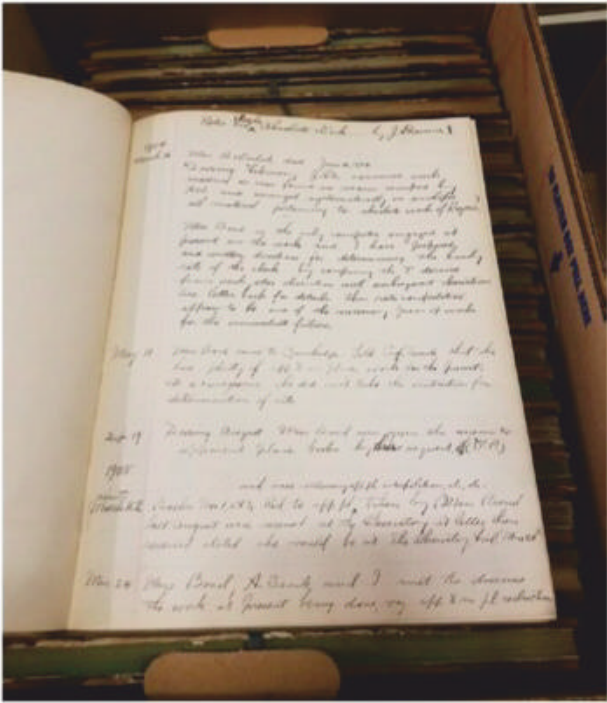
the Harvard College Observatory by identifying the glass plates they worked on and transcribing their research notes,” explains Carver.

“What we really need is to know which pages have plate numbers so that we know who worked on which glass plate. That also allows us to tie the actual notes that they took to the glass plates. Right now, that information isn’t available.

“We also don’t know the history or even names of many of the Harvard Computers, as many are currently only identified by initials. We also hope this effort may help us discover who these women were and assist researchers in telling their stories.”

The Star Notes project also hopes to further understanding of how the Universe looked a century ago, so that we can learn more about how the study of astronomy has developed.

“By studying the notebooks, we can understand how they did this science at the time,” says Carver. “It’s really fascinating



“The observations could impact our understanding of the Universe and its evolution”

Many of the logbooks’ recordings remain anonymous; Carver hopes the project will discover more about the women who contributed.

because it required really excellent eyesight – because you’re looking at stars that are really, really small on the glass plate photographs.

“They were making measurements based on these physical gauges they had called ‘flyswatters’ to try and understand and classify the stars. It’s very different from what we can do today with computers.”

In the long run, the researchers hope the results of this project, combined with others, will not only recognise the Harvard Computers for their work, but will give researchers a rare opportunity to investigate change.

“The digitised glass plates combined with the transcribed historical observations could impact our understanding of the Universe and its evolution,” says Carver.

AMELIA NICHELE



UPDATE

BUTTERFLIES AUSTRALIA

PROJECT MANAGER Chris Sanderson reports that the Butterflies Australia app has been installed more than 3200 times since its October 2019 launch, and that more than 800 verified records have already been captured.

Sanderson took time out from the project’s Hobart workshop in February for a spot of butterfly hunting with *Cosmos* in the Royal Tasmanian Botanical Gardens. He demonstrated how easy it is to use the app (right) – adding an observation of a meadow argus (*Junonia villida*) for good measure – and waxed lyrical about the project’s impact.

“Initially the most valuable thing we’re going to get is a record of where things occur,” he says. “We’ll be able to use real data to drive our range maps, which is really exciting. But for me that’s sort of the quick and easy win. The next step is getting more time-based information – what times of year things are emerging, and is that

GETTING STARTED ON STAR NOTES

Visit the Star Notes page on the Zooniverse website, preferably on a computer (it's difficult to navigate the project pages on a smartphone). Click on "Classify". A short tutorial will take you through all the tools in Zooniverse that will help you with your plate identification.

Then, all you need to do is get hunting for the plate number on the page. Plate numbers start with one or two letters followed by a string of numbers. Once you've found a plate number click "Yes" and draw a box around it. After that, transcribe the number, and move on to your next page.

www.zooniverse.org/projects/projectphaedra/star-notes

RIGHT NOW After the fires

BY EARLY FEBRUARY, with summer barely half done, more 186,000 square kilometres of Australia had burned in bushfires. Lives – human and wildlife – had been lost and homes and habitat destroyed. For most people outside the impact zones there's one simple question: what can I do?

Here's something: sign up for the Environment Recovery Project. A scientific understanding of how bushland bounces back from fire is critical, and you can help by making observations in recently burnt areas and uploading the data. The project wants to get information about common as much as rare species. It's seeking records of:

- plants (native and weeds) as seedlings or resprouting



- animals (natives and ferals) alive or dead, or their tracks and scats
- fungi and lichen
- landscapes – especially scorch height (how high the fires went and the amount of leaves burnt in the canopy), shrubs and ground cover damaged.

To begin, go to www.inaturalist.org/projects/environment-recovery-project-australian-bushfires-2019-2020, set up a user account – and get out there.

changing from year to year and geographic location to geographic location.”

With moderators trained and sightings flowing in, Sanderson expects the pace to pick up in following months. But already the scientific knowledge is increasing, with two reported range extensions recorded through the app – one in Coppernook, NSW, of a spotted pea-blue (*Euchrysops cnejus*); and the other in Bellingen, NSW, of an indigo flash (*Rapala varuna*). Sanderson emphasises that recording the routine is every bit as important as the rare.

“We want people to record cabbage whites in their backyards, we want people

who are going on expeditions to Cape York to record everything they can find – and everything in between that,” he says. “We’re not in this to be elitist.”

To illustrate the importance of ongoing recording he cites eBird, the global bird observation database started in 2002, which in recent years has recorded about 100 million observations.

“The stuff they’re doing with the data they have now just would never have occurred to them when they started out,” Sanderson enthuses.

“The best example is a waterbird migration that goes down the USA west coast. Because so much of the habitat for waterbirds through California has been turned into agricultural land, what they do is actually pay farmers to flood their fields at the right time to intercept the migration as it comes down the coast. They use real-time data to say, ‘okay, this is where we need some wetlands in a week’. It’s insane.”

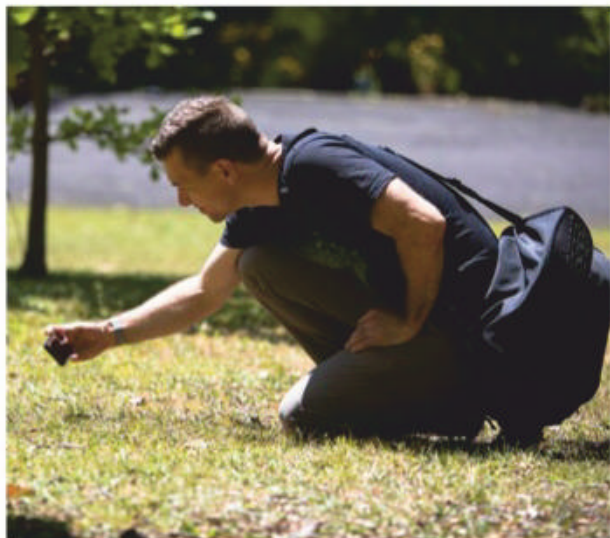
It might be too early to speculate about the future uses of Australian butterfly data, but Sanderson understands the potential. He’s completed Butterflies Australia workshops in several cities and there are more to come – keep an eye on their website



for news. And download the app and get out there observing.

As Sanderson says: “Recording everything you see might turn out to be something that’s seriously useful for scientists in the future.”

www.butterflies.org.au

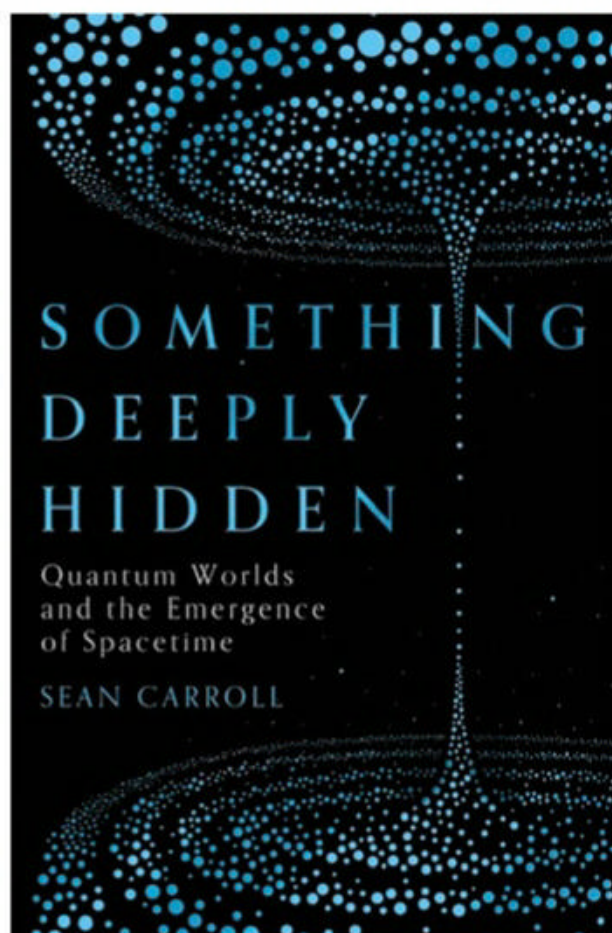


Something Deeply Hidden: Quantum worlds and the emergence of spacetime

by Sean Carroll

Oneworld

\$39.99



QUANTUM MECHANICS is a fascinating topic that inspires, captivates and bamboozles in equal measure. And as there's no shortage of explainers for readers of all levels, attempting to write a book on this physics theory is almost as intimidating as the subject itself.

Yet few works carry readers into this complexity as successfully as *Something Deeply Hidden*. Sean Carroll's latest work moves from a basic introduction to the field to in-depth discussions of mathematics (such as wave functions and uncertainty principles) and then goes further: grappling with the nature of the quantum realm.

This is ground where few physicists dare to tread, and for good reason: the compellingly articulated theory in this work would see the entire universe "split" in two by simply measuring whether an electron is spinning up or down. Even more incredibly, it makes perfect sense.

Carroll is one of those rare scientists who excels in both science and its

communication. His studies are at the forefront of theoretical physics, but he also grapples with concepts of philosophy and more in his Mindcast podcast and Preposterous Universe blog, and through his multiple best-selling books.

This project is particularly close to Carroll's academic heart, as is the description – and advancement – of Hugh Everett's description of quantum mechanics: the so-called many-worlds interpretation.

The most direct treatment of quantum mechanics (that a wavefunction traces out – and indeed is – the behaviour of the Universe as a whole) has the astounding consequence that apparently probabilistic outcomes of a measurement are in fact deterministic – but in a different universe.

Going back to our electron, it can be in a quantum state of indecision (known as a superposition), spinning both up and down and not becoming one or the other until it's measured.

Something Deeply Hidden argues that, rather than some ill-defined and philosophically fraught "observer" reaching down to a somehow separate quantum realm to impact that result, the measurement of an electron as "up" is in the universe you are in now, and "down" in the universe that split from itself just before.

The splitting of universes to form this multiverse occurs in just the right mix as the probabilities that quantum mechanics so uncomfortably appears to present in experiments. Still with me?

What makes this book so impressive is how natural, indeed stunningly logical, such an incredible statement appears. Yet the choice of interpretation is ultimately yours.

Something Deeply Hidden presents the current ideas of quantum mechanics in an entertaining and beautifully explained way, albeit unashamedly favouring the many-worlds interpretation over the rest.

Carroll correctly – and almost as a challenge to the scientific establishment itself – states in the beginning of this engaging book: "As scientists we use quantum mechanics but we don't understand it." After reading this we all have a chance.

ALAN DUFFY

Shaken Brain: The science, care, and treatment of concussion

by Elizabeth Sandel

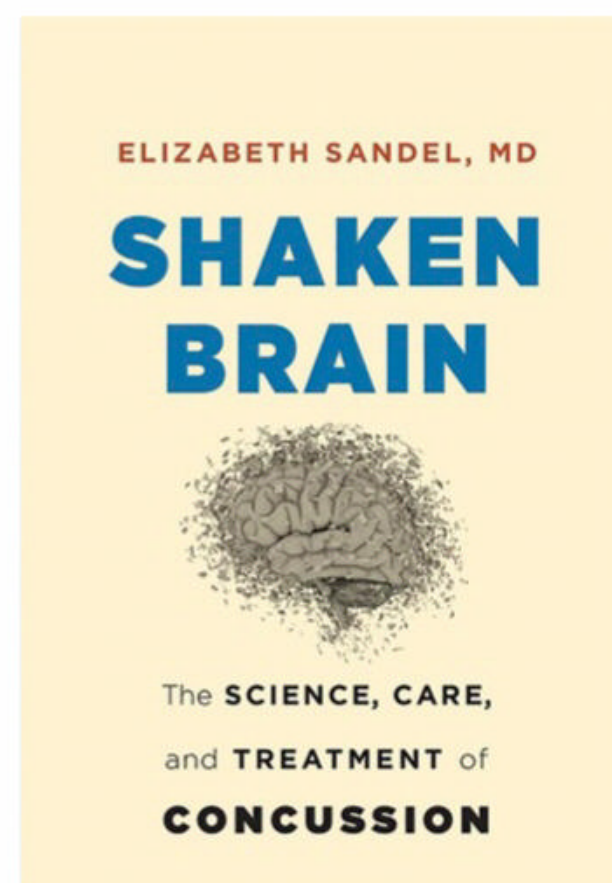
Harvard University

RRP \$72.99

CONCUSSION IS GROWING in importance as an issue as more research reveals the dangers of repeated injury. In *Shaken Brain*, Elizabeth Sandel – a physician with three decades' experience studying and treating concussion – details what happens in the human brain when it is injured, and how medical providers can help.

Sport has been a key driver on this front, with more concussion protocols being introduced at the professional level. But it's pointed out that damage often occurs earlier in an athlete's sporting career, at junior levels where such measures are not adhered to.

A recent high-profile case featured professional American football player Aaron Hernandez, who was tried and convicted of murder. He committed suicide in prison at 27, and at the request of his family, his brain was released to Boston University to be studied for signs of chronic traumatic encephalopathy (CTE), a progressive degenerative disease found in people who have had a severe blow or repeated blows to the head, including football players who suffer concussions.



CTE results in such things as poor judgment, lack of impulse control, aggression, anger, paranoia and emotional volatility. The researchers diagnosed Hernandez with CTE, described his brain as a classic case of the pathology, and suggested that this may explain some of his criminal acts.

Of course, it's not just sport. Head injuries can result from vehicle collisions, incidents at work and from everyday activities – think children falling over. In *Shaken Brain*, Sandel looks at the specific groups of people with a higher-than-normal chance of concussion, such as the elderly, victims of domestic violence, the homeless and the young.

She also examines prevention as a public health issue to address it on an institutional level. Her work features stories from a wide range of patients, to provide an insight into prevention, diagnosis, and treatment.

CHUCK SMEETON

Scatterbrain: How the mind's mistakes make humans creative, innovative and successful

by Henning Beck

NewSouth Books

RRP \$34.99

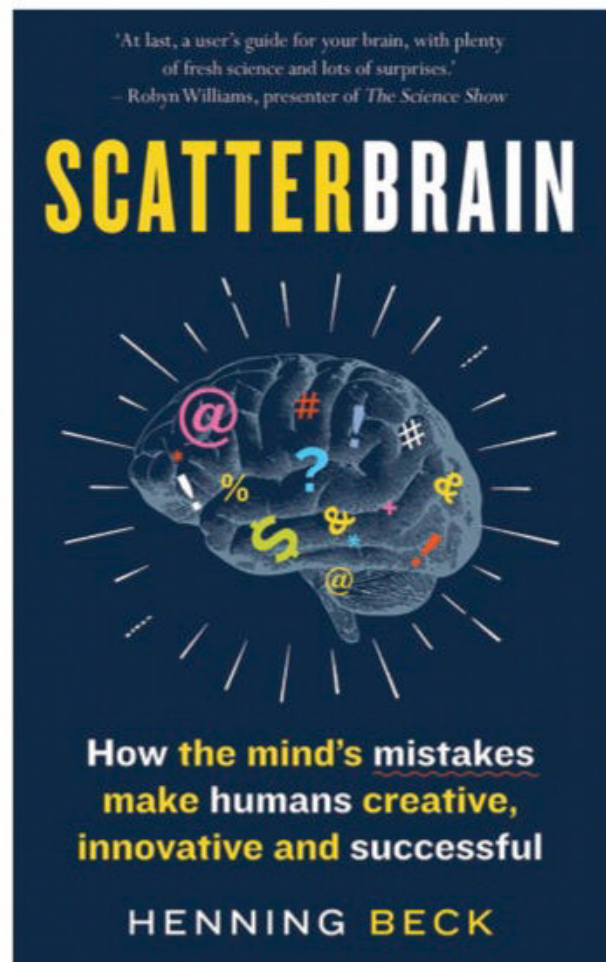
IF YOU CATCH YOURSELF worrying about your memory, decision-making skills or creativity, *Scatterbrain* is definitely worth a read.

Combining his in-depth knowledge of neuroscience with his passion for science communication, Henning Beck uses just the right amount of biology to engage readers who have little understanding of brain structure and function – all the while reassuring them that their brains are, in fact, simply too intelligent, too creative, or working too well to function like a machine.

“...the ability of our thoughts to wander is in fact a human strength that enables us to solve problems in a new way,” he writes.

Throughout, the book provides many practical and relatable examples of brain advancements and failures, and even has some tests for readers to challenge their brains.

Scatterbrain will leave you feeling reassured and proud of your brain's



abilities. It will even provide you with some strategies to improve its performance under pressure, when making decisions and when needing creative inspiration from it.

JENNIFER CHALMERS

Under the Stars: Astrophysics for bedtime

by Lisa Harvey-Smith,

illustrated by Mel Matthews

Melbourne University Press

\$39.99

ANY PARENT WILL TELL you that along with “No!”, “Why...?” is the most popular word among children. Their wonder for the world around us is an amazing thing, and Lisa Harvey-Smith manages to capture that wonder, and keep the passion for discovery going, in her beautifully illustrated and engaging first foray into children's publishing.

Each chapter of *Under the Stars* tackles a thorny question about space, the Universe and everything up to a galaxy far, far away. It's a brilliant read for older children to amuse themselves and dip in and out of when they want answers to random space-related questions (keeping away from the often incorrect landmine that is internet information). It's also detailed

and interesting enough for teenagers and young-at-heart adults (why is the sky blue?).

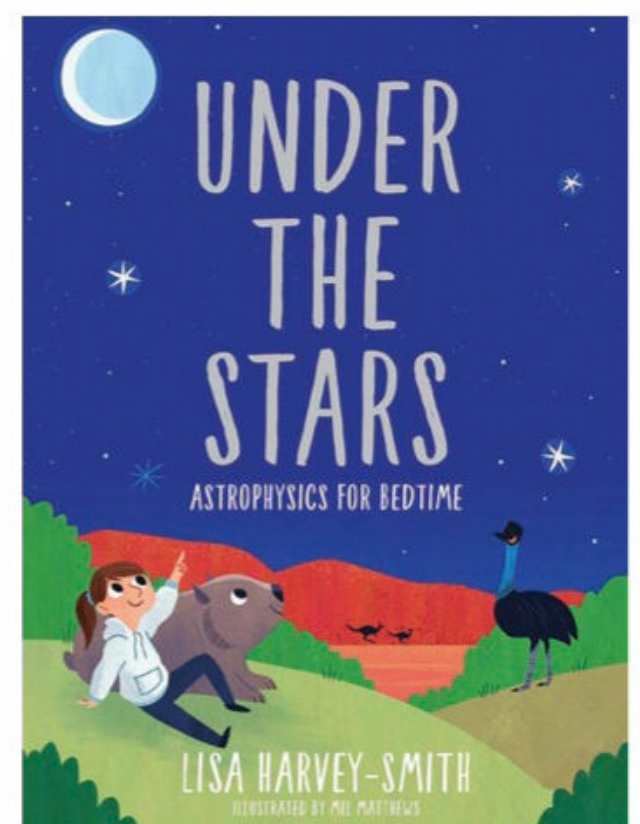
The book is organised into clear parts covering spacey themes such as the Earth, the Solar System and the Universe, flagging for readers as to what area of space their question might come under. Clearly posed questions for each chapter direct readers quickly to the answers they're burning to know. Text is super easy to navigate for the generation used to instant results.

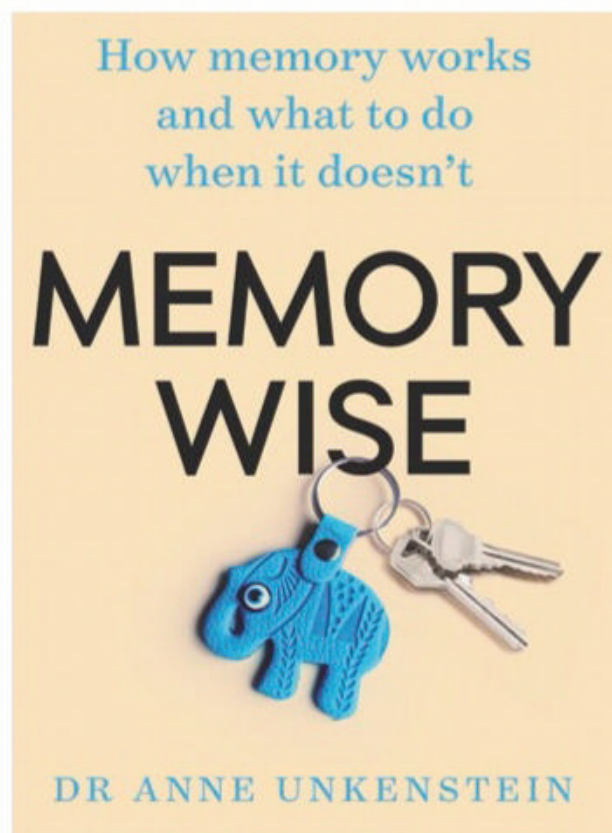
The volume of questions means this is a book that will become well thumbed over time, with readers returning to gratify new curiosities as they arise. Questions also instantly make the subject matter more accessible, as readers don't have to wade through chapters that might not be of immediate interest.

Harvey-Smith has captured how children think and want to access information perfectly, and she entertains as she goes, with humorous references to poos included – right on the target demographic. “How to say” help peppers the entire book, giving children a helping hand to access the knowledge and be able to talk about it and understand concepts further, without ever talking down to them or making them feel like they should already know something.

Overall, this is a delightful book – and one I can't wait for my infant daughter to read, once she learns how to!

HILARY SCHUBERT JONES





Memory Wise: How memory works and what to do when it doesn't

by Anne Unkenstein

Allen & Unwin

\$29.99

IF LIKE ME you've noticed that your mind isn't as sharp as it once was, or you think that a person in your life is showing signs of memory change, then *Memory Wise* could be for you. Anne Unkenstein provides an easy-to-read explanation of how memory works, changes that occur as we get older, and issues that can affect memory.

Memory Wise examines issues such as memory and menopause, working and learning as you age, Alzheimer's disease and dementia. It offers various strategies for everyday memory, maintaining brain health and supporting people in the early stages of dementia.

Unkenstein has drawn on her more than 25 years of experience as a clinical neuropsychologist and uses real-life stories to help illustrate everyday issues of people going through memory change. "I used to have a photographic memory and now I read a novel and can't recall what I was reading," says Vicki, 54. It's reassuring to know you're not alone. There's a phrase used throughout the book – that as we get older, we need to "pay attention to paying attention".

It's easy to navigate through the chapters and at the end of each one there's a list of key points for reminder and easy

reference. For people who feel they need to obtain further information, there are contact details of organisations that can provide advice and support

This book isn't going to blow your mind with lots of medical jargon and it won't provide you with tips to develop hyperthymesia (a neurological condition whereby people remember vast swathes of their life in vivid detail). Some suggestions offered are simple common sense, but could be helpful if you find yourself challenged by deteriorating memory.

Memory Wise provides an insight into what could be going on "upstairs". It may well take away some stigma, or help you take further action if you are concerned about your own, or a loved one's, memory.

SARAH BRENNEN

STORY TIME

What's inspiring our writers right now

WRITING

Ilya Mandel

Teaching physics to monks (p. 64)

"Cargo Cult Science" by Richard Feynman

Every couple of years, I re-read Richard Feynman's 1974 Caltech commencement address, published as a short essay titled "Cargo Cult Science". In it, Feynman talks about the crucial importance of scientific integrity – as he puts it, "a kind of leaning over backwards" to be maximally critical of your own results as a scientist, to be utterly honest about all of the possible flaws in your experiment or your model, to check that your theory really adds some prediction beyond just matching existing data, and to hold on to that honesty and integrity in the face of pressure to get funding or progress your career.

The exhortation seems, if anything, more pertinent now than half a century ago, and all of us can benefit from heeding Feynman's advice.

Ashley Hay

Ode to green (p. 96)

Nightfishing: Stingrays, Goya and the singular life by Vicki Hastrich

Vicki Hastrich's beautiful book of essays could also be described as a collection of expeditions or explorations. From her starting point of one small patch of Brisbane Water, north of Sydney, she leans into science, art, philosophy, and nature, letting ideas and connections ebb and flow – sometimes gently, sometimes dramatically – from seaweed and rays to turtles and prawns, invasions and loves.

Hastrich calls herself an amateur – amateur marine biologist, amateur writer – but the scope and richness of the knowledge she pins down here and the existential shape it makes (for her own self and for the broader world) speak to consummate observational skills. When she writes that Galileo's "great achievement was to show us what was already in plain view", she could be describing her own work.

Natalie Parletta

Hook, line and thinker (p. 80)

The Giver of Stars by Jojo Moyes

I recently unearthed this gem. Based on events in depression-era America, the powerful zeitgeist of the story is as pertinent nearly a century later as it was then, if not more so. Assorted women battling their own tragedies and challenges bond while forming a community library against the backdrop of rampant ignorance, sexism, racism and a ruthless coal company destroying people's health, homes and habitats. The women's extraordinary courage and ultimate triumph against all odds inspire us – compel us – to rise up and tackle the planet's unfolding climate catastrophe and mass extinctions.

At a time when many of us feel despairing and hopeless, stories like this are a vital reminder that the human spirit can prevail; that with the Greta Thunbergs of this world we can defeat Goliath.

PODCASTS

Ivy Shih

Windows to the stars (page 32)

Brain on Nature by Sarah Allely

Recently I've rediscovered my love of experimenting and being braver with

different forms of narrative/science communication, which led me to discover *Brain on Nature*. It's a narrative documentary podcast series produced by Sarah Allely about her experiences after recovering from a mild traumatic brain injury. It's a lovingly produced six-part audio documentary. I blitzed through it all in a single night. Have a listen and let yourself sink into the sound design and Sarah's story.

Nathan Byrne

Head in the clouds (p. 99)

Cautionary Tales by Tim Harford

I absolutely chew through podcasts.

Right now, I'm particularly enjoying Tim Harford's *Cautionary Tales* – life lessons from history that show us why it's important to learn from our past. Tim expertly weaves together scientifically rigorous analysis with a charming look at some of our greatest mistakes, to create a

wonderful story that you probably haven't ever heard before. Definitely check it out – season one was just eight episodes, so the back catalogue isn't too daunting at all.

TV & MOVIES

Katie Mack

Hubble trouble (p. 22)

TV show: The Expanse developed by Mark Fergus and Hawk Ostby

The one piece of media I won't shut up about is *The Expanse*. It's a science fiction TV series on Amazon Prime set in a future where humans have spread out through the Solar System and broken up into three separate factions based on Earth, Mars, and the asteroid belt.

It's a great show for the drama and writing and plot but it also generally does a really great job with physics (with some exceptions around aliens, which I think is fine). It's fun to see a show where

the speed of light delay is an actual plot device, or where ships only have "gravity" when they're accelerating or spinning. I'm generally pretty partial to media involving space travel, but *The Expanse* is definitely top of my list right now.

Drew Turney

Internet of Disposable things (p. 54)

Film: Joker, directed by Todd Phillips

If you're sick of superhero movies, you might be tempted to give Todd Phillips' *Joker* a wide berth. Don't – it's one of the best designed and well-written dramatic character studies of the last few years, and the best film of 2019. It just happens to be about a comic book character. Phillips' brilliant direction is elevated by Joaquin Phoenix's sublime performance and you'll realise that superhero/comic book movies can be something very different and still thrilling.

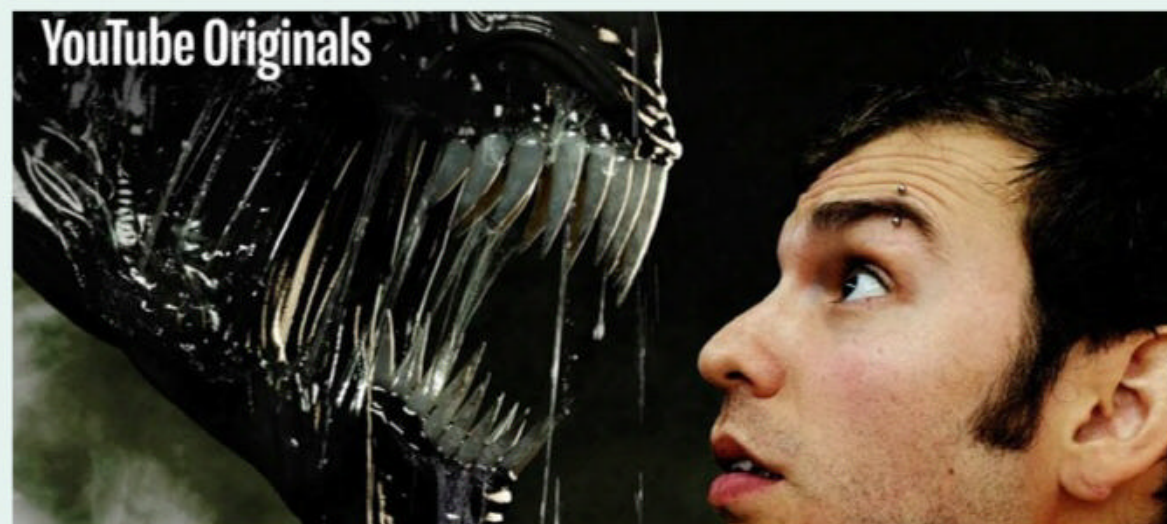
WORLD WIDE PONDERING

EXPLORE.ORG

A website that should come with an addiction warning, Explore.org is the ultimate animal-lover slow TV, with live-streaming cameras in sanctuaries from conservation areas to the more domestic: popular feeds include a great Dane puppy room. The site's strength lies in its combination of global reach (from Panama fruit feeders to African waterholes) and its speed, or lack thereof: exchange car crashes and Netflix gore for swaying hummingbird nests and bee zen cam. Open a window to the wide world, if you dare ...

WHEN 24 hours a day

HOW LONG 24 hours a day



COULD YOU SURVIVE THE MOVIES? (above)

Launched in 2007, the VSauce Youtube channels are tall trees in the internet forest, with 23 million subscribers and billions of views of its offbeat, high-production science and tech. This recent VSauce3 series takes on iconic movies like *Men in Black* and *Ghostbusters*, recreating scenes before stirring in the science in a fast-paced version host Jack Roper describes as "accidental learning". Each episode's footnotes allow you to learn – or recreate the effort. Proton pack, anyone?

WHEN On demand

HOW LONG 10-15 minutes

SHORT WAVE

This tight and smart podcast from the US's not-for-profit National Public Radio adds the STEM to current affairs, explaining the research and data hidden behind headlines such as coronavirus and Australia's bushfires. checking in with scientists, researchers and NPR's network of reporters and correspondents from around the globe, host Maddie Sofia stays on target, adding clear and concise scientific information to the news of the day.

WHEN Weekdays

HOW LONG 10 minutes

Cosmos Codeword

NO.12

17	15	25	13	26	20	16	15		5	15	2	8	13	24
9		12		1		1		26		16		1		9
17	2	12	26	5	16	14	12	14		17	16	20	26	3
2		26		7		12		11		9		12		8
23	1	20	8	26	20		22	1	8	13	12	1	20	26
25		23		10		5		9		2		20		25
12	20	9	19	9	2	15		20	26	15	16	2	3	
26		1		14		2		26				8		2
	2	10	2	12	26	1	20		14	26	6	12	16	8
12				9		14		21		2				3
4	9	8	3	13	7	9	15	15		20	2	18	16	20
9		2				23		26		14		26		16
12	9	3	2	15		15	26	26	13	7		20	9	17
13		9		26		26		13		16		16		26
7	26	20	23	2	15		22	26	12	12	9	14	16	8

1	2	3	4	5	6	7	8	9	10	11	12	13
14	15	16	17	18	19	20	21	22	23	24	25	26

Codeword requires inspired guesswork. It is a crossword without clues. Each letter of the alphabet is used and each letter has its own number. For example, ‘A’ might be 6 and ‘G’ might be 23.

Through your knowledge of the English language you will be able to break the code. We have given you three letters to get you started.

SOLUTIONS: COSMOS 85
CODEWORD

G	A	L	A	X	I	E	S		B	E	N	I	G	N
E		I		Y		V		J				N		U
N	I	G	E	L	L	A		A	M	N	E	S	I	A
O	H	E		L		W		U		I				N
T	I	T	A	N	I	U	M		T	R	A	G	I	C
Y		N		E		A		K		T		H		E
P	A	I	R		A	T	T	E	N	U	A	T	E	
E		N		F		E		Y		R				D
	I	G	L	O			A	S	T	E	R	O	I	D
Z			L		G		T			S		U		
I		A	I	L		A	G	R	O	N	O	M	I	C
R		L		I	M		O		O		O		A	
C	U	B	I	C	L	E		K	U	D	O	S		T
O		U		L		T		E			I		O	
N	U	M	B	E	R	E	D		Q	U	A	S	A	R

1	M	S	D	Z	Q	T	U	I	O	X	J	R	H
14	L	E	B	P	F	G	N	C	Y	W	V	A	K

IT FIGURES

	1	2	3	4
A	5	15	8	2
B	16	4	1	9
C	6	12	14	10
D	7	3	11	13

WHO SAID?
Carl Sagan

COMPETITION WINNERS

WHOSE LAW?
In the Northern Hemisphere, if a person stands with her back to the wind, the atmospheric pressure is low to the left, high to the right.

Buys Ballot

Congratulations!
Three lucky winners will receive a copy of *Cosmic Chronicles: A user’s guide to the Universe* by Fred Watson, from NewSouth Books.

Brittany Davis,
Victoria
Levi Borshch,
Victoria
Jennifer Eime,
South Australia

It Figures

NO.12

	1	2	3	4
A	1	2	3	4
B	5			
C	6			
D	7			

INSTRUCTIONS
Using the clues below place the numbers 1 to 16 correctly in the grid. How many clues do you need?

LEVEL 1 - CHIEF SCIENTIST

- 1 The sum of each individual row and column is divisible by four.
- 2 An even numbered column begins with ascending teens and ends with ascending square numbers.

- 3 The product of the three smallest numbers in the last column is 6 less than the second number in that column.
- 4 An outer column which begins with descending multiples of five contains three numbers which are divisible by three.
- 5 75% of corner and bottom row numbers are single digit primes.

LEVEL 2 - SENIOR ANALYST

- 6 The sum of Row B is 48.
- 7 The upward sloping diagonal contains all single digit numbers.

LEVEL 3 - LAB ASSISTANT

- 8 The last two numbers in Row C add to the first.
- 9 The product of the outer two numbers in Column 3 is 42.

Cayne Layton

Seaweed whisperer

IT'S FUNNY HOW often childhood informs life choices.

"I grew up fishing, snorkelling, bird watching," says marine biologist Cayne Layton. "I was that kid that used to collect the crab shells and fish skeletons from the beach and bring them home to my parents – we used to have a table in the house with all the weird stuff that I'd collected that probably stank to high heaven."

Layton reckons he did "really poorly" in high school and went to uni to study science only after friends encouraged his interest in the natural environment. After a year in Cairns he'd scored good enough marks to transfer back to ANU in Canberra to be closer to family and friends. While at ANU he regularly travelled to the Great Barrier Reef for fieldwork, but his heart always led south.

"Working on the Great Barrier Reef is fun – it's warm and there's tropical islands – but growing up on the NSW south coast my passion had always been for cold water reefs," he says. "I wasn't initially attracted so much to seaweed as to everything else that lived in it... the more you learn about something the more you come to appreciate it and I've certainly done that with seaweed."

Layton moved to Tasmania to complete a PhD on kelp forests in 2013, and he's been in Hobart ever since. "All science is about answering questions, right?" he says. "That's what I find really interesting – that idea that you're treading into new ground and answering things that we just don't know."

CAYNE APPEARS IN OUR PICTURE ESSAY ABOUT KELP, PAGE 48.



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