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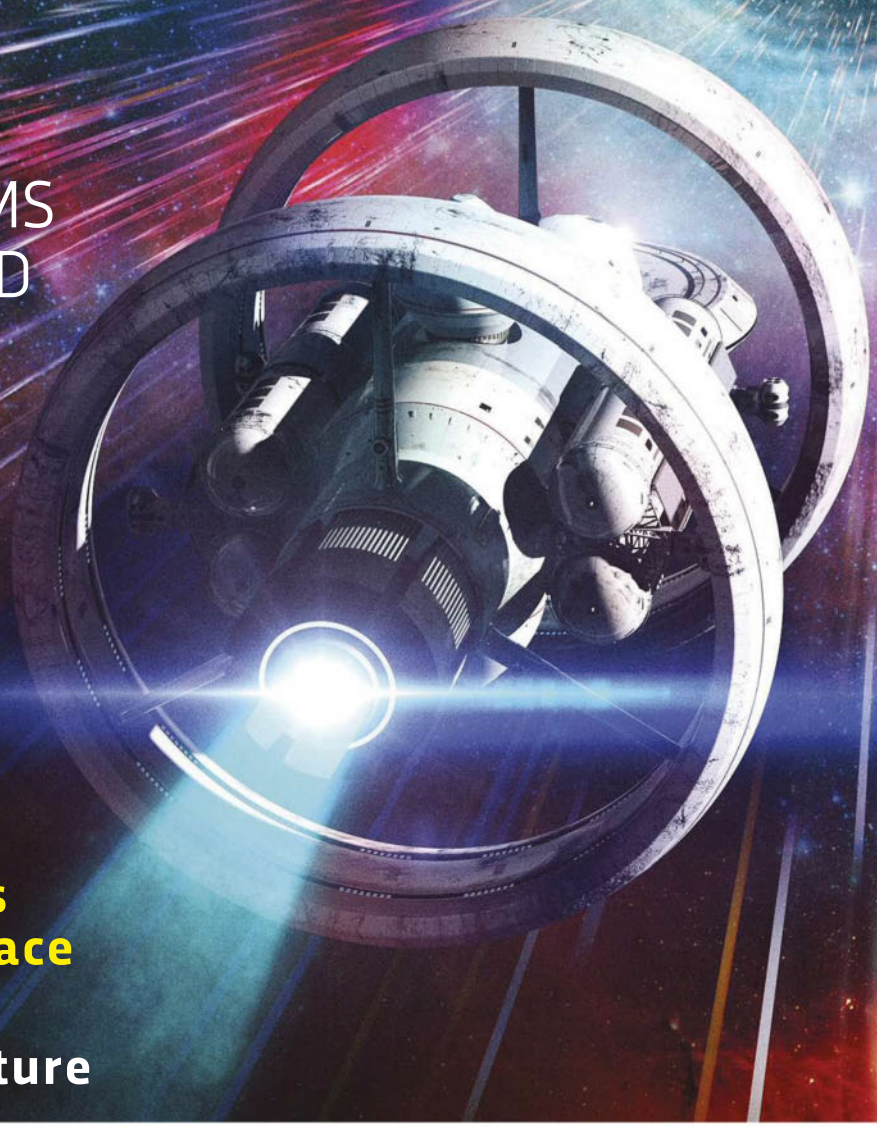

DISCOVER

The future of zoos

The world's first Roborace

A new fifth force of nature

Q&A

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WELCOME

Scientists may have found another Earth. This newly discovered exoplanet ticks all the right cosmic boxes: it orbits its star within the habitable zone, it's similar in size to our planet, it's probably rocky and, in astronomical terms, it's just around the corner, circling 'nearby' star Proxima Centauri. But using current technology, it would still take 70,000 years to get there.

The trouble is that the rocket – the notion of burning a fuel to create hot gas that pushes a vessel upwards – is getting on in years. The Ancient Greeks had the idea first, around 2,500 years ago, though it wasn't until 1232, when Chinese archers used gunpowder-fuelled rocket arrows to repel the Mongols, that anything recognisable as a rocket actually flew through the skies. The rockets that leave the planet today are the result of thousands of years of experimentation with this one idea, honed to a point where it's enabled humankind to chart most of the Solar System. But if we're ever to bridge the vast distances that separate us and other Earth-like planets, then rockets and their thirst for heavy fuel might have reached their limits. It's time for something new. On p32, Stuart Clark investigates the ideas that could help us close the gap between worlds.

This month, the Formula E championship kicks off for its third year, but this time there's a new race in town. Driverless robocars will zip through city circuits in a contest to see who can program the fastest racer. Turn to p58 to find out more.

Enjoy the issue!

Daniel Bennett

Daniel Bennett, Editor

IN THIS ISSUE

DR LORI MARINO

Neuroscientist and animal behaviour expert Lori is founder and executive director of the Kimmela Center for Animal Advocacy. In this issue, she tackles the tricky topic of captive animals. → **p76**

JHENI OSMAN

In the world's most extreme environments, scientists have discovered intriguing microbes that feed directly off electrons. Science writer and former *BBC Focus* editor Jheni went to find out more. → **p42**

REINER RIEDLER

Inspired by the machines that kept his critically ill newborn son alive, Austrian photographer Reiner set about capturing the world of medical equipment. We showcase the incredible results. → **p50**

Sea lions have the most accurate sense of rhythm in the animal kingdom. No one tell Seal... → p17

WHAT WE'VE FOUND OUT THIS MONTH

Being 'hangry' (angry when hungry) is a real thing. In psychological tests, low glucose levels correlated with low tolerance levels. →p97

Newborn monkeys smile in their sleep. This lends credence to the idea that smiling isn't uniquely human. → p15

20° is the optimum throwing angle for skimming stones at the beach. → p104

A spacecraft with an 'e-sail' could allow us to travel across interstellar space – but the 'sail' would need to be roughly the size of London. →p34

CONTACT US

Advertising
neil.lloyd@immediate.co.uk
0117 300 8276

Letters for publication
reply@sciencefocus.com

Editorial enquiries
editorialenquiries@sciencefocus.com
0117 314 7388

Subscriptions
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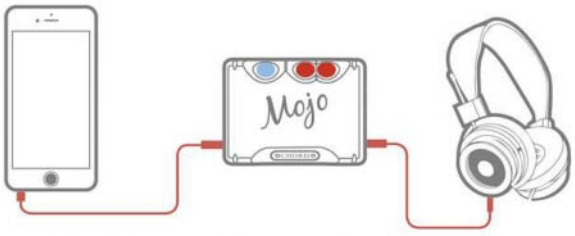

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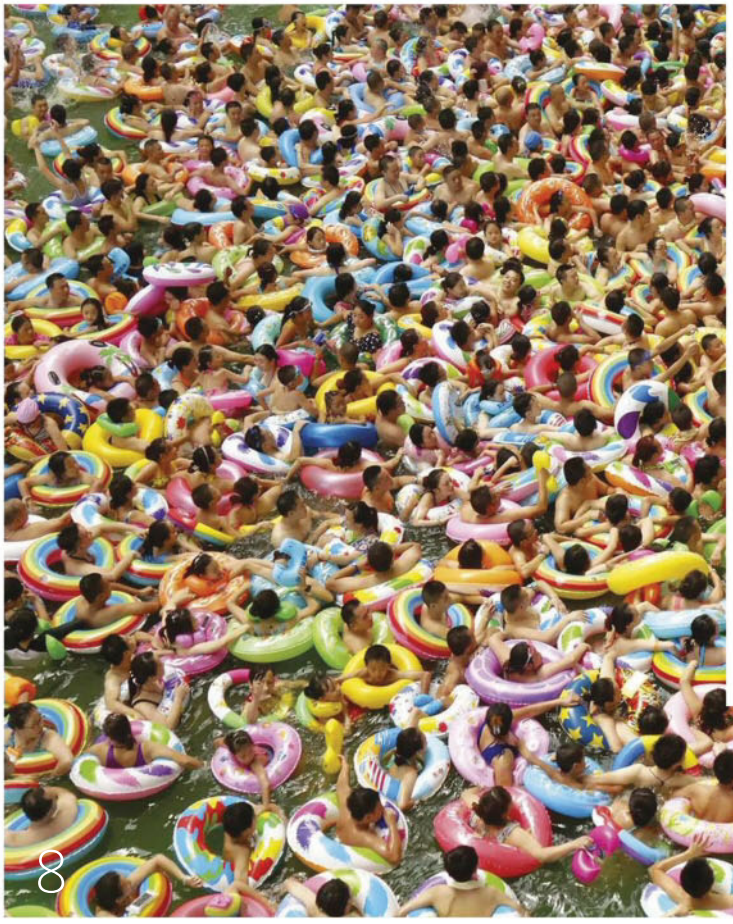
8

25


100


13

CONTENTS

REGULARS


114


69

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CONTENTS

FEATURES

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What Hi-Fi? Award 2015, UK

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Digital Trends - Editors Choice Award 2015, USA

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EYE OPENER

Horde of the rings

DAYING COUNTY, SICHUAN PROVINCE, CHINA

And you thought your local swimming pool was crowded. Thousands of rubber-ringed revellers descended upon the Dead Sea of China water park this summer when temperatures in the Sichuan province soared to nearly 40°C.

This pool, which can fit up to 10,000 people, was inspired by the Dead Sea in the Middle East. Visitors are encouraged to float in the naturally buoyant saltwater, although we admire anyone who can relax when multiple limbs are jabbing into their inflatable.

Globally, this July was the warmest month on record. Incredibly, each consecutive month this year has broken its own temperature record, a fact which experts are attributing to rising greenhouse gas emissions.

"While the El Niño event in the tropical Pacific this winter gave a boost to global temperatures from October 2015 onwards, it is the underlying [long-term warming] trend which is producing these record numbers," says Gavin Schmidt at NASA's Goddard Institute for Space Studies.

PHOTO: EYEVINE

EYE OPENER

The very hungry caterpillars

HUANJIANG MAONAN, GUANGXI, CHINA

These silkworms are chowing down on their favourite food – mulberry leaves. After about a month of voracious feeding, the fast maturing caterpillars begin to spin a silken cocoon made from proteins found in their saliva in preparation for their metamorphosis into silk moths.

"A molecular marvel, the protein fibroin has a high tensile strength and a toughness that makes commercially produced silk an incredibly useful and valuable material," explains entomologist and BBC presenter Adam Hart. "Another protein, sericin, coats the fibroin and allows it to stick together, forming thicker and stronger fibres."

To loosen the silk to prepare it for being fed onto a spinning wheel and woven into fabric, the cocoons are thrown into boiling water or pierced with a needle. In China, sericulture, the rearing of silkworms for the production of silk, is big business. In 2015, the industry produced 170,000 tonnes of fabric, which is nearly six times the output of India, its closest competitor.

PHOTO: EYEVINE

The first 360° VR Action Cam in 4K

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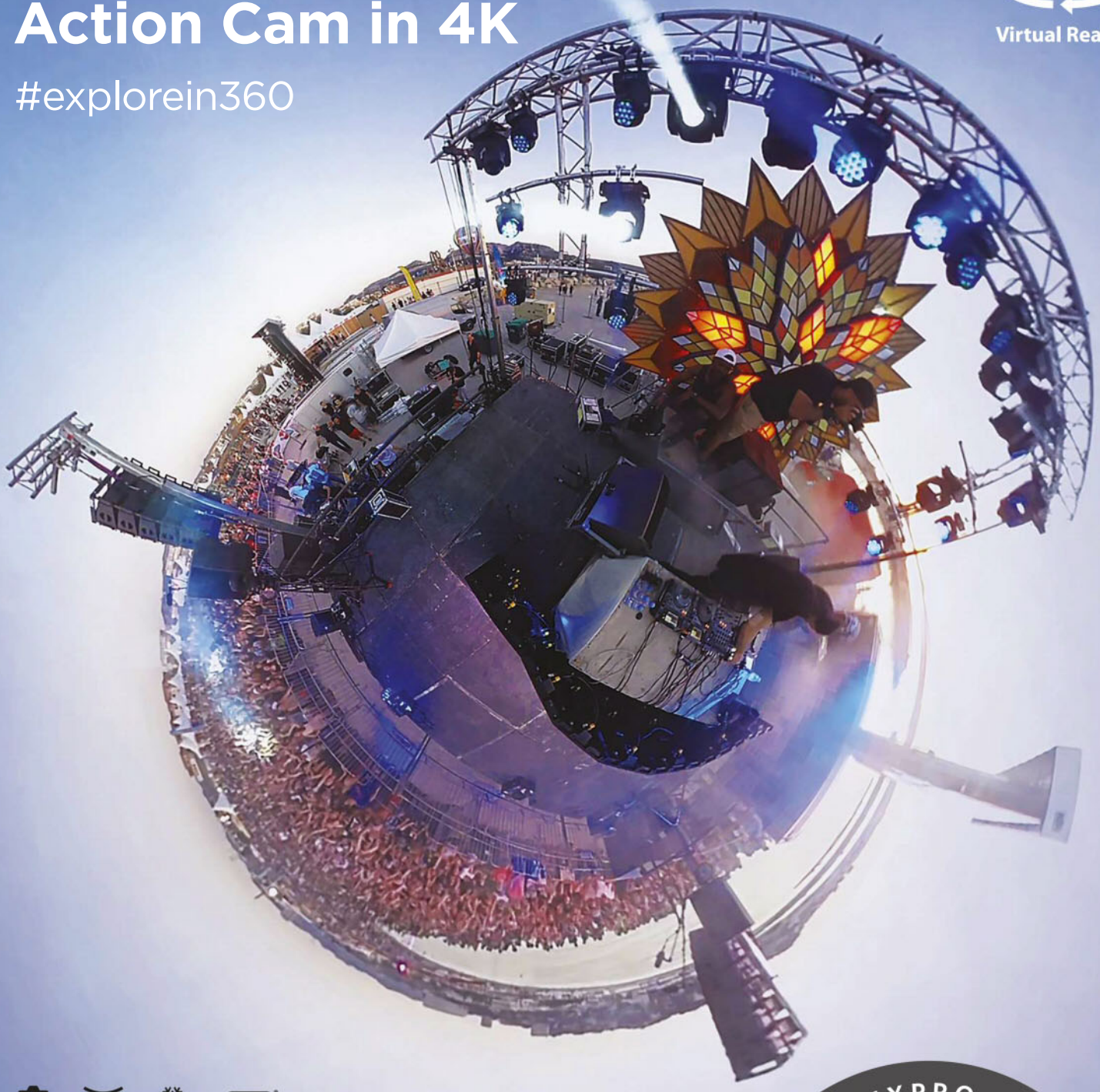

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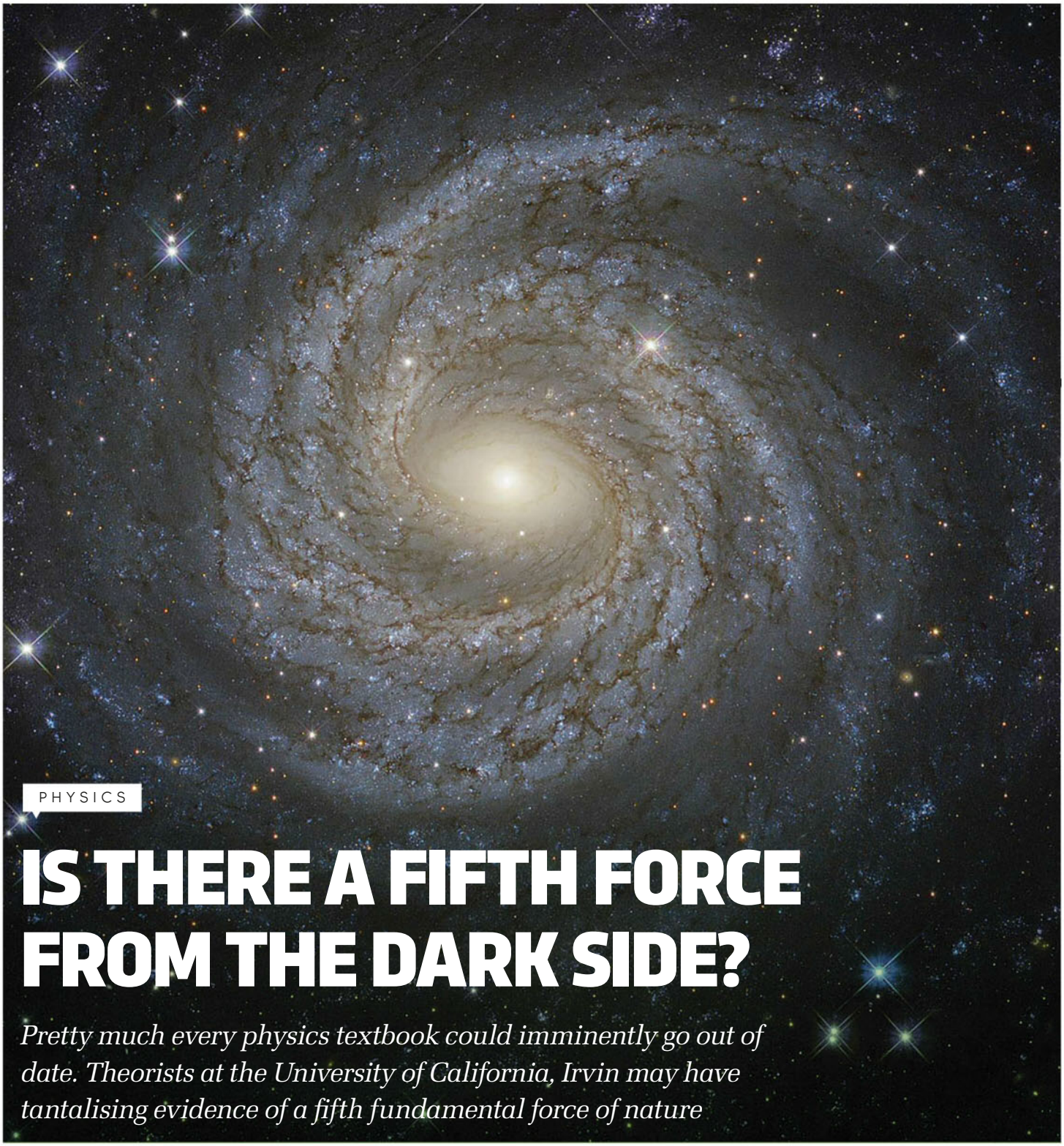
DISCOVERIES

DISPATCHES FROM THE CUTTING EDGE

OCTOBER 2016 | EDITED BY JASON GOODYER



PHYSICS

IS THERE A FIFTH FORCE FROM THE DARK SIDE?

Pretty much every physics textbook could imminently go out of date. Theorists at the University of California, Irvin may have tantalising evidence of a fifth fundamental force of nature

PHOTO: ESA/HUBBLE/NASA

According to particle physics, there are four fundamental forces: gravity, electromagnetism, the weak force and the strong force. Electromagnetism, the weak and the strong forces have particles associated with them called bosons, which are the force-carriers. Gravity is yet to be integrated into the Standard Model, but is thought to have a force-carrying particle known as the graviton.

Last year, a group of Hungarian researchers spotted an unusual radioactive decay signal while searching for evidence of 'dark photons' – a hypothetical particle proposed to be the electromagnetic force carrier for dark matter. Though details were unclear, the signal appeared to have come from an unknown particle just 30 times the mass of an electron.

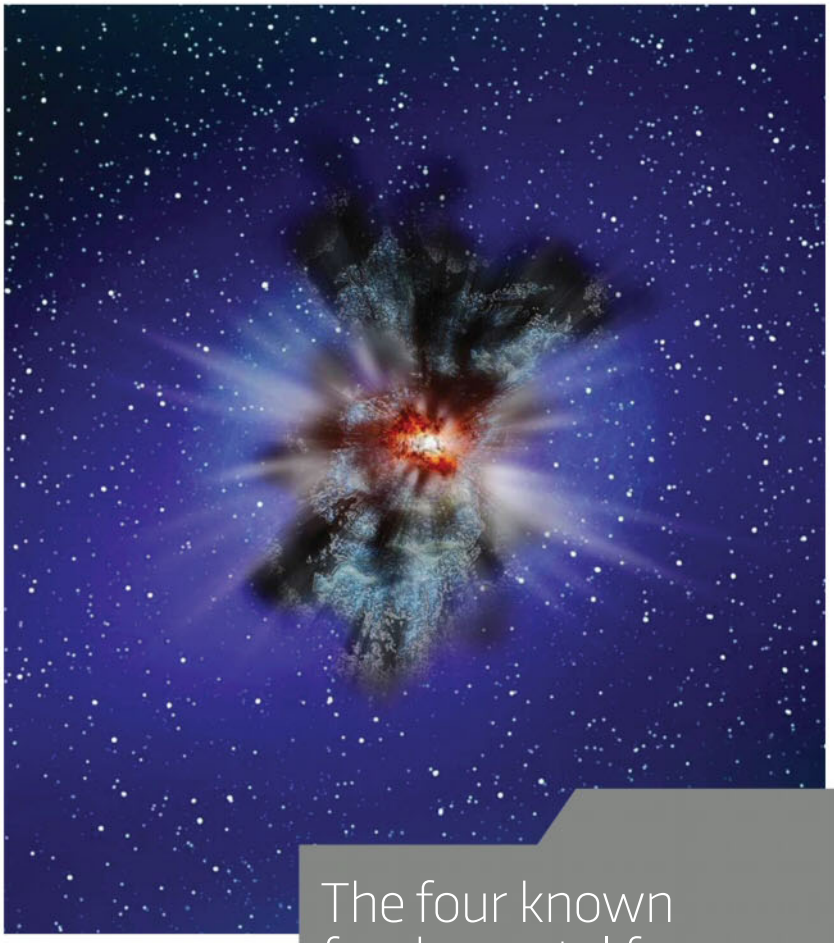
"If true, it's revolutionary," said researcher Jonathan Feng. "For decades, we've known of four fundamental forces: gravitation, electromagnetism, and the strong and weak nuclear forces. If confirmed by further experiments, this discovery of a possible fifth force would completely change our understanding of the Universe, with consequences for the unification of forces and dark matter."

After combing through the data and ruling out matter particles and dark photons as candidates, the UCI team have proposed the signal may have come from a 'protophobic X boson', a new type of force-carrying particle, so-called as it interacts only with electrons and neutrons over an extremely limited range, rather than with electrons and protons like the photons do for the electromagnetic force.

If they are correct, the finding would mean that there is a fifth fundamental force operating alongside the electromagnetic and strong and weak nuclear forces, and possibly even a separate dark sector with its own matter and forces.

"It's possible that these two sectors talk to each other and interact with one another through somewhat veiled but fundamental interactions," said Feng. "This dark sector force may manifest itself as this protophobic force we're seeing as a result of the Hungarian experiment. In a broader sense, it fits in with our original research to understand the nature of dark matter."

"A POSSIBLE FIFTH FORCE WOULD COMPLETELY CHANGE OUR UNDERSTANDING OF THE UNIVERSE"



ABOVE: The team discovered the potential fifth force while hunting for the force carrier of dark matter, visualised above

The four known fundamental forces

FORCE	EXPERIENCED BY	FORCE CARRIER PARTICLE	RANGE	RELATIVE STRENGTH
Gravity acts between objects with mass	All particles with mass	Graviton (not yet observed)	Infinity	Much weaker
Weak force governs particle decay	Quarks and leptons	W^+, W^-, Z^0 (w and z)	Short range	
Electromagnetism acts between electrically charged particles	Electrically charged particles	γ (photon)	Infinity	
Strong force binds quarks together	Quarks and gluons	g (gluon)	Short range	Much stronger

PHOTOS: SCIENCE PHOTO LIBRARY, FLPA

ZOOLOGY

Infant monkeys smile in their sleep, just like human babies

Who's a cheeky monkey? Researchers from Japan's Kyoto University have discovered that macaques sometimes break out into smiles while sleeping – a behaviour previously thought to be unique to higher order primates such as humans and chimpanzees.

The facial expressions, known as spontaneous smiles, are considered to be the evolutionary origin of human smiles and laughter.

"About a decade ago we found that chimp infants also display spontaneous smiles," said researcher Masaki Tomonaga. "Since we see the same behaviour in more distant relatives, we can infer that the origin of smiles goes back at least 30 million years, when Old World monkeys and our direct ancestors diverged."

The team observed seven infant macaques during their routine health checks, with all of them smiling at least once.

"Spontaneous macaque smiles are more like short, lopsided spasms compared to those of human infants. There were two significant similarities; they both happened between irregular REM sleep, and they show more lopsided smiles compared to symmetrical, full smiles," said researcher Fumito Kawakami. "A major difference, though, is that the smiles were much shorter."

It has previously been argued that infants' spontaneous smiles developed to help parent-child bonding. However, the Japanese team think they may simply be used to develop cheek muscles, enabling macaques, chimpanzees and humans to form complex facial expressions.

The smiles of sleeping infant macaques probably help develop the facial muscles

IN NUMBERS

4.243
LIGHT YEARS

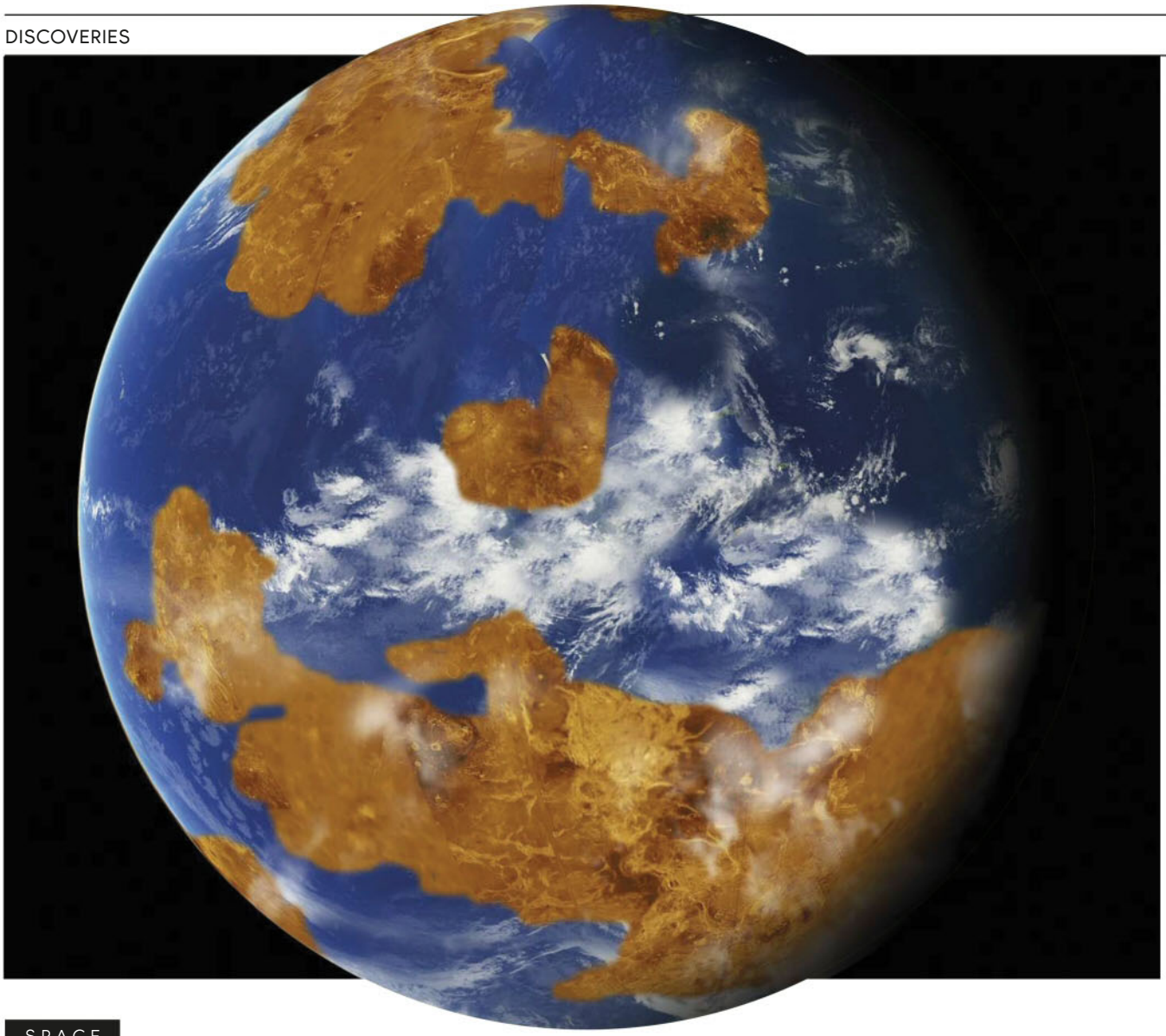
The distance of the nearest known exoplanet from Earth, Proxima B, discovered by astronomers at the Carnegie Institute orbiting the red dwarf star Proxima Centauri, the closest star to the Solar System.

1,075
YEARS

The age of a Bosnian pine tree found growing in northern Greece by a team from the University of Stockholm. It is the oldest living thing known in Europe, they say.

£5
BN

The amount of money required to save Australia's Great Barrier Reef from dying of coral bleaching, as estimated by Queensland's Water Science Task force.



SPACE

VENUS MAY ONCE HAVE BEEN HABITABLE

With a temperature hot enough to melt lead and a suffocating, toxic atmosphere 90 times thicker than Earth's, the surface of Venus resembles the classical idea of Hell. But this was not always the case.

A team at NASA's Goddard Institute for Space Studies (GISS) has found Venus may have had an ocean of liquid water and a surface with habitable temperatures for two billion years of its history.

"Many of the same tools we use to model climate change on Earth can be adapted to study climates on other planets, both past and present," said researcher Michael Way.

The GISS team plugged information about Venus's early oceans, taken by the Pioneer mission, into their model. They combined this with data detailing conditions of a hypothetical early Venus, then gave it an atmosphere similar in density to Earth's, and a day as long as Venus's current day (117 Earth days).

"THE CLIMATE COULD HAVE BEEN A FEW DEGREES COOLER THAN EARTH'S TODAY"

"In the simulation, Venus's slow spin exposes its dayside to the Sun for almost two months at a time," said researcher Anthony Del Genio. "This warms the surface and produces rain that creates a thick layer of clouds, which acts like an umbrella to shield the surface from much of the solar heating. The result means climate temperatures could have actually been a few degrees cooler than Earth's today."

Here's hoping Earth doesn't follow in its neighbour's footsteps.

PHOTOS: NASA, LORI SANDERS/HARVARD; ILLUSTRATION: RAJA LOCKEY

ROBOTS

MEET THE FIRST SOFT ROBOT THAT CAN MOVE BY ITSELF

Here's one bot we definitely have a soft spot for. Researchers at Harvard University have created the world's first entirely soft robot capable of moving around under its own steam.

Dubbed 'octobot' for obvious reasons, the robot is around the size of an SD memory card and is able to move its limbs pneumatically by transforming liquid hydrogen peroxide fuel into a much larger volume of gas. This gas flows from a central reservoir into the bot's arms, inflating them like a balloon and allowing it to move its limbs without the need for rigid electronic components such as batteries and circuit boards.

"One long-standing vision for the field of soft robotics has been to create robots that are entirely soft, but the struggle has always been in replacing rigid components like batteries and electronic controls with analogous soft systems and then putting it all together," explained researcher Robert Wood. "This research demonstrates that we can easily manufacture the key components of a simple, entirely soft robot, which lays the foundation for more complex designs."

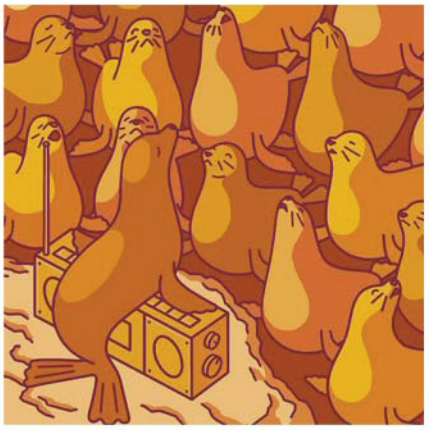
Each part of the robot was custom designed and put together using a combination of various moulding and 3D printing techniques and is simple to assemble.

"This research is a proof of concept," said researcher Ryan Truby. "We hope that our approach for creating autonomous soft robots inspires roboticists, material scientists and researchers focused on advanced manufacturing."

The team is now working on creating an octobot that can crawl, swim and interact with its environment.

The squishy robot is made entirely with soft components

THEY DID WHAT?!

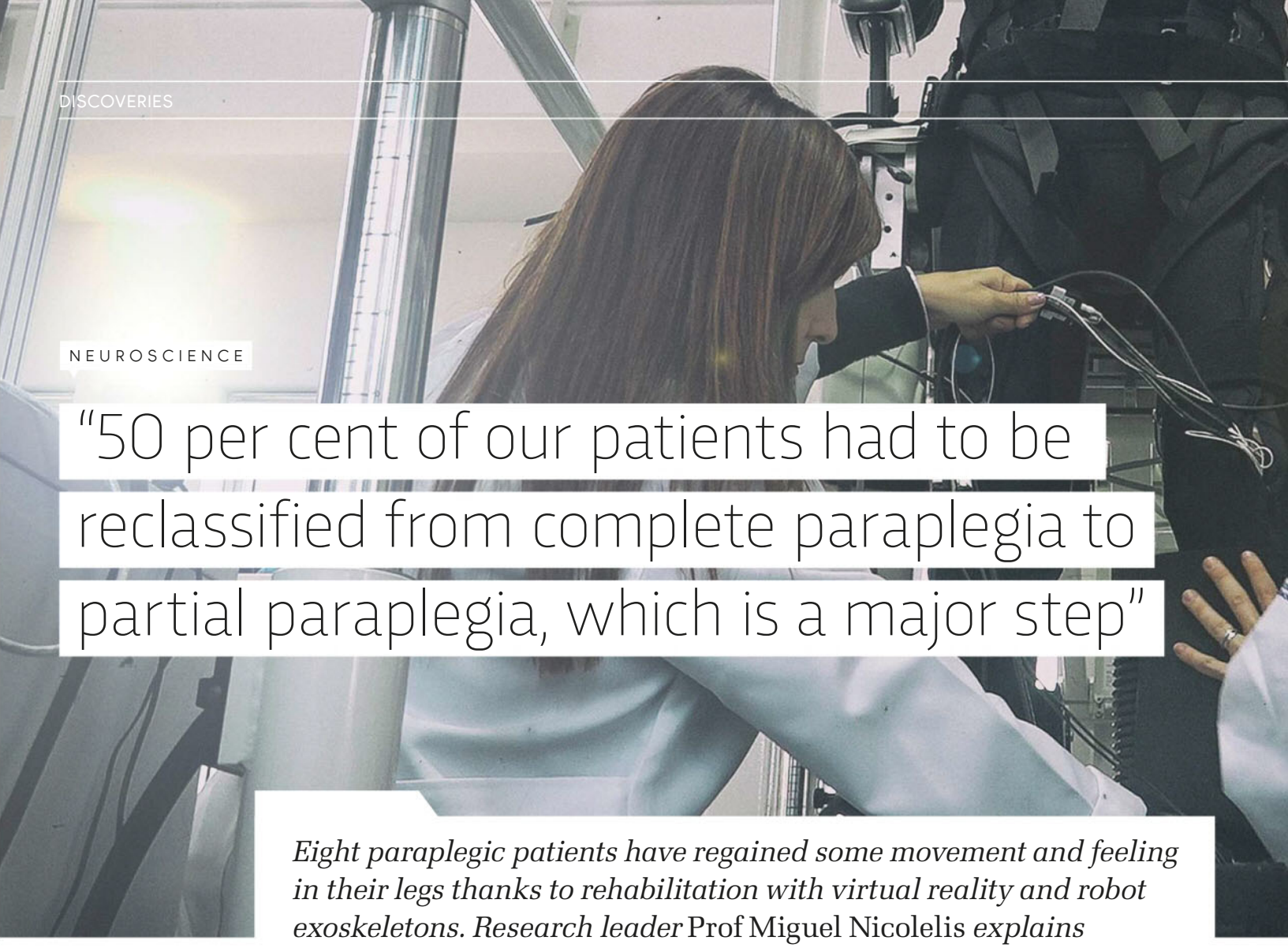


SEA LION TAUGHT TO KEEP A BEAT

What did they do?
Researchers at the University of California played a constant click track to a sea lion named Ronan, rewarding her with fish every time she nodded along in time. They then upped the ante by playing her Earth, Wind and Fire's funk-soul floor-filler *Boogie Wonderland* and varying the tempo at random intervals.

What did they find?
Not only was Ronan able to keep the beat better than any other non-human animal ever tested, she could also quickly adapt to the new tempos. The manner in which she did this suggests that neurons in her auditory brain centres first synchronised with the rhythm and then passed on the timing to the motor centres that control movement.

Why did they do that?
Over the last decade chimps, bonobos, parrots and budgerigars have all been seen to move in time to music. By further study, the researchers hope to deepen their understanding of the biological roots of musicality in humans.



NEUROSCIENCE

"50 per cent of our patients had to be reclassified from complete paraplegia to partial paraplegia, which is a major step"

Eight paraplegic patients have regained some movement and feeling in their legs thanks to rehabilitation with virtual reality and robot exoskeletons. Research leader Prof Miguel Nicolelis *explains*

What is the Walk Again project?
About six years ago, I decided to start an international collaboration with the goal of accelerating the development of 'brain-machine interfaces' and the potential application of this technology in rehab medicine. We started with eight patients who'd suffered anything that caused dramatic, traumatic injuries to the spinal cord.

How does a brain-machine interface work?
We used a cap fitted with electrodes that can record the motor commands the brain is producing. The interface translates those commands into digital signals that artificial VR devices can understand.

RIGHT: First, the patients used their brainwaves to control a digital avatar of themselves, via an Oculus Rift VR headset

On the sleeves of a shirt, we stitched vibrating elements that could deliver tactile information to the skin on the arms of patients. As the patients still had feeling in their arms, the shirt could simulate the sensation of touching the ground. Once they'd trained their brains in this way, they moved into a robot exoskeleton. Every time the patient walked, they would receive information about ground contact via the shirt. By combining this with visual feedback, we fooled the brain into generating a kind of phantom limb sensation. The patients reported that they felt their legs moving.

When did patients regain movement?
In the first 12 months, 50 per cent of our patients had to be reclassified from complete paraplegia [total paralysis of the lower limbs] to partial paraplegia [some sensation and movement], which is a major step. One patient dropped out of this study because he had to move, but the remaining seven patients, after 28 months of training, are now classified as partial paraplegics. They train for about one hour a week. It's different from classical techniques, in which the patient is a passive recipient of physiotherapy – the patient is actively engaged in every single manoeuvre. We

PHOTOS: DUKE CENTER FOR NEUROENGINEERING X3

ABOVE: Once the patients had trained their brains with VR, they used a robotic exoskeleton that they could control with their minds

BELOW: The patients wore shirts that gave them information about the floor, via vibrating elements

ILLUSTRATION: RAJA LOCKEY

believe the brain has to be engaged all the time to trigger this clinical improvement.

Why was your approach successful?

When we measured brain activity, we noticed it was almost like patients had forgotten what it means to have legs. Through virtual reality, we had to reinsert that in the brain. When the concept of walking was relearned, there was a process of functional reorganisation of brain circuits. The brain probably started generating new electrical commands and tried to transmit these down the spinal cord. My hypothesis is that since the original trauma, even more than a decade ago, a few nerves may have survived and just stayed there, silent. But when we rekindled these circuits, somehow the brain found a way to send messages through those nerves. During training the spinal cord neurons were hit at the same time by sensory information, because patients were being moved by the robotic devices when they walked. So I think this combination triggers an important process of 'plasticity' – the term we use for functional rearrangement of the brain. We are going to track these patients for as long as we can, because we haven't yet found a plateau for their recovery.

THE LAZY

Like nothing more than putting your feet up? Well, you might be a genius. Smart people spend more time lost in their thoughts and so are less likely to alleviate boredom with physical activity than less intelligent counterparts, researchers from Florida Gulf University have found.

SINGLETONS

After looking at 800 studies on single people carried out over the last 30 years, the University of California's Bella DePaulo found that single people are more likely to feel a sense of continued growth and development than those in relationships.

GOOD MONTH

BAD MONTH

FACEBOOK PHONIES

The more our 'Facebook selves' differ from our true selves, the more likely we are to be stressed, depressed and socially isolated, say researchers at the University of Tasmania.

CONSPIRACY THEORISTS

Take off the tinfoil hat. Chemtrails, long-lasting streaks left by aeroplanes, are a product of climate change and new engine designs, not part of a scheme to spray toxic chemicals into the atmosphere, a team at Carnegie Institution has found.

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BIOLOGY

SEE-THROUGH MICE OFFER UNPRECEDENTED VIEW OF THE NERVOUS SYSTEM

How do you peer inside an animal without taking an X-ray or MRI scan? By making it transparent, of course.

Researchers at Ludwig Maximilian University of Munich in Germany have developed a technique to render the bodies of small mammals such as mice and rats completely see-through, allowing their nervous systems and organs to be studied in greater detail than ever before.

Dubbed uDISCO, ultimate 3D Imaging of Solvent-Cleared Organs, the new method works by stripping the water and fat out of the bodies of dead mice and rats using a solvent. After three or four days of treatment, the researchers are left with a shrunken, almost entirely transparent version of the animal.

By targeting the organ systems of interest with fluorescent proteins, the researchers were able to create detailed images of the various structures within the animal such as veins or neurons.

"Since it allows individual cells to be localised, the method could be used to detect and characterise metastatic tumours [cancers that spread to other parts of the body] at an earlier stage than is now feasible, or to monitor how stem cells behave in the body following a bone-marrow transplant," said researcher Ali Ertürk.

As the technique is refined, it may be applied to larger animals such as monkeys and potentially even a whole human brain, the researchers say. This could help us learn more about neurological disorders such Alzheimer's and Parkinson's.

This mouse has been made transparent with the uDISCO method, allowing scientists to see its organs

Ötzi's clothes are made from both domesticated and wild animals

ANTHROPOLOGY

These are some pretty cool threads

Despite being 5,300 years old, this outfit probably wouldn't look out of place as part of one of the edgier catwalk shows at London Fashion Week.

The clothes belonged to the Tyrolean Iceman, or 'Ötzi', a mummy discovered in the Ötztal Alps on the border of Italy and Austria in 1991. The garments were stitched together from the hides of at least five different animals, according to a DNA analysis carried out at University College Dublin.

The finding suggests that Neolithic people were skilled tailors who selected different animal skins based on their different properties, the researchers say. "Given that there appears to be pattern to the Iceman's clothes assemblage, he was a resourceful individual using all that was available to him," explained researcher Niall O'Sullivan.

The leggings were made using goat leather, the loincloth sheep leather, the shoelaces cow leather, and the coat both sheep and goat leather, which are all domesticated animals. However, the hat was made from brown bear fur and the quiver from roe deer hide, suggesting that Ötzi was a hunter as well as a farmer.

Until now, scientists were unable to clearly identify the specific materials used in the Tyrolean Iceman's clothing, thanks to their advanced state of decay. However, by sequencing the mitochondrial genomes, which contain DNA transmitted exclusively through the female line, they were able to target and magnify certain strands to identify the different species.

PHOTOS: ALI ERTWERK, INSTITUTE FOR MUMMIES AND THE ICEMAN

WHAT WE LEARNED THIS MONTH

HUMANS CAUGHT THE COMMON COLD FROM CAMELS

This is enough to give anyone the hump: the first human to ever suffer a common cold caught it from a camel, researchers at the University Hospital of Bonn say. They made the discovery while studying Middle East respiratory syndrome, which is also passed from camels to humans.

WHY WE NEED TO PARTY

If you're the sort that loves nothing more than a good ol' knees-up, thank your ancestors. Gathering in groups and dancing was a key way for early humans to bond and ultimately prosper, researchers from the University of Montreal say.

YOUR BRAIN HAS A 'PHYSICS ENGINE'

It doesn't matter whether you understand Newton's laws of motion or not, we all have a 'physics engine' in our brains that allows us to predict how physical objects will behave, a team at Johns Hopkins University has found. It performs real-time physics calculations to help coordinate our movements.

WE'VE ALREADY USED UP THIS YEAR'S RESOURCES

Well, this is depressing. International climate research organisation Global Footprint Network has reported that 'Earth Overshoot Day' fell this year on 8 August. This is the day on which humanity used up the Earth's resources for the year.

SPACE

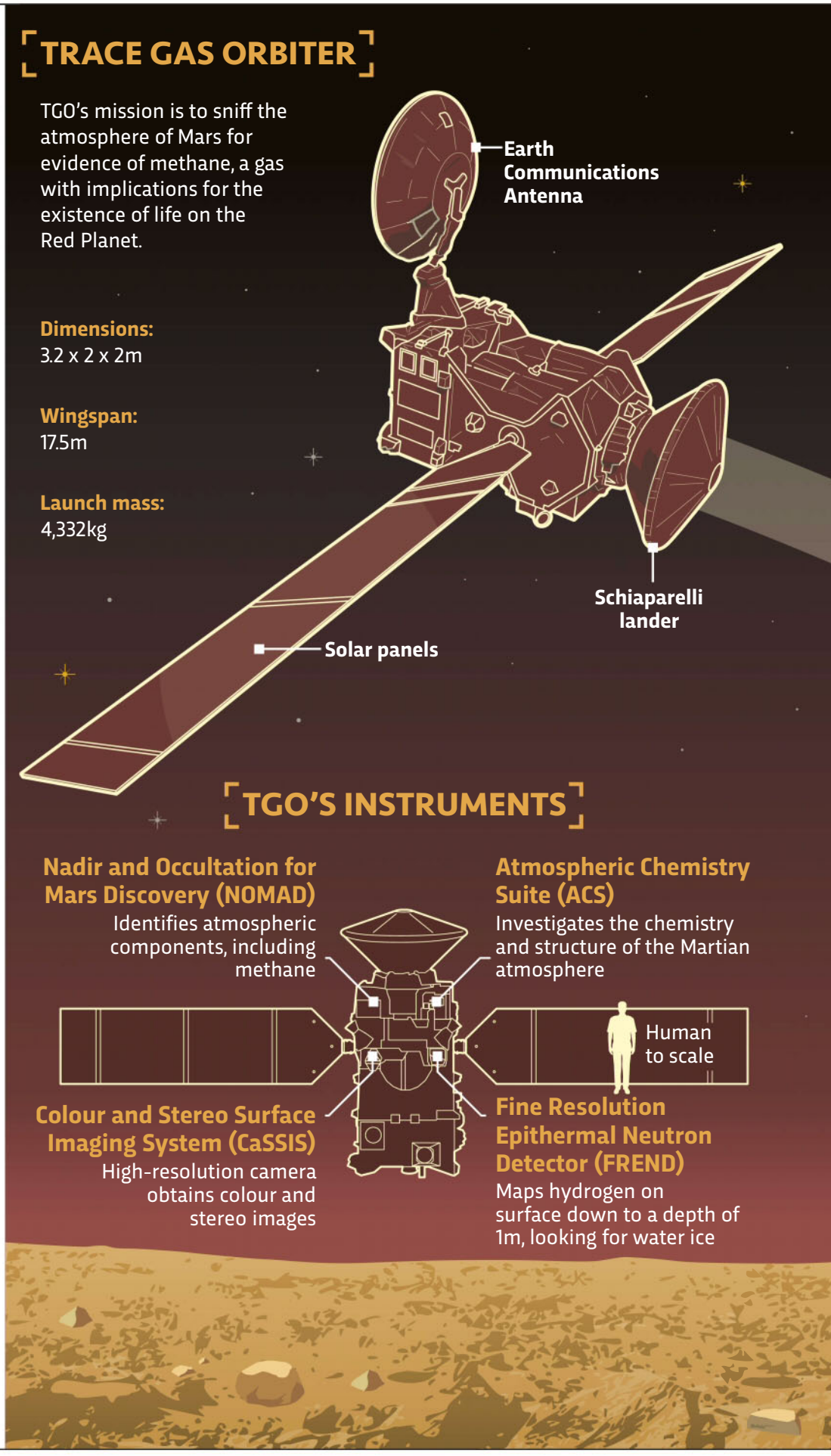
EXOMARS READY TO SNIFF OUT LIFE ON MARS

The first mission of European Space Agency's (ESA) ExoMars programme is set to complete its seven-month journey to the Red Planet on 16 October.

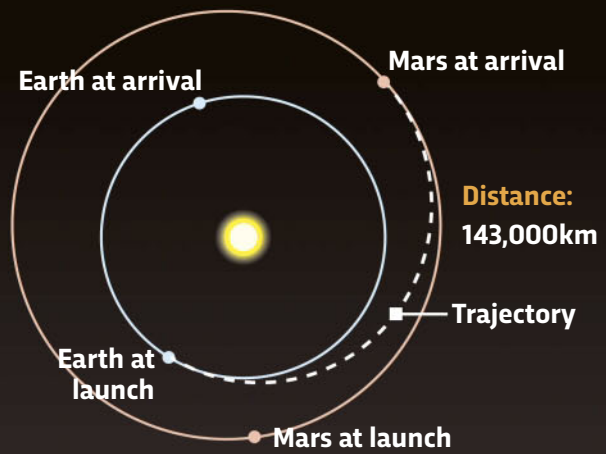
The spacecraft comprises two separate instruments: the Trace Gas Orbiter (TGO) and the Schiaparelli landing demonstration module. Once in orbit the TGO will perform detailed observations of the Martian atmosphere, searching for evidence of gases indicative of the existence of biological life, such as methane.

Also, at this point the Schiaparelli lander will be ejected from the orbiter towards the Red Planet, entering the atmosphere at 21,000km/h before using a combination of thrusters, aerobraking and parachutes to land on the surface. Once safely on solid ground, the lander will deploy its payload of scientific instruments to take measurements the atmospheric conditions on the surface.

The lander will only remain operable for a few days but the TGO will stay in orbit for five years, waiting for the arrival of a second rover in 2020 that will drill into the surface of the Red Planet.

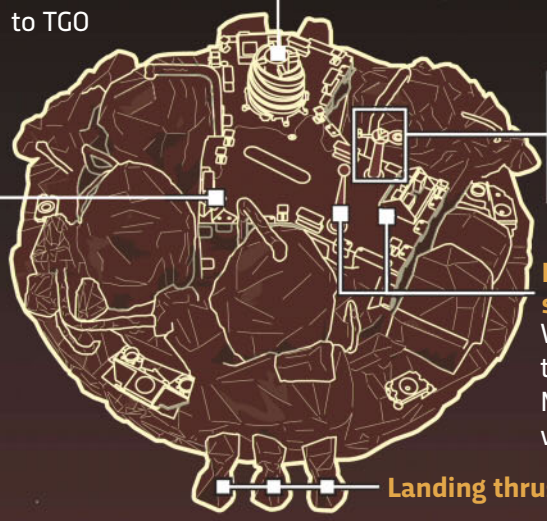


JOURNEY TO MARS



SCHIAPARELLI LANDER

Schiaparelli's main purpose is to demonstrate Mars-landing technology. It is expected to survive only a few days on the surface, running off its internal batteries. The little lander is 1.65m in diameter and weighs just 600kg. Schiaparelli has instruments to measure wind speed, pressure, temperature and electric fields.



Heatshield protects lander

Parachute deploys

Front shield separates
At an altitude of 7km, the heat shield separates and the landing radar is switched on

Thruster ignition
Slows for landing on Mars surface

Touchdown

ILLUSTRATION: ACUTE GRAPHICS

CHORD

Chord Electronics Ltd.

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Hi-Fi Choice EDITOR'S CHOICE

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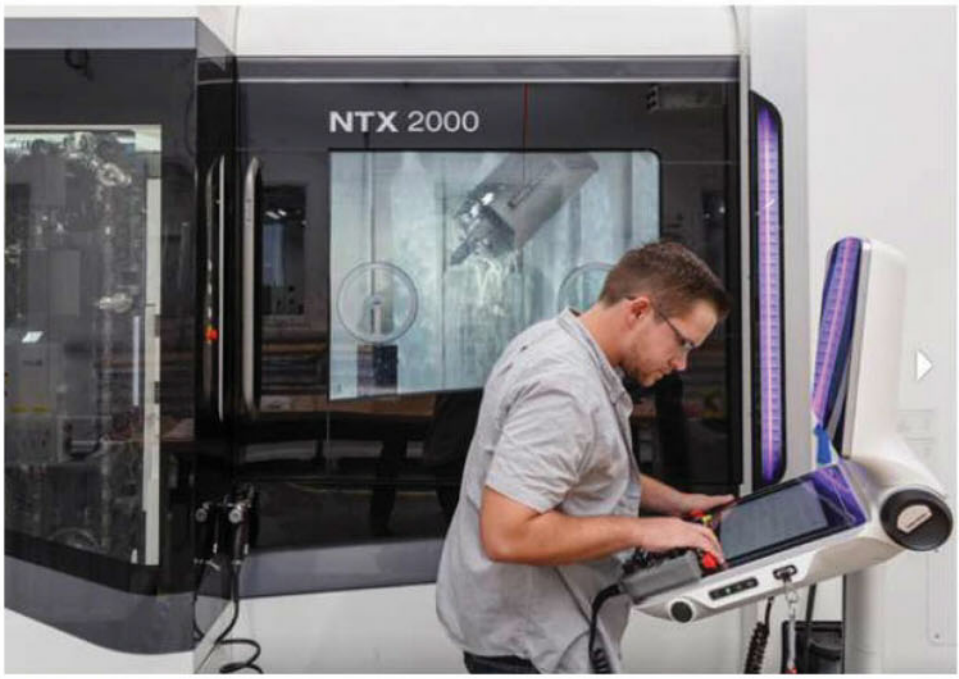
DO THE ROBOT

Robots set new Guinness World Record

These are just a few of the 1,007 robots that recently set a new Guinness World Record by dancing in unison for 60 seconds. The record attempt was staged as part of China's Quingdao Beer Festival by Chinese battery manufacturer Ever Win. The robots, which stand 43.8cm tall, were reportedly controlled from a single smartphone.

Even though 33 of the robots keeled over during the attempt, those remaining were more than enough to smash the previous world record of 450 dancing robots, which was set by UBTECH Robotics Corp at the CCTV Spring Festival Gala back in January. To watch the record-breaking robots in action, visit bit.ly/dancing_bot

PHOTO: GETTY



WELCOME TO AREA 404

Facebook launches new hardware development lab

Facebook is the world's biggest social media network. And while this brings advantages, it also brings challenges. When around a sixth of the world's population is relying on you for its news, entertainment and communication with friends, family and colleagues, you need a versatile and resilient hardware network to keep things running smoothly.

That's why Facebook has just opened Area 404, a large facility at the company headquarters in Menlo Park, California. Named after the error code for a website failing to load, this state-of-the-art laboratory is where Facebook's engineers will design, build and test new technology intended to keep those Likes and Shares flowing freely.

THIS STATE-OF-THE-ART LABORATORY IS WHERE FACEBOOK ENGINEERS DESIGN NEW TECH

As well as electrical engineering labs, Area 404 is home to a number of prototyping workshops. Equipped with all manner of machinery such as lathes, milling machines and a high-pressure water jet that can slice through sheet metal, as well as equipment such as electron microscopes and CT scanners, these workshops are where new Facebook-related tech will be developed. Next time you hear Mark Zuckerberg enthusing about bringing internet access to isolated areas via solar-powered drones, or talking up the new Facebook Surround 360 video capture system for VR applications, be assured he's not just spouting hot air – these are the kind of projects that are being worked on inside Area 404 right now. For example, those lathes we mentioned earlier can be used for making gimbals, which are used in communications lasers, while the electron microscopes can check hardware for faults.

"Connectivity Lab, Oculus, Building 8, and our Infrastructure teams can now work collaboratively in the same space, learning from one another as they build," says a statement on the company website.

The building of Area 404 isn't a radical move on Facebook's part. But as Facebook continues to acquire start-ups in all kinds of technological fields, the construction of the facility is further proof of the company's wide-reaching ambitions.

Let's just hope that, with a name like that, it doesn't suddenly disappear!

NEWS BYTES

GOGORO REACHES BERLIN

Gogoro, the battery-swapping electric scooter network we told you about in August 2015, has launched in Berlin, with 200 scooters available for hire in the city.

MISTAKEN IDENTITY

A US couple is suing IP mapping company MaxMind after it used their address as the default location for over 600 million IP addresses – leading to numerous visits from the police investigating identity theft and other crimes.

NO MORE MOORE?

A new study has suggested that Moore's Law – which says that computer processing speed doubles every two years – will no longer apply by 2021. Then again, its demise has been predicted several times before...

BITCOIN HEIST

At the start of August, hackers managed to infiltrate Hong Kong-based Bitcoin exchange Bitfinex and made off with over $60m worth of the cryptocurrency.

iPLAYER LOOPHOLE CLOSED

As of 1 September, you can't dodge the BBC licence fee by only watching iPlayer – the terms of the licence have been amended to cover all forms of BBC broadcast, regardless of the medium involved.

Imagine that looming over you while cycling to work...

TRANSPORT

China test-drives elevated bus

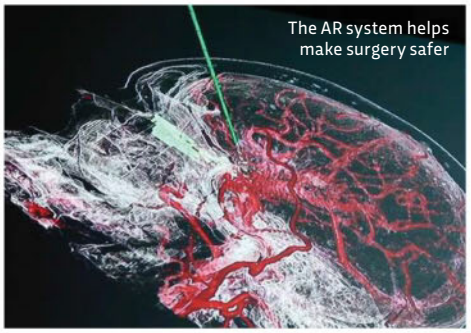
Back in May, at the Beijing International High-Tech Expo, Chinese engineers showed off a radical public transport vehicle called the Transit Elevated Bus (TEB) that straddles roads, running on rails like a tram while cars pass freely underneath. And now, just a few months later, a working prototype has been demonstrated, completing a 300m test-drive in the city of Qinhuangdao on the northeastern coast of China.

On this first outing, the bus travelled extremely slowly, but the engineers say that eventually the 22m-long bus, which stands 4.8m tall and measures 7.8m across, could attain speeds up to 60km/h (37mph) while carrying 300 passengers. Chief engineer Song You Zhou even suggests it could be running regular TEB services by the end of this year.

However, some experts have cast doubt on the bus's ability to deal with real-world hazards such as pedestrian crossings and bridges, while there's even been speculation in the Chinese press that the whole project may be part of an elaborate financial scam. We'll keep you posted on further developments.

HEALTH

AR comes to ER



The AR system helps make surgery safer

Augmented reality could soon be saving lives, thanks to researchers at New York's Mount Sinai hospital. They've developed an app that enables a surgeon to look through the surgical microscope and see video overlays of, for instance, the precise location of key blood vessels, even if these are physically hidden from view.

Joshua Bederson MD, of Mount Sinai's Dept of Neurosurgery, compares the system to sat-nav in your car. "We know where we're going most of the time," he says, "but if we have a map that's updated in real time, and can see the position of our car in relation to that map, that can make the drive more efficient. We're trying to bring in other lines of information that make doing these procedures even safer."

CARS

The glide of your life

Back in 2013, Nissan introduced a concept electric sports car called the BladeGlider. It was originally slated to go into production, but then any such plans were quietly shelved.

Now, though, Nissan has been showing off a working prototype of BladeGlider, fuelling speculation that it may one day hit showrooms after all. Let's hope so, because with a top speed of 185km/h (115mph), the ability to go from 0-60 in under five seconds and, perhaps most importantly, very cool butterfly doors, this is one electric vehicle that should spare you all the tree-hugger jibes… even if the three-seater's triangular shape *is* a little bit odd.

Electric cars: not just for tree-huggers

PHOTO: FACEBOOK, GETTY, PRESS ASSOCIATION, NEWSPRESS

WANTED!

GO ONE BETTER

QUAD VA-ONE

Combine the convenience of digital music with the rich, warm sound of analogue with this new integrated valve amp from Quad. A built-in digital-to-analogue converter (DAC) turns digital audio signals into analogue before passing them on to its high-end, valve-based preamp and two 15W power amp stages. There are coaxial, optical and USB as well as RCA inputs, and it'll stream music from digital devices using Bluetooth, too. The price tag may look pretty hefty, but in the bizarre parallel universe of 'true hi-fi', £1,295 is actually relatively affordable.

£1,295, quad-hifi.co.uk

RIGHT ON TIME

OCTOPUS

Dubbed 'the training wheels for good habits' by its makers, Octopus is a watch and scheduler/personal assistant designed for children aged three to eight. Available in a range of bright, kid-friendly colours, the watch displays the time alongside relevant, parent-selected icons (a toothbrush for 7.30am, a bowl of cereal for 8am and so on) so that little 'uns don't just learn to tell the time – they get to grips with the concept of time itself. It's already smashed its Indiegogo funding target 15 times over, and will start shipping next spring.

$69 (£55 approx), octopus.watch

Feast your eyes on this

4K FOR UNDER £1K

HISENSE M7000

While 4K UHD offers far better picture quality than standard HD, take-up of the format has been somewhat sluggish due to the high price of 4K sets. Now, though, Chinese manufacturer Hisense has started selling its 55-inch M7000 ULED TV for just £799 – an incredible price given that the set also meets the new HDR (high dynamic range) standard, which was only agreed upon earlier this year. There's also a 65-inch model, but that'll set you back a little more at £1,199.

£799/£1,199, hisense.co.uk

LET'S GO ROUND AGAIN

NINTENDO CLASSIC MINI

There's no shortage of retro-themed gaming devices on the market, but this miniature, HDMI-enabled version of the classic NES console is slightly unusual in that it actually comes from Nintendo itself. Coming preloaded with over 30 games including the likes of *Pac-Man*, *Final Fantasy*, *Super Mario Bros* and *Donkey Kong*, it's due to go on sale in November – and with a price tag of £50, we could be looking at one of Christmas 2016's biggest sellers.

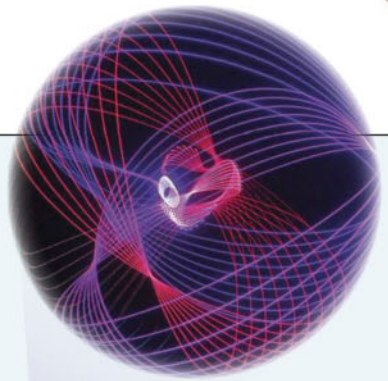
£50, nintendo.com

PRIVATE DTEK-TIVE

BLACKBERRY DTEK50

BlackBerry may no longer be the high-flying executive's go-to smartphone, but the company isn't taking the loss of its market-leading position lying down. Its latest attempt to revive its fortunes is the DTEK50, an Android phone that it's touting as "the world's most secure". The phone has a 5.2-inch touchscreen, 16GB of storage and a 13MP camera, but it's the custom, security-first build of Android Marshmallow that BlackBerry is hoping will bring the suits rushing back.

£275, blackberry.com



REACH FOR THE LASERS!

LASERDOCK

Turn your home into a nightclub with LaserDock, a unit that combines lasers and musical visualisation software to put on a stunning show right there in your front room. It's the brainchild of Wicked Lasers – maker of some of the most stupidly OTT laser pointers in the world – and gives you the choice of selecting from one of over 100 pre-programmed displays, or creating your own using the supplied Spaghetti Lite and LaserShow Xpress apps.

$299 (£230 approx), wickedlasers.com

APP FEED

Verne: The Himalayas

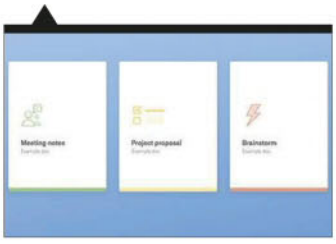
This app lets kids explore the Himalayas as Verne the yeti, who can climb mountains, or fly using a jetpack, balloon or hang glider.

Free, Android

Paper

Paper is a new Google Docs-style collaborative working tool from Dropbox. It's just gone into public beta, and now comes with apps for Android and iOS devices.

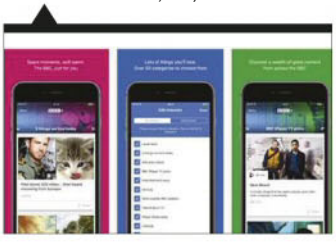
Free, iOS/Android



BBC+

This new app lets you select topics you're interested in, from business news to rugby league, then alerts you when relevant content appears anywhere across the BBC.

Free, iOS/Android



REPLY

Your opinions on science, technology and BBC Focus

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MESSAGE OF THE MONTH

Smoke signal

Robert Matthews' article on diesel pollution (September, p81) appears to be based on some very controversial 'science'. In 2014 there were 36,000 deaths from lung cancer in the UK, the vast majority of those being heavy tobacco smokers. He now tells us there are 50,000 additional deaths per year from inhalation of NOx and particles from diesel engines. This can only be true if millions of people have taken up the habit of inhaling directly from diesel exhaust pipes.

He then states that diesel cars are bigger and heavier than petrol cars. They are the same size as their equivalent petrol-powered siblings and on average about five per cent heavier. A BMW 320i weighs 1,505 kg and a 320d weighs 1,580 kg, but the 320i uses about 30 per cent more fuel, so producing 30 per cent more CO_2. When I drive from Calais to Munich, I can do the trip without stopping for fuel in my 320d, but this would be impossible in a 320i.

I believe these death figures are untrue, but in any case most diesel pollution is coming from lorries, taxis, buses and of course ships. If you want to outlaw such efficient vehicles you will put the UK out of business in no time flat.

Dan Parker, Cobham

The mortality figures come from the government's own policy paper on the subject (**bit.ly/2bU6rRJ**). I too found them shocking, but not nearly as shocking as the determination of some motor manufacturers to put profit ahead of public health. ***– Prof Robert Matthews*, BBC Focus *columnist***

Diesel engines: not always a cleaner option

Logic of logarithms

Neelofer Banglawala referred to John Napier as the inventor of logarithms (August, p107).

The purists among us would of course insist that logarithms have always existed! However, it took a mathematical genius like Napier to discover their presence.

Fraser Gillespie, Dumbarton

Sticky fingers

Regarding Helen Czerski's problem with opening plastic bags in supermarkets (August, p55), I was told a few years ago by someone 'in the know' that there is a trick to opening the bags without having wet fingers. If you take the handles of the bag in your hands and gently but firmly pull them apart this opens up the inner corners of the bag enough to get your fingers in.

Also, could Helen provide any explanation as to why children's hands are always sticky, no matter what you do to clean them?!

Will Hatton, via email

Not even science can solve the problem of kids' sticky fingers! ***– Ed***

WRITE IN AND WIN!

The writer of next issue's *Message Of The Month* wins a fantastic **MiniStation Slim portable hard drive**. This slimline 1TB drive uses USB 3.0 for faster data transfer and is Mac- and PC-compatible right out of the box. Check it out at **buffalotechnology.com**

WORTH £100

ILLUSTRATION: ADAM GALE

MORE FOCUS FOR YOU

Don't forget that *BBC Focus* is also available on all major digital platforms. We have versions for Android, Kindle Fire and Kindle e-reader, as well as an iOS app for the iPad and iPhone.

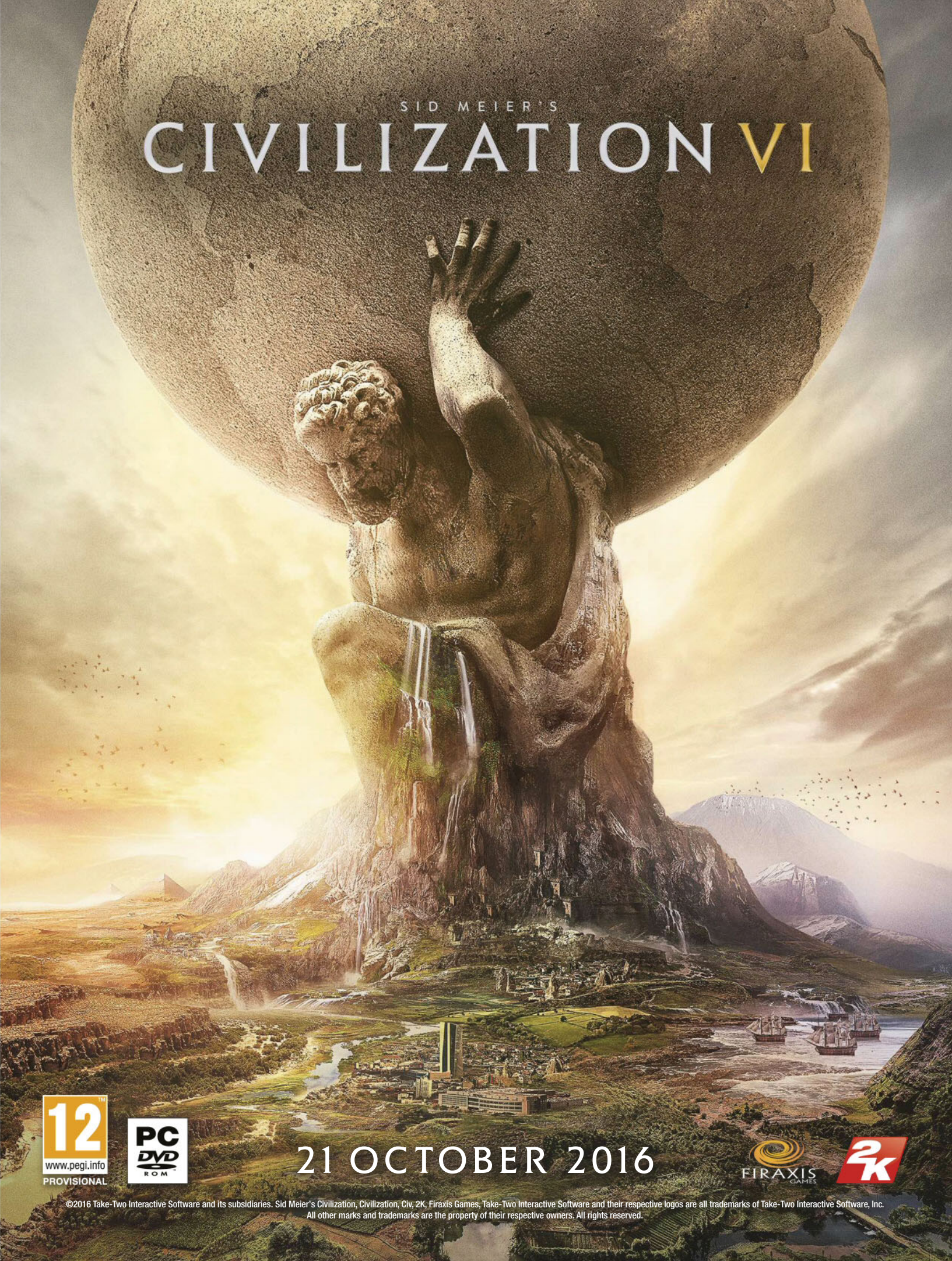
Can't wait until next month to get your fix of science and tech? The Science Focus website is packed with news, articles and Q&As to keep your brain satisfied. **sciencefocus.com**

Special issue

ON SALE NOW

THE AMAZING BRAIN

The organ between your ears is one of the most complex machines on the planet. This special edition from the *BBC Focus* team explores the science behind free will, intelligence, addiction, and more.



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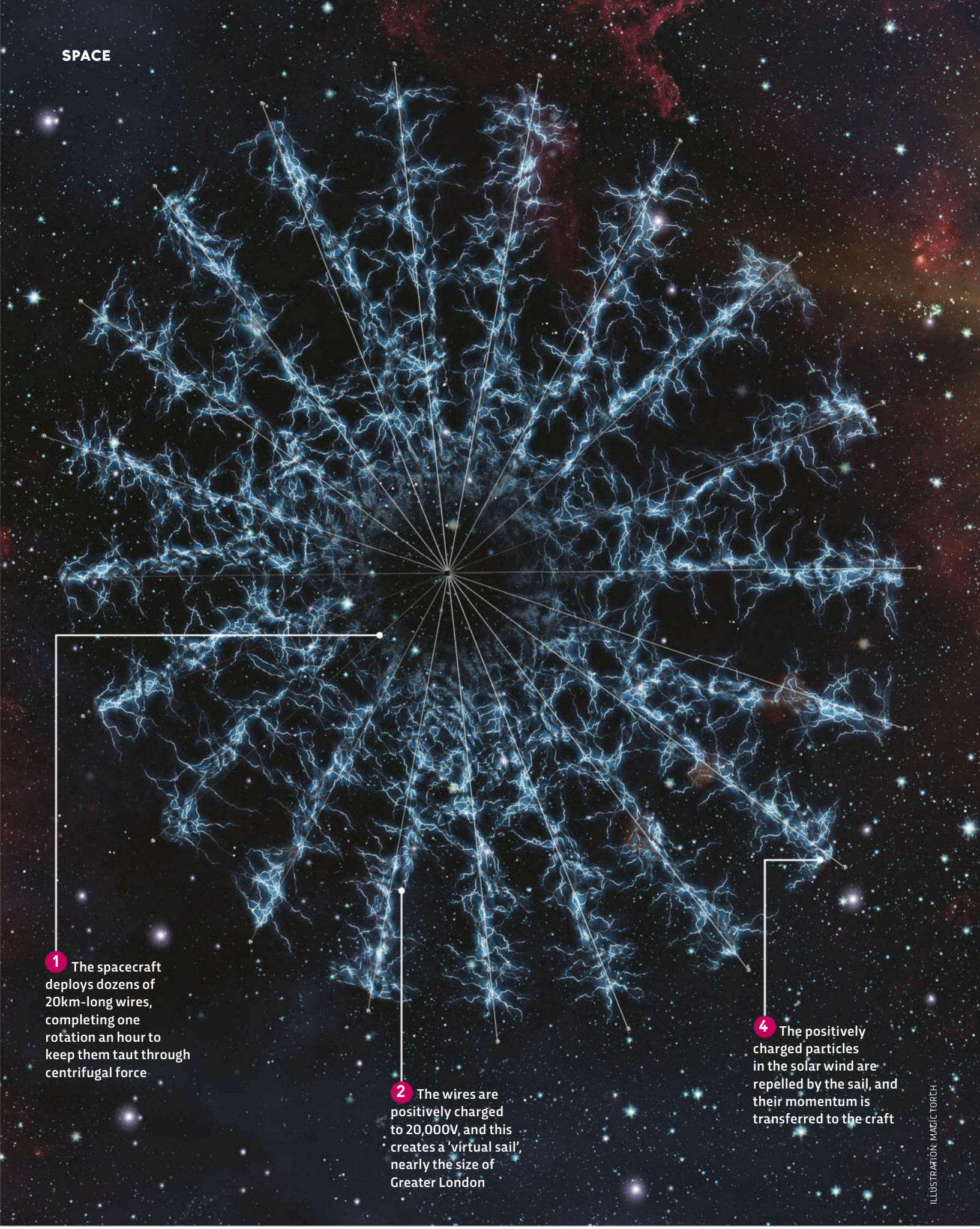
THE NEXT GIANT LEAP

ILLUSTRATION: MAGIC TORCH

An Earth-like planet has been discovered orbiting our nearest star after the Sun. Current tech could take around 70,000 years to get there. We look at the outlandish projects vying to rewrite space exploration as we know it

Words: **Dr Stuart Clark**



1 The spacecraft deploys dozens of 20km-long wires, completing one rotation an hour to keep them taut through centrifugal force

2 The wires are positively charged to 20,000V, and this creates a 'virtual sail', nearly the size of Greater London

4 The positively charged particles in the solar wind are repelled by the sail, and their momentum is transferred to the craft

ILLUSTRATION: MAGIC TORCH

NASA's half-tonne New Horizons craft took nine years to reach Pluto; an e-sail could transport twice the mass in half the time

THE E-SAIL

In 1980, Carl Sagan's TV series *Cosmos* introduced audiences to his 'spaceship of the imagination'. This fantastic design resembled a dandelion seed floating on the 'winds' of the Universe. Now it seems Sagan's imagination may not have been so far-fetched.

The electric sail (e-sail) is the brainchild of Dr Pekka Janhunen, at the Finnish Meteorological Institute. He conceived the idea while studying the Northern and Southern Lights, which are produced when electrically charged particles from the Sun interact with molecules in our atmosphere.

Janhunen calculated how to build a virtual sail that could harness the electrical charge from this continuous solar wind and transform it into momentum to propel a spacecraft. He imagined a central craft deploying between 50 and 100 wires, each some 20km in length. These wires would be electrified to around 20,000 volts with positive electrical charge, and so would repel the positively charged protons from the solar wind like light bouncing off a mirror. This would transfer momentum from the particles to the spacecraft.

According to the maths, a one-tonne spacecraft would be accelerated by 1mm/s every second. That may not sound much, but this constant acceleration would quickly add up. After a year, the terminal speed would be 30km/s. NASA's half-tonne New Horizons craft took nine years to reach Pluto; an e-sail could transport twice the mass in half the time.

A version of the e-sail will fly on the Finnish Aalto-1 satellite, which is scheduled for launch in October. Instead of using the sail to accelerate, the satellite will deploy the sail at the end of its life to slow down and re-enter Earth's atmosphere, to avoid becoming space debris.

"The e-sail technology has great potential. It can provide much cheaper and much faster propulsion for planetary missions, saving tens of millions of dollars in launch cost," says Jaan Praks, principal investigator of Aalto-1. "The most important aspect of this technology is that it is plausible to manufacture already. It does not require any mysterious future inventions, just good engineers and wise decision-makers are needed."

NASA has become interested in this technology too. Janhunen and US colleagues won $500,000 of funding in 2015 to continue testing in the lab. As they study the concept, those involved are interested in going much further than Pluto.

While an e-sail would take just 10 years to reach the very edge of the Solar System, it would still take thousands of years to reach the nearest stars.

ANTIMATTER ROCKETS

Antimatter is the staple fuel source in *Star Trek* – and perhaps the reason why Scotty always looks so worried. This notoriously volatile substance is the perfect fuel in one sense because it converts matter into energy with 100 per cent efficiency. In other words, it can release vast amounts of oomph.

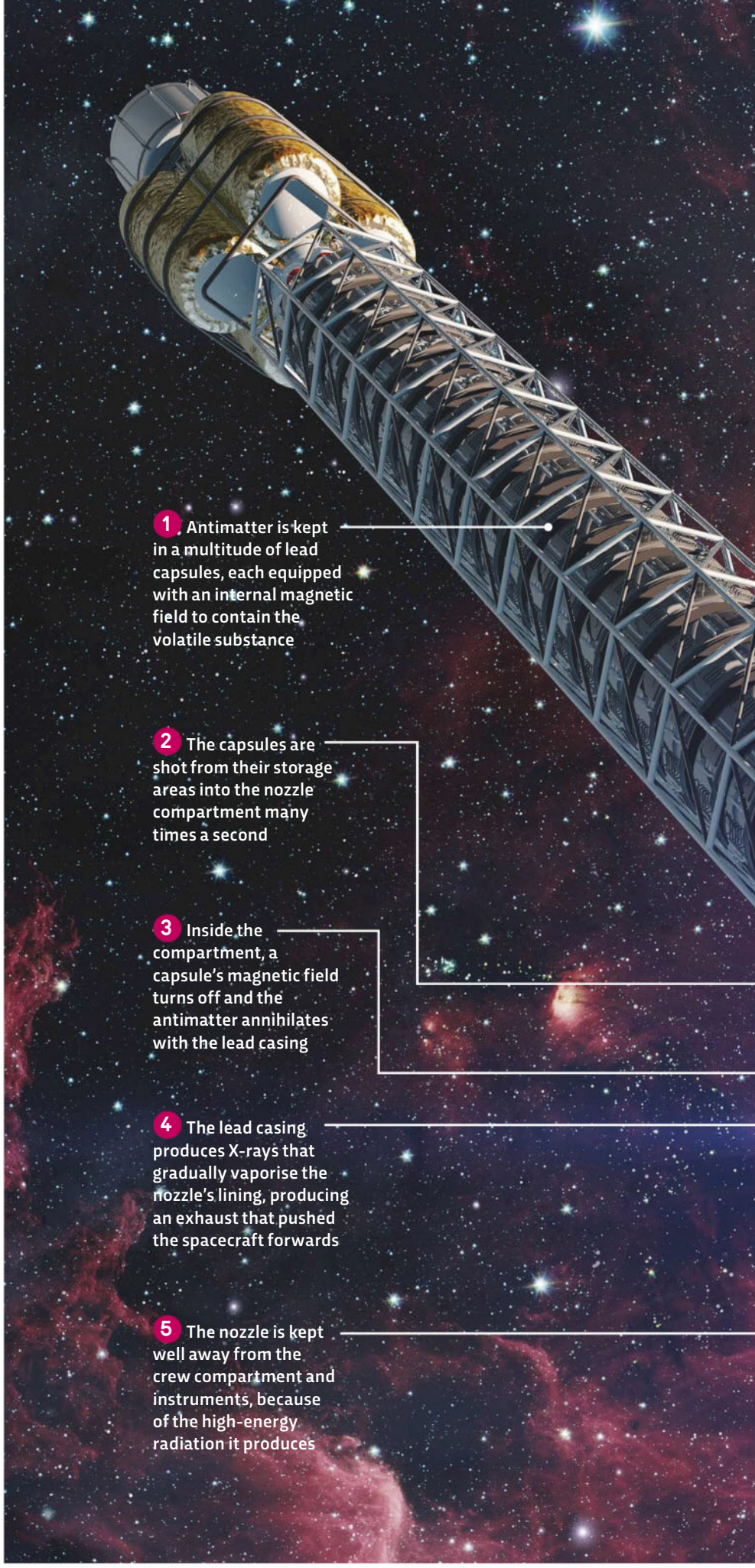
In 2006, the NASA Institute for Advanced Concepts funded the study of a possible antimatter spacecraft. Led by Gerald Smith of Positronics Research, the work concluded that a ship could be propelled to Mars in just 45 days, using a minuscule one-hundredth of a gramme of antimatter. With potency like that, why stop at Mars?

In 2003, physicist Gerald Jackson and nuclear engineer Steven Howe, both of US company Hbar Technologies, LLC, published their own study. It showed that with 17g of antimatter, a spacecraft could cross one light-year of space in just a decade. This would mean that the nearest star system, Alpha Centauri, could be reached in about 40 years.

But there's a catch. Antimatter is the most expensive substance on Earth. Back in 1999, NASA estimated that to create a single gram of it would cost $62.5tn. Even today, the cost is hovering around a trillion dollars. This is because tiny quantities of antimatter are created as a by-product in particle accelerators, which are super-expensive to start with. Of all the particle accelerators in the world, including the Large Hadron Collider at CERN, less than 20 nanograms of antimatter have been made.

Storage is another problem. Antimatter is the opposite of matter. The antimatter equivalent of an electron is called a positron. Although it contains the same mass, its electrical charge is opposite. When a positron and an electron meet, they annihilate each other back into energy. So trying to store antimatter in something made from matter is doomed to explosive failure – hence Scotty's perpetual anxiety.

However, since antimatter carries an electrical charge it can be deflected by a magnetic field. This means antimatter could be stored in some form of bottle that creates a magnetic lining inside to prevent it touching the sides. Despite the difficulties, the promise of such a power keeps researchers coming back to studying antimatter. Earlier this year, Jackson and Howe started to look for funding to build laboratory prototypes of an 'antimatter sail' that they hope could make this theoretical idea a reality.



With 17g of antimatter, a spacecraft could cross one light-year of space in just a decade

PHOTOS: GETTY, NASA/X4, ESO ILLUSTRATION: MAGICTORCH

WHERE SHOULD WE GO?

Proxima b

For our first interstellar trip, it's a no-brainer that we should go to the nearest exoplanet, Proxima b. The Earth-like planet was recently discovered orbiting the red dwarf star Proxima Centauri, which lies around 4.2 light-years away. Proxima b is a rocky planet, and is close enough to its host star to allow liquid water to exist. Could life be lurking on its surface?

Kepler 452

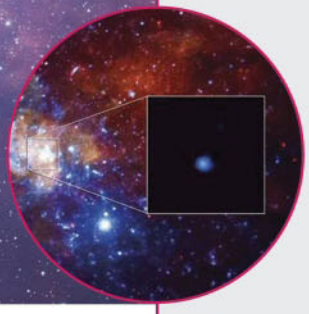
If we had a warp drive, this star would be worth a visit. At 1,400 light-years away it is a fair distance to travel but in 2015 NASA announced that this star possesses a planet similar to Earth. The star itself is almost identical to the Sun, the planet is as far from it as Earth is from the Sun, and it's a bit bigger than Earth. At present, it's the most Earth-like planet discovered.

Wolf 1061

Just 13.8 light-years from Earth, this red dwarf star plays host to a potentially habitable planet. It was discovered by astronomers from the University of New South Wales in 2015 and has a radius 1.5 times larger than Earth. As its host star is smaller and much dimmer than the Sun, the planet has a far shorter orbit than Earth. Its year is just 17.9 days long.

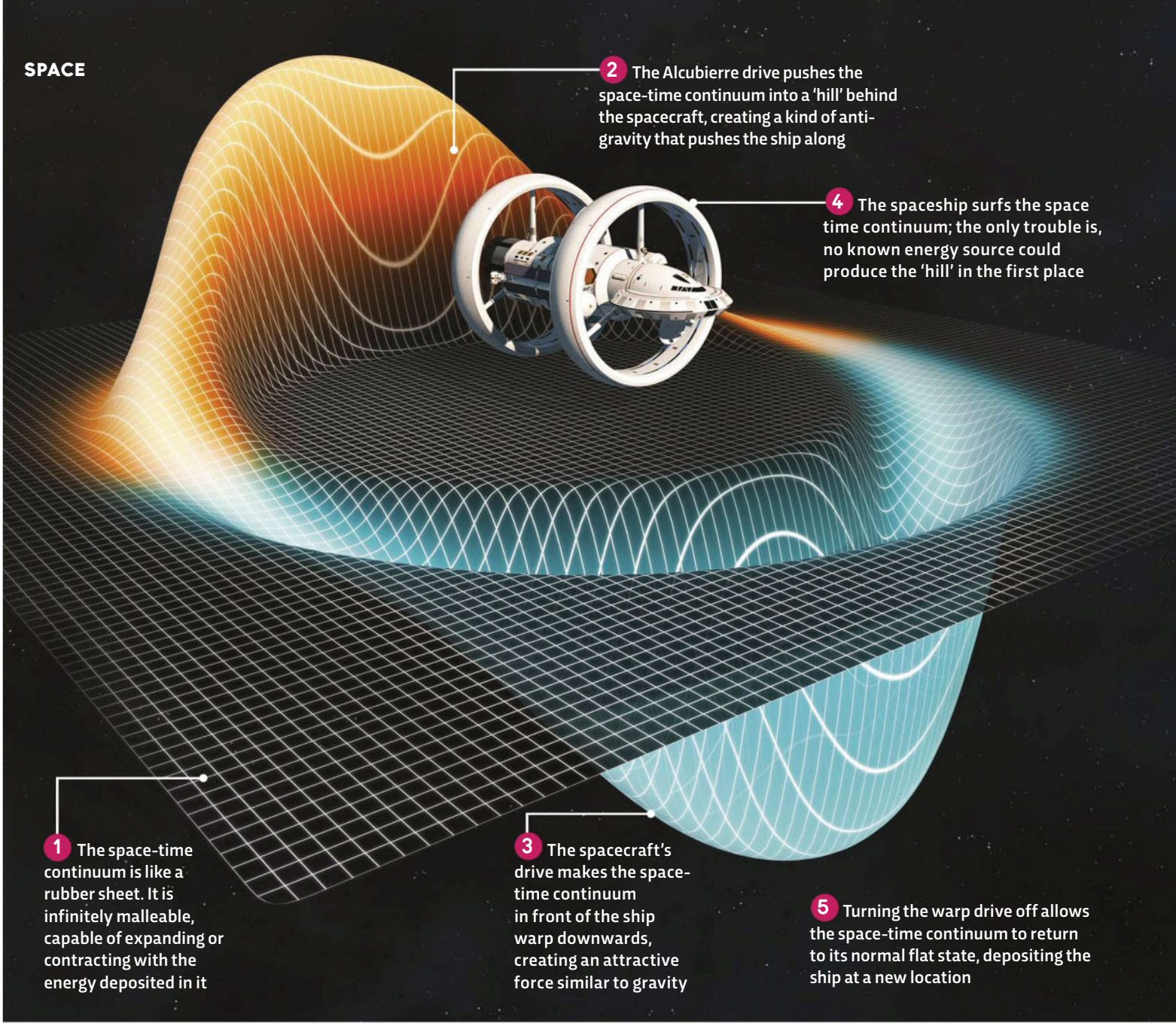
Orion Nebula

Astronomers have used ground-based telescopes to observe this faint smudge in the constellation of Orion, where thousands of stars are being formed. The Orion Nebula lies 1,344 light-years away, and whole solar systems of planets are being glimpsed in their nascent form, while others are being destroyed by radiation from surrounding stars.



The centre of the Milky Way

With a warp drive we could travel to the centre of the Galaxy, some 30,000 light-years away, and observe the vast black hole thought to reside there. It sits inside a bright, compact radio source called Sagittarius A* – astronomers would salivate at the possibility of watching as a star or a gas cloud fell into the black hole.



ALCUBIERRE DRIVE

No discussion of interstellar travel would be complete without making reference to a warp drive. This hypothetical device, again a staple of *Star Trek*, gets around a problem with physics, namely that nothing can travel faster than the speed of light.

Einstein's Special Theory of Relativity showed that the speed of light was a cosmic speed limit. Even though light speed is roughly 300,000km/s, that's still slow compared to interstellar distances. The nearest star to Earth other than the Sun, Alpha Centauri, is 4.3 light-years away, so light takes 4.3 years to cover that distance. Unless we can break the light barrier, it will always take longer than this to get there. This is where the warp drive comes in.

It has its basis in Einstein's next theory, the General Theory of Relativity, which expanded the earlier version to include a description of gravity. Einstein found that the most natural way to explain the action of gravity was to imagine space as being like a rubber sheet. He called this the space-time continuum. When heavy objects, such as stars or planets, were placed in the space-time continuum, they warped it and created gravity.

In 1994, physicist Miguel Alcubierre Moya published a paper showing that there was a way to warp the space-time continuum so that it would be capable of propelling a starship faster than the speed of light. No physics would be violated because General Relativity only excludes things travelling through space, not space itself moving. The trouble is that to make the 'warp bubble', as Alcubierre called it, the space-time continuum would have to be warped in a way that no known natural object or energy can do.

Partly in response to Alcubierre's work, NASA launched the Breakthrough Propulsion Physics Program in 1996, to investigate whether this or any other way to break the light barrier seemed plausible. But after six years and a total investment of $1.2m, the programme was disbanded. The conclusion was that no propulsion breakthrough was imminent.

Unfortunately, travelling to the stars as easily as we cross continents is something that is highly unlikely to be achieved in our lifetimes, and may be completely impossible. That still doesn't stop us dreaming about the possibilities, of course. And perhaps one day, someone will see the way to make our dreams come true. Never say never…

ILLUSTRATIONS: MAGIC TORCH

1 Microwaves are produced in a traditional magnetron by the interaction of electrons with a magnetic field

2 The microwaves are fed into a resonating cavity where they bounce back and forth, exerting pressure on the walls

3 According to experiments that have been conducted, the thrust on the large end is larger than on the small end

4 The conical shape of the cavity was shown by NASA to be essential: without it, no thrust was measured

5 Some physicists think the microwaves are interacting in an as yet unknown way with space itself to produce the thrust

THE PEOPLE PROBLEM

The biggest problem with spaceflight is always mass. Robotic space probes can be fairly compact and lightweight, but when you add humans, things get more complex. People need to space to live and work, as well as complicated life support systems, water and food stores. Put this all together and the mass of a spacecraft skyrockets.

But what if you could send humans as cargo and revive them when the craft reaches its destination? NASA has been investigating a 'torpor-inducing transfer habitat' in conjunction with an American company called SpaceWorks Enterprises. The inspiration comes from the care of heart attack victims. For years, doctors have been inducing a sleep-state, or torpor, in such patients by lowering their body temperature. This slows the metabolism and gives a chance for their body to recover. The patient stays that way for a few days.

Now NASA is investigating whether astronauts could be kept in a torpor state for weeks or months. Their body temperature would be lowered by a few degrees by inhaling a coolant through a fluid line fed through the nose. Nutrients would administered intravenously, and their vital signs would be monitored remotely.

NASA is already looking seriously at using this to send people to Mars, but a journey to an exoplanet would be a far more difficult proposition. Unless we make some kind of spectacular breakthrough, voyages could take decades or centuries, and that's a long time to be asleep.

ELECTRO-MAGNETIC DRIVE

How about a thruster that uses no fuel at all? Most physicists say the electromagnetic (EM) drive is a fantasy – but to its proponents, it is a game-changer.

When we launch a craft, most of its mass is the fuel. The Space Shuttle was 16 times heavier with its fuel than without. Most physicists say there is no way to get around this, because as the rocket fuel is burnt and expelled at high speed in one direction, it propels the rocket in the opposite direction. This is encapsulated in Newton's Third Law, which states that all forces have an equal and opposite reaction.

Without requiring fuel, the EM drive violates a basic law of physics and therefore cannot work. The trouble is, when people test it in the lab, it seems to work. Also known as the radio frequency (RF) resonant cavity thruster, the EM drive was conceived by British aerospace engineer Roger Shawyer. Despite profound theoretical objections, a number of independent groups have built their own versions and tested them. These include a team from Northwestern Polytechnical University in Xi'an, China, and one from Dresden University of Technology. None have been able to rule out that the engine was producing thrust, and in 2015, NASA's Eagleworks research group reported seemingly positive results from prototypes its built.

Critics are unconvinced. They say it is as impossible as lifting yourself off the ground by tugging at your shoelaces, and attribute the results to experimental error. It has been suggested that the EM drive works through interaction with the vacuum of space, which some physicists believe will turn out to be a seething mass of quantum particles rather than the nothing of traditional physics. But one thing is certain, it is odd that such a simple experimental setup can cause results that are so hard to explain.

"In science, new data must take precedence over old theory. There is always the risk of experimental error, but the fastest progress has always come from paying attention to interesting anomalies," says Mike McCulloch, a lecturer in the school of Marine Science and Engineering, University of Plymouth. "If the EM drive is confirmed, then new physics is needed."

If the EM drive holds up to scrutiny, then it could change space propulsion forever.

Dr Stuart Clark is an astronomy writer with a PhD in astrophysics. His latest book is *The Search For Earth's Twin* (£20, Quercus).

DISCOVER MORE

BBC FOUR Don't miss *The Sky At Night*, on BBC Four every month. Check *Radio Times* for more details.

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ILLUSTRATION: JAMES OLSTEIN

LIFE BUT NOT AS WE KNOW IT

Bizarre microbes that feed and breathe on electricity alone could be the missing link for how life began on Earth, and may even offer clues as to whether alien life exists on other planets

Words: **Jheni Osman**

Armed with a head torch, canisters and electrodes, Yamini Jangir slowly descends into the darkness. Dank air closes around her. She passes roughly hewn layers of rock, hacked back years ago to make way for the lift shaft.

The lift cage eventually judders to a halt, 1.5km below the surface. Picking her way along the gold mine's maze of passages, she finally locates an old metal pipe. Siphoning off the water inside, she inserts the electrodes and waits for her prey to 'bite'.

The airless, dark depths of a gold mine in South Dakota might not seem like the best place to look for life. But here, deep under the surface, microorganisms surviving on electricity alone could hold clues as to what kick-started life on Earth, and where aliens could exist in our Solar System and beyond.

THE POWER OF LIFE

Laptops, smartphones and other electronic devices rely on electricity, specifically the flow of electrons. Electrons are found in all atoms, and are the negatively charged subatomic particles that carry electricity through solids.

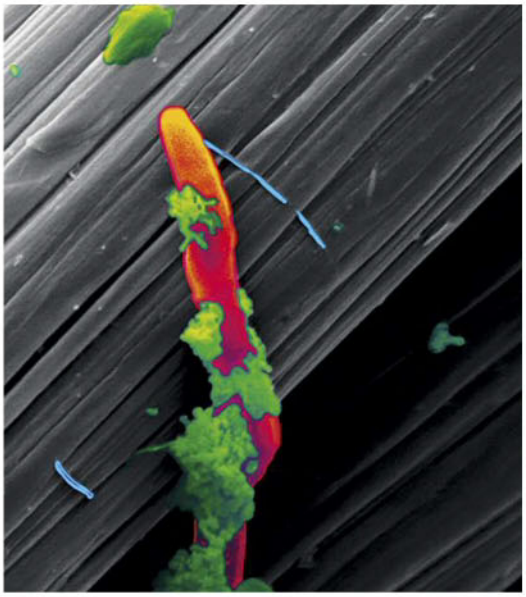
But electron flow isn't just limited to gadgets and gizmos. It is also vital for living cells. Our cells, our organs, and effectively our bodies are powered by the movement of electrons, which are present in the atoms of the food we eat. Food is therefore considered an 'electron donor' – it's the power supply. But for these electrons to flow, something needs to be drawing on the supply. Oxygen, an 'electron acceptor', scavenges these electrons from other molecules during chemical reactions, therefore generating a flow. The actual process is more nuanced than this but, at its core, this is how all living things are powered. ▶

These microorganisms, lurking in the deep, dark places of the world, seem to have harnessed the ability to directly consume electrons from their environment – they have a direct line. "All life essentially feeds off electricity," explains Jangir's supervisor Prof Moh El-Naggar, from the University of Southern California. "But microbes have managed to take it to the next level."

METAL MUNCHERS

Microbes like the ones that are currently being studied by El-Naggar and his team were first discovered decades ago. Back in the 1980s, researchers found that two different species, *Shewanella* and *Geobacter*, were able to survive without the oxygen that typically generates the flow of electrons. Instead, the bacteria used metal-based minerals, like iron- or manganese-based rocks, as 'electron acceptors' to produce an electron flow when oxygen wasn't present in the environment. Since then, different research groups have discovered more of these microbes, and found that the bacteria weren't just able to 'dump' electrons directly into minerals – they were able pick them up too. In other words they were feeding directly from the minerals by creating a living circuit.

No one knows exactly how many of these electron-eating species there are, but scientific research suggests it is a fairly widespread ability in many kinds of microbes. However, the microbes are most likely to be found in extreme environments that are rich in insoluble



This electrode (grey) was left underground for five months and attracted electron-eating microbes (orange)

substrates. "Deep underground is an obvious place for the electron-eating microbes to live, where the rocks contain elements, such as sulphur and iron, which easily lose or gain electrons," says Jangir. "But microbes are extremely versatile and use all sorts of methods to survive. Depending on the environment, some use multiple electron donors and acceptors. For example, the microbe that picks up electrons from electrodes may be perfectly capable of using other more conventional sources of electrons. And the ones that send electrons away to surfaces might be able to use more conventional molecules to breathe, such as nitrates, sulphates and even oxygen."

PHOTOS: YAMINI JANGIR/PROFESSOR MOH EL-NAGGAR, MATTHEW KAPUST/SANFORD

BELOW: The Sanford Underground Research Facility offers an intriguing space for scientists to hunt for unusual microbes

HOW MICROBES FEED ON ELECTRICITY

Every organism gains its energy by the flow of electrons from an electron donor to an electron acceptor. In humans and other animals these electron donor and acceptor molecules are free to diffuse *inside* our cells, where they synthesise the 'energy currency' of cells, adenosine triphosphate (ATP), in the power stations of the cells.

The same process happens in single-celled organisms (such as archaea and bacteria), but the electron transfer also occurs *outside* the cell. The microbes that feed on electricity alone transfer electrons to metal oxides, such as iron and manganese minerals in rocks, either by electron-shuttles called 'flavins' or along nanowires known as 'pili'.

Key:

Electrons | Heme group | Flavins

1 Cytochromes are proteins that are present on the outer membrane of the bacteria. Cytochromes contain 'heme groups' that accept and donate electrons, enabling charge to flow along the membrane.

2 Molecules called flavins act as electron shuttles, picking up electrons from the cell and dropping them off at a nearby electron acceptor, such as a mineral substrate. Once the flavins have dropped off the electrons, they travel back to the bacteria to collect some more.

3 Electrons can also travel along nanowires, called 'pili', sticking out of the microbe cell body. The pili are also covered in cytochromes, and the electrons use them to 'hop' along the nanowire.

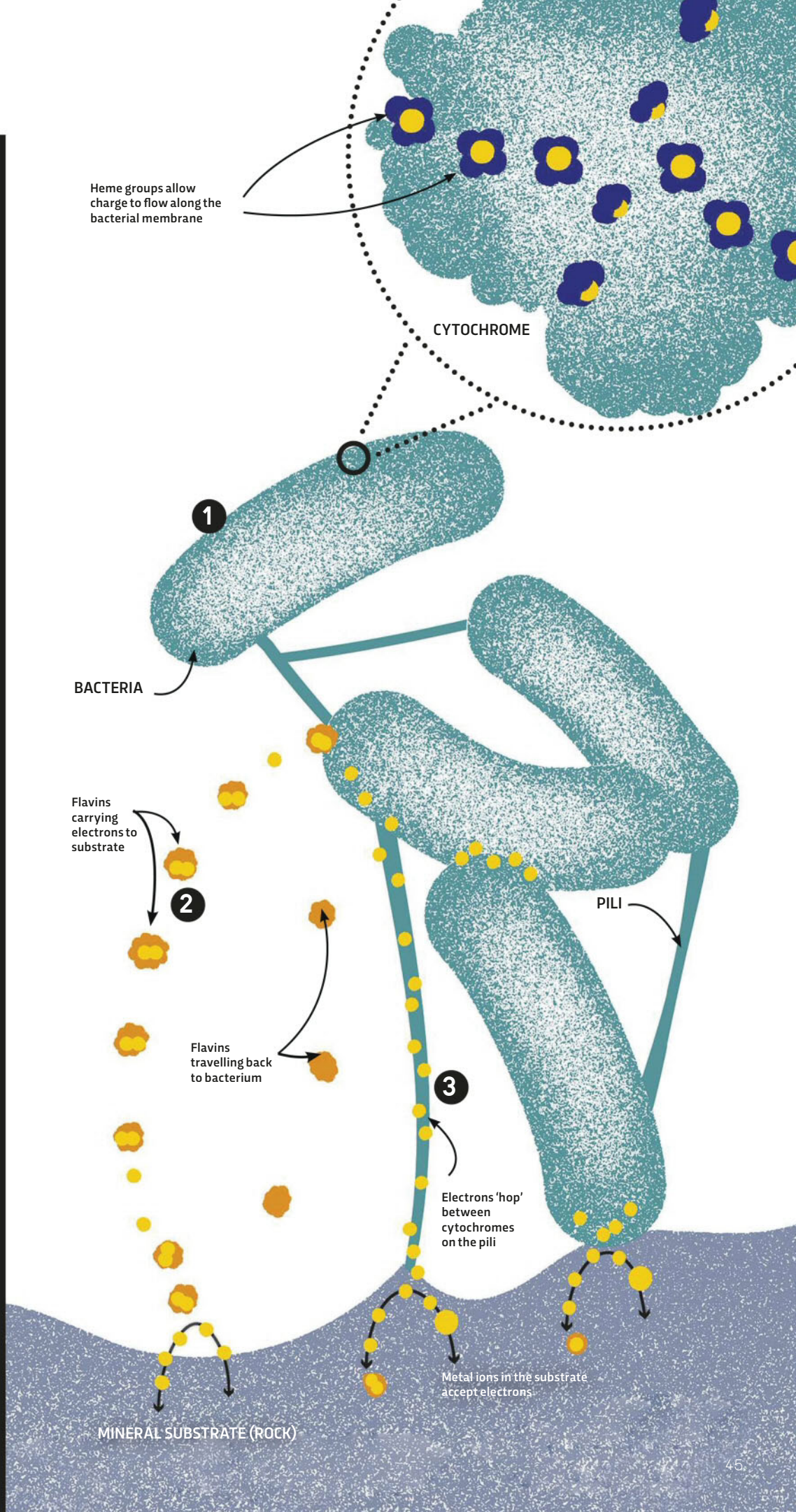


ILLUSTRATION: JAMES OLSTEIN

A MARVELLOUS MICROBIAL MENU

The strange eating habits of some of the world's most bizarre bugs

POTTY MOUTH

Microbes are often used to break down waste at sewage treatment plants. *Brocadia anammoxidans* can survive without oxygen and loves nothing better than to lunch on ammonia and nitrate in human waste, producing a fuel that could, theoretically, be used for space probes.

SLICK SOLUTION

In April 2010, the Deepwater Horizon oil rig burst into flames, spilling almost five million barrels of oil. Genetically modified *Alcanivorax borkumensis* microbes were brought in to help with the clean-up operation by breaking down the oil's molecular structure.

NUKED!

In 2014, a team from the University of Manchester discovered that various microbes can degrade the organic material found in nuclear waste. The microbes use the waste as a source of food and energy, and prevent radioactive elements leaking into the environment.

SMARTY PANTS

Stinky underwear can be a problem on any long journey – particularly if you're aboard the International Space Station. The solution? In the 1990s, Russian scientists tried using various bacteria to degrade soiled underwear and turn the resulting methane into biofuel.

PLASTIC SURGERY

Around 300,000 tonnes of plastic swirl around the planet's oceans at any one time. That is one giant plastic problem. The good news is that a team of Japanese scientists has discovered a bacterium (*Ideonella sakaiensis*) that eats the plastic found in most disposable bottles.

LIFE ON THE EDGE

These metal-munching microbes are just some of the many tiny, super-powered organisms living in extreme environments on Earth.

So-called 'extremophiles' can survive in conditions that are hostile to other life. Take the case of the *Aquifex* genus of bacteria, which lives in hot springs in Yellowstone National Park, where temperatures can reach a toasty 96°C. Or the salt-loving *Halobacterium halobium*, which survives in sediments that are 10 times saltier than seawater. And then there is 'The Daddy' of all extremophiles – Conan the Bacterium (aka *Deinococcus radiodurans*), which can withstand acid baths, radiation doses and huge extremes of temperatures.

But El-Naggar and his team are intent on finding out more about the electron-eating microbes in particular. They've already made some astounding discoveries about their anatomy. One day when filming *Shewanella* under a microscope, it dawned on the team that seemingly innocuous hair-like appendages were vital to the electron transfer system. Electrons were travelling along these 'nanowires' to the mineral substrate. And El-Naggar believes that when microbes are piled one on top of another in sediment, the nanowires act a bit like straws, so that the microbes at the bottom of the pile can still transfer electrons.

Until a couple of years ago, the team studied the microbes in a lab setting, because they wanted to use physical electrodes in place of the electron donors or acceptors that these organisms interact with in nature."Electrodes give a huge advantage since they don't get consumed and allow physical interrogations of the mechanisms by changing electric potentials and so on," says El-Naggar.

Recently, the team put their electrode-reactor in the gold mine of the Sanford Underground

PHOTOS: ALAMY, SCIENCE PHOTO LIBRARY ILLUSTRATION: JAMES OLSTEIN

"Electron transfer is fundamental to all of life's energetics. Perhaps it holds the key to discovering life on other planets!"

Research Facility in South Dakota. They are writing up the results of that research right now. "We don't yet understand the movement of electrons in biology as well as we understand them in metals or semiconductors," says El-Naggar. "Yet look at the amazing developments of our digital age that were enabled by an understanding of how electrons move in 'hard materials'."

Microbes that transfer electrons have already been used for tasks like degrading toxic and industrial waste, and recovering metals. Scientists are now looking at how to harness microbial electron transfer to synthesise nanomaterials, and are working on technologies that use microbes to generate electricity.

But, crucially, El-Naggar and his team believe that their research could reveal clues as to how life developed on Earth and how it could have evolved on other planets.

HUNTING FOR ALIENS

Every day, each of us breathes in and out around 20,000 times. We take it for granted that there is oxygen in the atmosphere. But billions of years ago breathing wouldn't have been possible, as oxygen did not exist. About 2.3 billion years ago, Earth's atmosphere radically changed in composition. In this so-called 'Great Oxygenation Event' (GOE), marine cyanobacteria, also known as blue-green algae, started to produce oxygen by photosynthesis, which led to the development of using oxygen to generate energy.

Before the GOE, microbes had to get their energy from elsewhere, and one source was minerals. Indeed, one theory for how life developed from the primordial soup of early Earth was that it developed on mineral surfaces that concentrated biological molecules and catalysed reactions. The discovery that these microbes can transport electrons into their cells from mineral surfaces could fill in the missing link in that theory. If that was the case, then it provides us with clues as to how life could exist on other oxygen-deficient planets.

"While the surface conditions of many planetary bodies seem inhospitable, it is possible that life either used to exist, or now exists, underground or in massive ice shells," says El-Naggar. "Electron transfer is not an Earth-centric notion, but it's fundamental to all of life's energetics. Perhaps it holds the key to discovering evidence of life on other planets!"

Astrobiologist and extremophile-guru Prof Lewis Dartnell, from the University of Westminster, agrees that these microbes could exist anywhere in the cosmos, even as close to home as the Red Planet: "By stripping electrons directly off metals in rocks, such microbes could have a ready source of energy pretty much anywhere – even on Mars, where there are plenty of iron-containing minerals and pockets of liquid water underground. In fact, most life forms in the Galaxy might turn out not to be sunbathers like the majority of surface life on Earth, but to be electron-munchers!"

Jheni Osman is a science journalist and presenter of *SciTech Voyager*. Her books include *100 Ideas That Changed The World* and *The World's Great Wonders*.

BELOW LEFT: New York State's Oneida Lake is where *Shewanella*, one of the original electron-eating microbes, was discovered in the 1980s

BELOW RIGHT: The long, hair-like structures on *Shewanella* are an important part of its electron transfer system

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THE ART OF SAVING LIVES

Poignant, surprising and otherworldly, this new photography project by Reiner Riedler shows medical machinery in a fresh light

Words: **Tom Ireland**

Photographer Reiner Riedler became interested in medical equipment after finding himself in an intensive neonatal care unit, where his critically ill newborn son, Viktor, was being cared for.

"I came from outside into a dark room, with all this soft light and beeping," says Riedler, who is based in Vienna. "It was such a strong feeling of safety – I trusted the machines."

Six months later he started to photograph machines that are used to save human lives, initially spending time in operating theatres. He soon decided he was uncomfortable with trying to photograph unconscious people and busy doctors.

Instead, he chose to photograph the technology itself, beginning with common hospital equipment such as dialysis machines. "Then I started to go to museums and archives, and I became more interested in those that tell a story, or those whose shape is metaphorical somehow," says Riedler.

DON'T MISS
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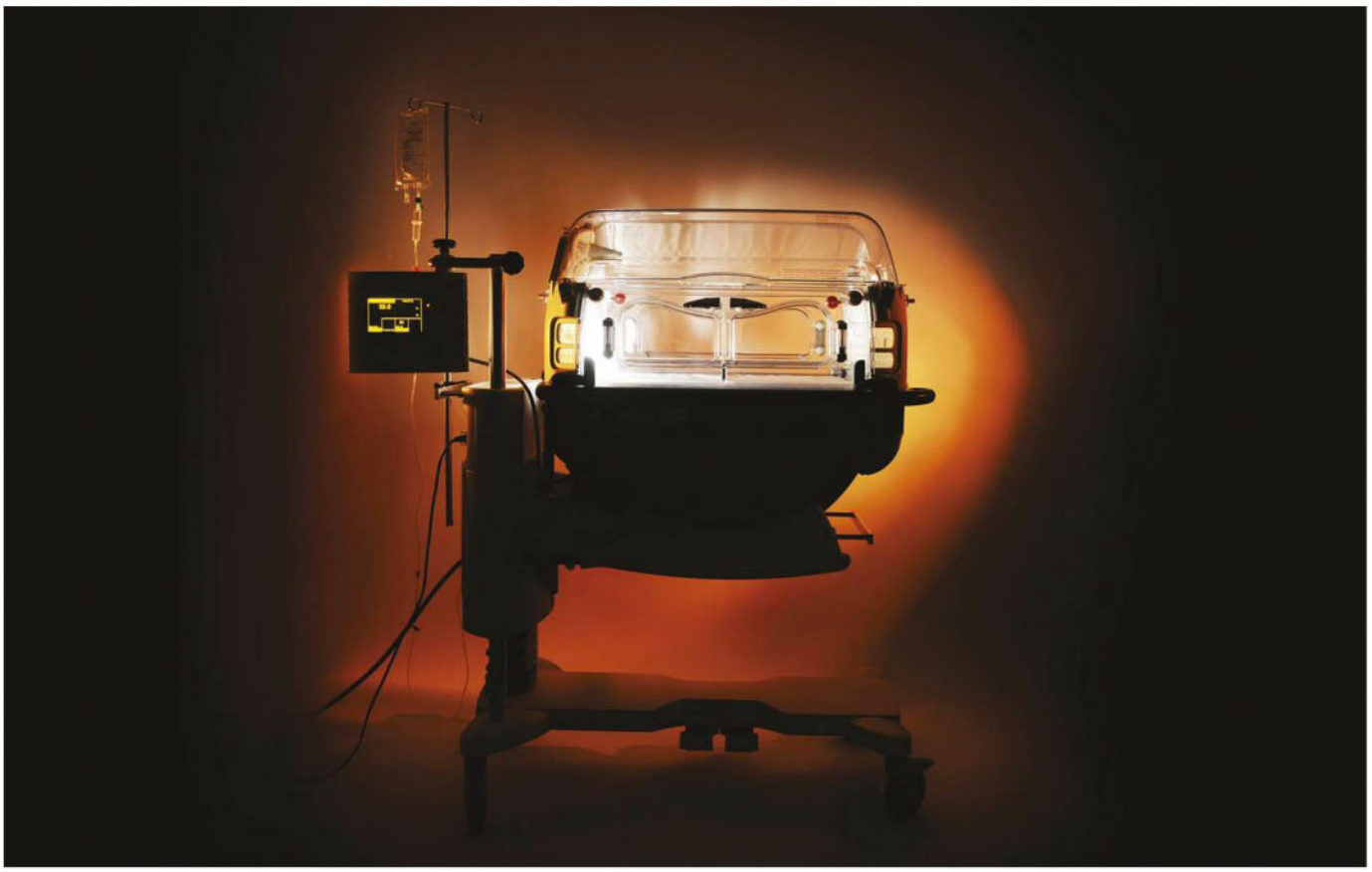
TWO LEGS GOOD

The Torque Controlled Humanoid Robot, or TORO for short, is used to study walking and balance. Keeping a 75kg machine upright is a huge challenge, but TORO can use its whole body to recover balance by, for example, grabbing onto solid objects or dropping to one knee. The aim is to create a robot that's comfortable in domestic settings, able to climb stairs, step over obstacles and – we hope – do the dusting.



SAFE PLACE ▲

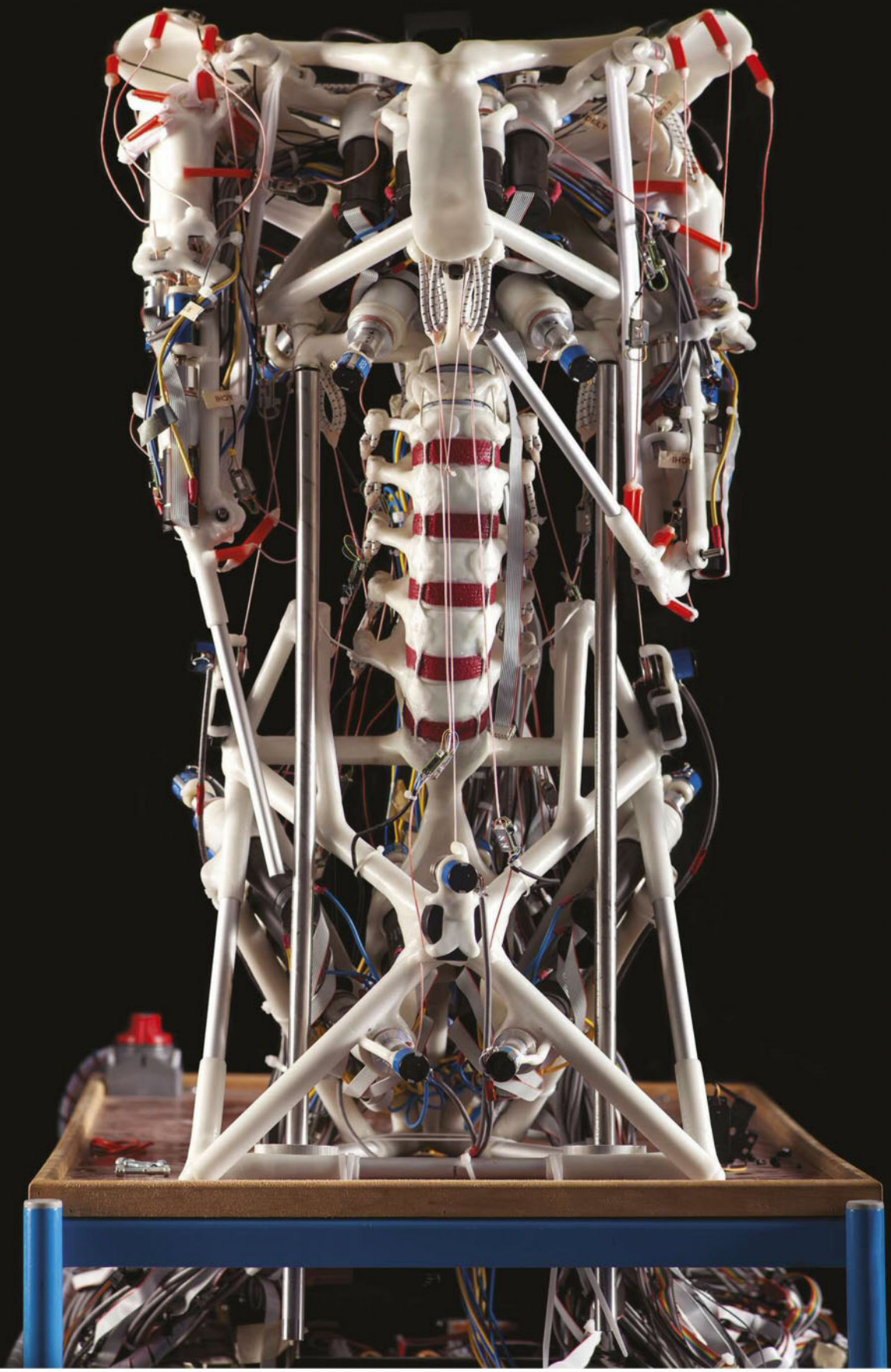
Incubators provide controlled warmth, humidity and oxygen for premature or sick newborns, and allow continuous monitoring of a baby's core body temperature. A double air curtain helps maintain a balanced climate inside the incubator. The incubator shown here is not the one that saved his now four year old son's life, but it still provokes strong feelings for Riedler. "The machine itself looks almost alive inside," he says.

◀ ROBO-DOC

The German Aerospace Centre's MiroSurge system is at the cutting edge of 'telesurgery', where surgeons manipulate robotic arms remotely rather than holding surgical implements themselves. The latest machines, such as this one, allow the surgeon to see a 3D display of the site of the operation and 'feel' what the robotic arms are touching, in real time, via the instruments at their workstation. This means a surgeon could, in theory, conduct an operation from anywhere in the world.

GROW A BACKBONE ▶

This is a rear view of the ECCE2 (Embodied Cognition in a Compliantly Engineered Robot), a world famous bot built at the Technical University of Munich. "This was exciting because it was part of the Human Brain Project, and they'd built this robot based on how the actual human neural and anatomical system works and moves," says Riedler. The robot has bones, joints, muscles and tendons, allowing researchers to investigate the brain mechanisms responsible for our own movement.



◀ SOFT MACHINE

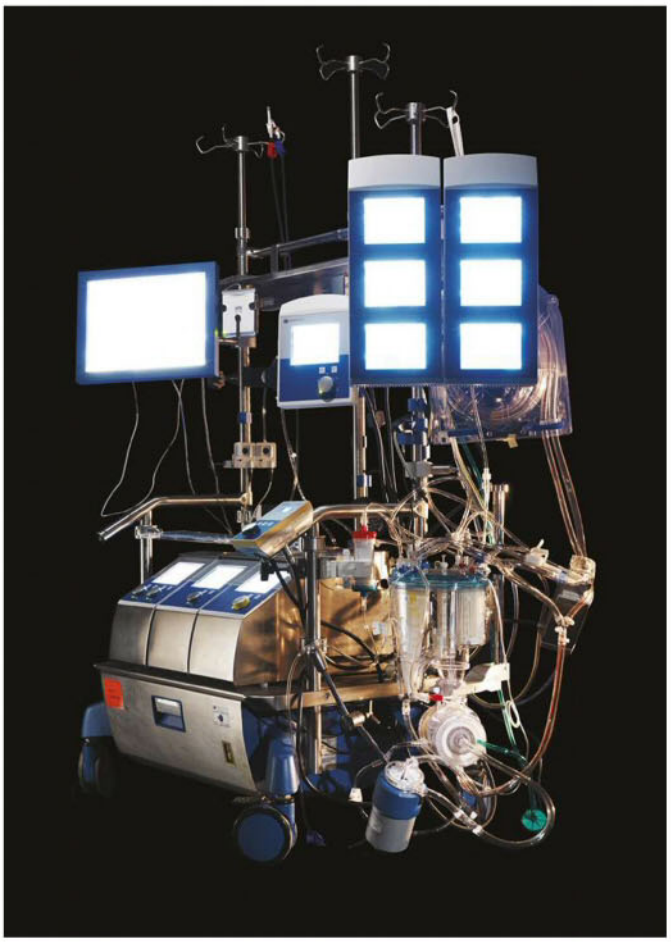
Like the ECCE2, this rather lonely looking robot, known as Roboy, is devised to emulate human anatomy and movement, with the aim of creating machines that can help us with our daily tasks in everyday environments. It is designed to move and interact with the physical world in the same way as our fleshy human bodies, and is part of a growing trend for 'soft robotics' non rigid machines built from deformable materials such as silicone and rubber.

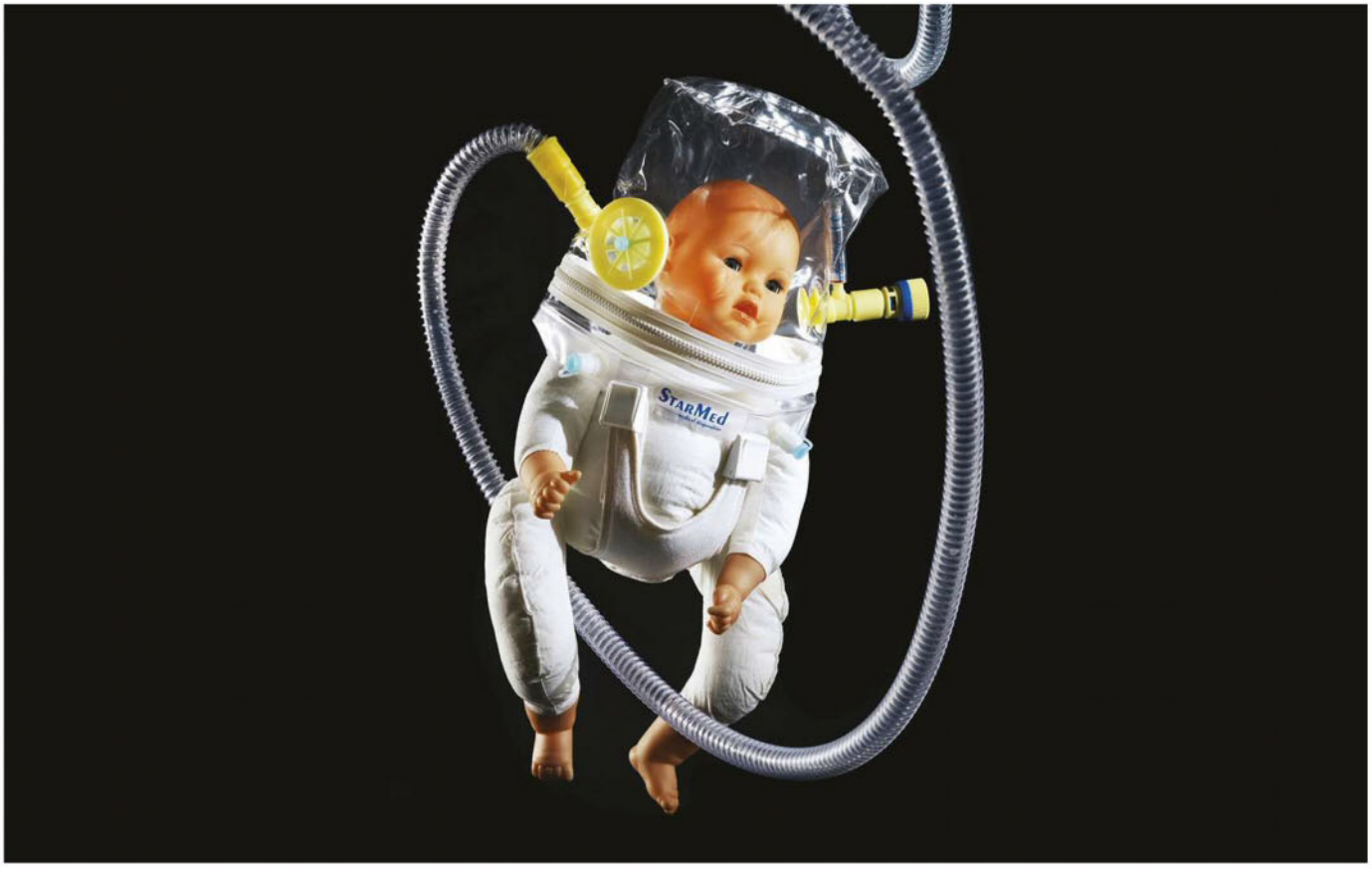
CHANGE OF HEART ▶

The S5 heart lung machine completely replaces the function of the heart and lungs during cardiac surgery, maintaining the circulation of blood and its oxygen content. "The heart lung machines are the most impressive," says Riedler. "They're really big, with all these screens and pipes. When the machine is in use, the pipes are full of blood, like blood vessels." This particular model can continue to support the patient for over two hours in the event of a power failure.

BABY BUBBLE ▼

This bizarre looking apparatus is an emergency breathing hood for infants in intensive care. "This is one of the more staged shots, but is one of my favourites," says Riedler. "It provides breathing assistance for a baby, and its entire head is in this bubble. But for me it looks like an astronaut." The device, which also comes in adult sizes, provides what's known as 'continuous positive airway pressure', keeping the lungs inflated during respiratory failure.





◀ HEAD SHOT

The 'Alderson Radiation Therapy Phantom' is a life size sculpture for testing the effects of radiotherapy. The model has exactly the same density as a real human body, and the 2.5cm thick slices can be filled with different types of artificial tissue for testing purposes. When asked why so many of the machines he photographed seem sinister or eerie, Riedler's answer is simple: "If you open a body it can be terrifying. The machines reflect the complexity and fragility of life."

OPEN WIDE ▶

This 'dental simulation unit' is one of a range of devices medical students use to hone their dental surgery skills before being let loose in clinical situations. The patient simulators have a full set of teeth, movable jaws, latex skin, and the same range of movement a real human would have. Like so many of the devices shot by Riedler, it has an otherworldly quality.

SHOW OF HANDS ▼

Say hello to these prosthetic hands, waving from a test station. Each one is opened and closed 1,000 times before being delivered for use. The prosthetics respond to the tiny electrical signals sent from the brain down the nerves of the patient's arm when they think about moving their hand. "As a photographer you see that sort of thing and just have to shoot it," says Riedler. "You should see it when they are all moving!" Ⓕ

DISCOVER MORE

The entire set of over 80 photographs can be found in Riedler's book *WILL The Lifesaving Machines* (€50, La Fábrica).

In *Trust Me, I'm A Doctor,* find out if turmeric lives up to its hype, if probiotics are good for you, and whether you should go gluten-free.

ROBORACE

THE RISE OF THE MACHINES

A fully autonomous, all-electric motorsport championship will get the green light later this year, and it's set to rewire the world of racing. But can drones really replace drivers? To find out, we speak to the people behind it

Words: **Leon Poultney**

Concept model of the futuristic-looking Roborace car, which will reportedly be capable of speeds of 300km/h (186mph)

1. **FRONT CAMERAS**
2. **COOLING INTAKE**
3. **GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS) ANTENNA** – USED FOR NAVIGATION
4. **AI 'BRAIN' NVIDIA DRIVE™ PX2** – PROCESSES INPUT FROM SENSORS, LIDAR, RADAR, ETC
5. **LIFT HOOK**
6. **V2X GNSS ANTENNA** – USED FOR NAVIGATION
7. **TOWER WITH 360° TV CAMERA, AI CAMERAS, PRESSURE INSTRUMENT, STATUS LIGHTS**
8. **REAR RADAR**
9. **REAR LIDAR**
10. **GURNEY FLAP** – INCREASES DOWNFORCE TO IMPROVE TRACTION
11. **BATTERY COOLING OUTLET**
12. **EXTENDED FLOOR**
13. **SIDE LIDARS**
14. **FRONT CORNER LIDARS**
15. **FRONT SPLITTER SLOTS**
16. **FRONT RADAR**
17. **ULTRASONIC SENSORS**

The autonomous car is perhaps one of the most exciting and intriguing subjects currently topping the agenda of most automotive manufacturers. We can already buy cars with a host of automated features. Some even allow us to take our hands off the wheel for long periods on the motorway, and we're probably just a few years away from a truly self-driving (and road-legal) vehicle.

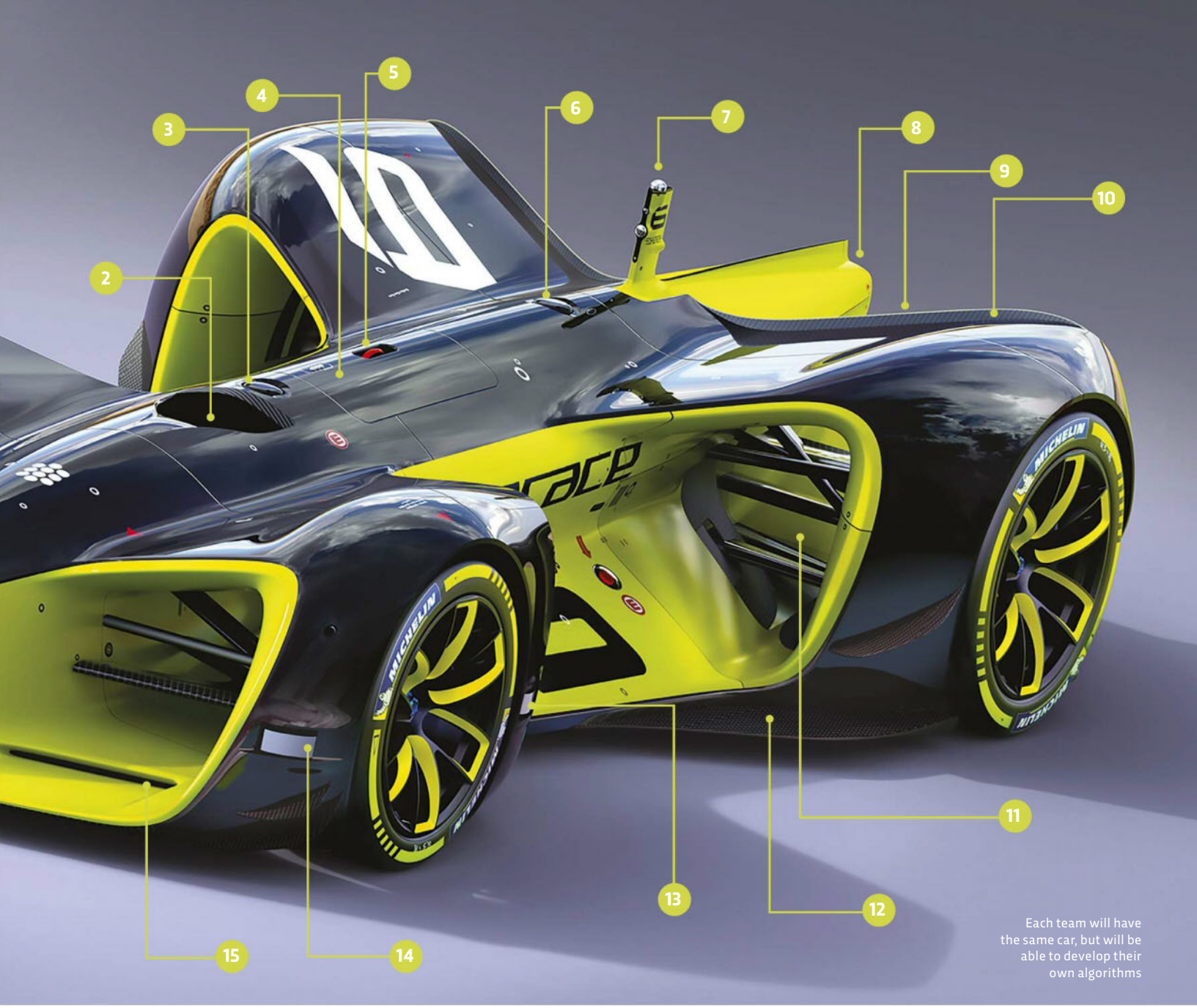
But however long it takes, one thing is clear: racing fans will soon be able to watch a completely driverless speed machine zoom around an inner-city circuit, and it will happen by the end of this year.

Roborace, a new fully-autonomous racing series, has confirmed it will host its first events during the rounds of the 2016/2017 season of the Formula E championship (the world's largest all-electric race series), which means we could see driverless machines do battle as early as this October.

Just picture the scene: a procession of space-age racers speed past a fully illuminated London Eye. Huge crowds of cheering fans line the tight urban streets as pounding techno music fills the air. The sleek machines, which emit only a faint whir from their electric motors, swerve and jostle for position.

The volume of the crowd rises as the sleek crafts approach the finish line. They snake and dart across the course but there are no drivers to hear the chants and shouts because, of course, these machines are fully, spookily, autonomous. They don't call it Roborace for nothing.

The marketing team behind the series has said it will showcase talent from the worlds of Artificial Intelligence (AI), as well as engineering and software development, while simultaneously entertaining fans around the world.



Each team will have the same car, but will be able to develop their own algorithms

PHOTO: ROBORACE/KINETIK

But can science fiction become fact so soon? Full details of the challenges and racing arrangement remain a secret but we have already seen that Audi can create a driverless RS7 that will happily tackle a pre-programmed race circuit at breakneck speeds without driver input. The RS7 Piloted Driving Concept joins the likes of BMW's 'self-drifting' M1235i – which can hold a tyre-smoking powerslide thanks to advance computing – and Yamaha's humanoid, superbike-riding MotoBot Concept, which hit 120mph during one test. Regardless, a fully-autonomous racing championship does sound a little far-fetched, but Roborace HQ is adamant it will have 10 teams ready to compete in contests and races held in some of the world's most famous cities towards the end of this year. And how exactly will it work? We know each team will have the exact same car fitted with the same standard hardware. So they will differentiate themselves by creating their own real-time computing algorithms and artificial intelligence technologies, which will ultimately assist the cars around the track and give them the competitive edge.

"Teams will create their own real-time algorithms and AI technologies"

"We want to champion the business of Artificial Intelligence," explains Justin Cooke, CMO of Roborace. "The series will celebrate where we currently are with AI, proving to people that it can be safe and fun, while helping to accelerate the technology in road cars. AI will revolutionise the way we get around, speed up travel, reduce accidents and clean up the environment," he adds. The idea is that Roborace will go far beyond a typical motorsport format, with its founders ▶

saying that they took inspiration from gaming and Hollywood when coming up with the formula.

"The world's media has been claiming we are a support series for Formula E," says Cooke. "I want to be clear, we are not. We are working in partnership with Formula E to lease the circuits from them. This means we can bring Roborace to the same inner-city courses that make Formula E so compelling. London, Berlin, Beijing, Paris to name a few, without the costs involved in going at it alone," he adds.

"The supercomputers can manage up to 24 trillion AI operations every second, and all in a case the size of a lunchbox"

It's clear from a conversation with Cooke that the target audience for Roborace isn't your typical Formula 1 fan. All ages and sexes will be welcome, while those not familiar with the smell of high-octane petroleum and burning rubber can still be entertained.

"Motorsport can be quite exclusive and anyone not at the event can feel a bit left out. We will ensure those watching on TV at home will have just as much fun by challenging them to 'code along' with every race," he says. "The viewer will be the 11th car on the grid – they can test their coding and algorithm-cracking skills on their own laptops and tablets."

However, the risk with removing the driver from a car is that you lose the stars and the characters that make more traditional motor racing so compelling. Justin Cooke isn't so sure about this claim; he sees it as a chance to level the playing field, and for fans to become loyal to the teams and technology firms behind each vehicle.

Former VW designer Daniel Simon's CV also includes some Hollywood work – he designed the Lightcycle from *Tron: Legacy*

A mammoth task, then, to ask race fans to swap their Ferrari baseball caps and Mercedes jackets for Compaq, Hewlett-Packard and Microsoft-branded goodies...

"We already have some of the world's biggest brands wanting to work with us because these cars look so cool," Cooke replies with some conviction. "Each car will have a name and bespoke designs, so these will become the personalities.

"You can imagine the merchandising possibilities. This sort of thing is so tribal and addictive, which is great from a fan base point of view, and we can create far more than just clothing and merchandise. I'm thinking video games, movies, toys and more," he adds.

There is still little information surrounding the exact scale of the Roborace machines, whether they will be the size of large remote-control cars or more like the dimensions of a Formula 1 car, but we do know futurist and sci-fi designer Daniel Simon is behind the sleek and suitably space-age shape.

THE MAN BEHIND THE BOTS

Science-fiction fans will likely be familiar with the work of Daniel Simon, a German-born vehicle designer and futurist responsible for some of the coolest machines to ever grace a big screen.

Despite humble beginnings at the Volkswagen Group, he went on to design the Light Cycles from Tron: Legacy, the awe-inspiring Bubbleship from Tom Cruise's epic Oblivion and various neo-Art Deco bad guy vehicles that feature in the recent Captain America franchise.

"My goal was to create a vehicle that takes full advantage of the unusual opportunities of having no driver without ever compromising on beauty," he said of his Roborace creation. The result is a visually stunning concept that adds truly innovative features, such as an aerodynamic floor that generates maximum downforce, to a genuinely jaw-dropping carbon fibre shell. Almost as jaw-dropping as his fantastical Cosmic Motors project.

PHOTOS: ROBORACE/KINETIK, DANIEL SIMON

However, Kinetik, the UK investment firm behind the championship, has confirmed that Nvidia will provide the computer processing power. The firm's Drive PX 2 units (which are also going into road-going robocars) perform up to 24 trillion operations a second, and all in a case the size of a lunchbox.

That's the processing power of 150 MacBook Pros, which is enough to incorporate input from a vast array of sensors, including the radar, LIDAR, cameras and GPS required to keep an autonomous car on the road. Plus, it can handle deep-learning abilities that allow the machines to acquire knowledge from the world around them so they improve with every race.

That's where the competitive element comes into play: a team of top programmers, software and computer engineers will be tasked with deciding how these vehicles behave, by tackling real-time algorithms to ensure the roboracers reach the finishing line in one piece... hopefully.

"If teams want to be aggressive, they will be able to programme this into the software," explains Cooke. "For example, Team A could programme their car so it doesn't react to anything unless it comes within a millimetre of its sensors. This car would continue on aggressive lines and more than likely crash at some point.

"Other competitors may want to programme in some safety margins to ensure the vehicle makes it around the course unharmed. But all of the overtaking and aggressive manoeuvres will be up to those in charge. We are simply taking the driver out of the car and sitting him or her on the sidelines. So all of that highly competitive behaviour will still be present," he adds.

Don't expect the races to be held on a typical loop of tarmac either, as Cooke claims that the amount of downforce provided by the heavily aerodynamic bodywork could see the cars drive upside-down. Specially adapted versions of the Formula E inner-city circuits, such as Buenos Aires or Mexico City, could feature bespoke obstacles and challenges that have rarely been seen in motorsport before.

"You can imagine what film content will look like if these cars loop through tunnels upside-down," he says. "It creates something so much more exciting than traditional motorsport. It becomes pure entertainment."

The scale, speed and true level of excitement offered by the Roborace series is yet to be seen, but the fact that we'll be watching vehicles racing each other without a driver at helm is an achievement in itself.

All that's left now is for the programmers, engineers and race organisers to make it a reality. No pressure, eh?

Leon Poultney is a freelance technology and motoring journalist.

IMMERSE YOURSELF IN 360° SURROUND SOUND

The versatility of surround sound audio isn't limited to home cinema systems – now you can enjoy aural illusions from the comfort of your very own headset

Words: **Dom Reseigh-Lincoln**

This Christmas, VR headsets will be the must-have gadget on many people's lists for Santa. But it's not only our eyes that can be treated to the immersive power of VR – now our ears can, too. The latest range of headphones cushion your ears in glorious 360° surround sound, to really bring your games, music and films to life…


SENNHEISER

Sennheiser PC 373D

£219.99
sennheiser.com

Much like many other Sennheiser headsets, the PC 373D might not be the most aesthetically pleasing set of cups in the world, but what it lacks in eye candy it more than makes up for with ear candy. For a start, there's the top-of-the-line retractable microphone, which offers one of the clearest voice channels we've ever heard on a gaming headset.

These PC-only headphones come with the sturdy construction you'd expect from German manufacturer Sennheiser, with that velvet finish on the ear cushions adding a real splash of luxury at this price point. That quality extends to the audio experience as well, with both highs and lows feeling powerful, punchy and accurate when using it for a wide variety of purposes. There is, however, a frustrating rattle when you push the bass up that can get a little distracting if you're into your bass-y setups.

Being able to switch between stereo and 7.1 surround sound is a real boon though, and one that comes courtesy of a special dongle – simply hit a single button and you're bathing in a rich, 360° soundscape. Sprinkle in USB connectivity and bespoke software that enables you to customise your setup even further, and you're looking at a serious contender in the gaming audio arena.

★★★★★

SteelSeries Siberia 800

£249.99
steelseries.com

One of SteelSeries' flagship audio products, the Siberia 800 is one of the most comprehensive and versatile headsets you can buy. While they're marketed as a gaming-focused package, these cups have been designed to extend their sumptuous Dolby 7.1 surround sound quality to everything from PCs to consoles and smartphones. With that hefty price tag this is a big investment for a headset, but with myriad leads, adaptors and connectors supplied, you're almost spoiled for choice.

With a wireless transmitter that plugs into the mains, you get a handy bit of software called LiveMix that detects incoming dialogue from your own mic and then adjusts the sound mix to ensure you don't miss a word in the sonic maelstrom of a match or firefight. Even if you're not a gamer, that Dolby 7.1 surround sound really sings inside the Siberia 800, making everything from soft ballads to bombastic film scores a pleasure to behold.

It's also a supremely comfortable headset to wear, but it's not without its flaws. The batteries can be fiddly to replace, as can calibrating it to suit so many different platforms. For the price, the build quality also doesn't look or feel quite as luxurious as it should, but they still sound like a dream.

★★★★★

PHOTOS: STEVE SAYERS/THESECRETSTUDIO.NET

Logitech G633 Artemis Spectrum

£124.99
logitech.com

Logitech has thrown the kitchen sink at its Artemis Spectrum range. In fact, it'd be a better analogy if we said it's thrown the whole kitchen at these full-fat headsets. Spend five minutes wearing the G633 or its bigger brother the G933 and you're immediately struck by all those bells and whistles.

Your ears get washed in two flavours of surround sound (namely the 7.1 Dolby and DTS Headphone:X varieties), bringing a punch to music playlists while picking out all the quieter incidental sounds from both multiplayer death-matches and a variety of single-player campaigns.

When we first tried these, the cups and headband pinched a little tight, but after regular use this issue soon fades. Along with the 40mm drivers that provide a standard gaming headset frequency response of 20Hz to 20kHz, there's even a mic hidden away in the left cup. It's non-directional, so it's not the best integrated mic out there, but it picks up audio just fine over chat or during a stream. While G933 is wireless, the G633 provides a USB connector for PC and consoles and a handy 3.5mm cable for mobile connectivity.

The G633's build quality impresses too, offering one of the sturdiest gaming headsets we've tested in quite some time.

★★★★★

SteelSeries Siberia 350

£99.99
steelseries.com

If there's one design ethos SteelSeries employed with its Siberia 350 headset, it's simplicity. From the retractable microphone that slips back into the left-hand cup to the in-line volume controls that sync with your laptop or PC without the need for additional drivers, the Siberia 350 is all about getting you immersed in your chosen game with a minimum of fuss.

This is still a lower-end 'premium' headset, so you're not getting the full complement of high-end features from the Siberia 800, but that doesn't mean you're investing in a cheap knock-off. The sound quality is robust and it's perfect for differentiating background and foreground effects – that surround sound feature working surprisingly well at this low price point. The suspension strap makes it extremely comfortable for long periods, but the USB wire is frustratingly short, making the Siberia 800 awkward to use if you're moving about a lot.

Sadly, it doesn't come with an adaptor for use with mobiles, tablets or consoles, so you'll have to get fiddly with a third-party adaptor if you want to take the Siberia 350 out of its PC gaming-only comfort zone. It certainly couldn't be described as a luxury headset, but the build quality SteelSeries offers here never feels cheap or flimsy.

★★★★★

Turtle Beach Elite Pro

£169.99
turtlebeach.com

The Elite Pro from Turtle Beach is one serious bit of kit. Whether you're a casual gamer who just wants to enjoy the best possible audio while playing *Fallout 4*, or a professional player who wants an accessory that's good enough for use in tournaments and competitions, the Elite Pro ticks all the boxes.

Turtle Beach says it built this headset from the ground up to be its most impressive offering yet, and you can see that re-energised focus in almost every facet of its design. The headset is impossibly light, with each side fitted with earcups made of spandex, leather and gel-infused memory foam. We spent entire evenings using them and almost forget they were there, such was the comfort Turtle Beach has conjured.

Then there's the sound – the 50mm 'nanoclear' speakers that sit behind those comfortable cups offer a satisfyingly clear experience, with enough bass to make your chosen game boom. Even without the Tactical Audio Controller that Turtle Beach strongly suggests you use with it (see right), you're still getting a full and robust audio experience. The very quietest of sounds were audible, making the Elite Pro ideal for gaming, listening to softer music and watching films.

Add in a noise-cancelling mic and all the accessories, and you've got one of the luxurious headsets on the market.

★★★★½

How does 360° surround sound work?

When it comes to recreating the depth of sound you get from a home theatre system with a set of carefully placed speakers, a headset needs to use its own brand of magic to trick your ears into thinking you're floating in sound. Virtual surround sound and 360°/3D sound works by much the same principle as its physical counterpart, but using just two speakers.

The seven speakers (hence the '7' in 7.1) of a room-based surround sound setup create a tangible sonic picture around you, including the placement of one above and another below to create a sense of immersion. In a headset, the magic begins by using algorithms that simulate the calibrated sound of a physical speaker. Waves of sound are sent out, which bounce off the contours of your ears, creating a faux sense of 360° audio. Each algorithm works at a slightly different volume, with bass and treble rebalanced to create a sound that moves around you while you're watching a particularly sonically-crowded film, or moving through the varied soundscape of a first-person shooter.

Turtle Beach Elite Pro Tactical Audio Controller

£149.99, turtlebeach.com

The Tactical Audio Controller (TAC) from Turtle Beach isn't cheap, costing almost as much as the headset it's marketed with, but it'll give you unparalleled control over your gaming audio. Plug it in and you've got access to 7.1 Dolby and DTS Headphone:X surround sound, giving you a 360° audio experience that will turn any game into a soundscape you'd struggle to replicate in any other headset. Being able to fine-tune everything from background noise to the level of your own mic makes a laughing stock of other setups. The TAC also comes with all the cables you'd need to connect up to PS4 and Xbox One as well as a PC, so closed-box gamers can get in on the surround sound action with ease.

★★★★★

HELEN CZERSKI... WHY ARE HAND CLAPS SO LOUD?

"THIS SIMPLE MOVEMENT IS CAPABLE OF GENERATING AIRFLOW THAT IS FASTER THAN THE SPEED OF SOUND"

A hand clap is an odd thing, when you start to think about it. We clap all the time, to accompany music, to communicate approval, to set a rhythm or to attract attention. A clap can be the sharp crack made by a flamboyant flamenco dancer, or the polite pattering of the unimpressed. But we rarely think about how that sound is made. Recently, I had to clap to synchronise cameras repeatedly over a few days. I noticed that the sound of my clap varied a lot, even though I thought I was doing the same thing every time. So I started to experiment.

I hope that you're not reading this on a train or in a library, because you're probably going to want to experiment too and you don't want to attract grouchy Paddington Bear stares from those around you.

Start by clapping with your hands parallel and level with each other, and then move one hand downwards bit by bit. My claps are noticeably louder when the fingers of one hand meet the palm of the other. Then go back to the starting point, and this time rotate one hand by a bit on each clap. You'll notice that the pitch of the clap goes down as you rotate. You might also see that you're starting to cup your hands, instead of letting them stay flat. The more you cup your hands, the deeper and softer the sound. So what's going on?

It turns out that there are two major contributions to the sound of a clap. When you bring two flat surfaces together, you squeeze the air in the gap between them outwards. Right at the last minute, when your hands are almost touching and the gap is very thin, the outward airflow becomes extremely fast. In addition, your hands aren't perfectly flat and so after the first edges have touched, air has to be squeezed out between the small gaps that are left, and this adds extra speed. The first sound happens when that outward flowing air gets very close to the speed of sound, possibly exceeding it for a tiny fraction of a millisecond. That generates a weak shock, like the crack of a bullwhip. This is what the flamenco dancers excel at, and that weak shock is the reason that a clap can be so startlingly loud. I've found that it works better when I've got wet hands, and I think that's because the edges of my hands seal better, making one very small gap for the air to escape from. After that initial crack, there are some extra oscillations as the air

reverberates around the space between your hands, but the whole sound probably only lasts for five thousandths of a second.

When you cup your hands, the sound comes from air oscillating in and out of the circular space in between your palms. The bigger the space, the deeper the note. It still depends on your hands sealing briefly around the edges, but you need a small gap to be left for air to move in and out. This doesn't make a sharp crack, because it comes from air flowing in and out a few times, so the sound of this clap will last a bit longer than the sharp crack of the weak shock.

It's astonishing that such a simple movement is capable of generating airflow (however brief) that is faster than the speed of sound. But this is what generates the loud flamenco clap.

I'd better leave you to apologise to the people around you, now that you've almost certainly got their attention. I recommend telling them that it's all in the name of science. Feel free to blame me!

Dr Helen Czerski is a physicist and BBC science presenter. Her book, *The Storm In A Teacup*, will be out in November.

NEXT ISSUE: WHY DON'T ALL CERAMIC BOWLS GET REALLY HOT IN THE MICROWAVE?

ILLUSTRATION: DARIA SKRYBCHENKO

OUT OF TIME

While cosmologists agree that the Universe will end in billions of years' time, what they're undecided on is *how* it will happen. Currently, there are four scenarios that have the most support: the Big RIp (visualised here), the Big Bounce, the Big Freeze and the Big Crunch.

PHOTO: SCIENCE PHOTO LIBRARY

THE END OF THE UNIVERSE

Will the Universe end in a bang or a whimper? We gaze into our cosmological crystal ball…

WORDS: **BRIAN CLEGG**

Cosmologists are always telling us about the beginnings of our Universe, but where are we heading? Can anything, the Universe included, last forever? It's hard enough being sure exactly what the Universe *is*, but thinking about how it ends is arguably even tougher. So strap in for a bumpy ride to the end of everything.

Will the universe be ending soon?

No need to panic. We don't envisage anything close to an end to the Universe for many billions of years. Depending on the scenario, we have between 20 billion and 100 billion billion years left to enjoy our cosmos. That's long after the Earth becomes uninhabitable in a mere billion years or so, and by then, humans are likely to have gone anyway.

The idea that the Universe can't last forever has its origins in the second law of thermodynamics, which states that systems have a tendency to degenerate when left to their own devices. This law was devised to explain how heat works, always moving from warmer to colder places unless we prevent it (for example in a fridge, where electric power moves heat from the colder inside to the warmer outside). This means that everything should eventually even out, leaving a uniform nothingness. Another way to describe this is that disorder naturally increases – not just in teenagers' bedrooms, but anywhere that doesn't have energy pumped into it to create order. The outcome is total disorder – there can be no stars, no planets, no life.

How old is our universe?

It's easier to look back than forward, partly because the Universe is like a visual time tunnel. Light takes time to reach us, so the further out we look into space, the further back in time we see. When, for example, we look at the Andromeda galaxy – the nearest large galactic neighbour to the Milky Way – we see it as it was 2.5 million years ago, because its light takes about 2.5 million years to reach us. Modern telescopes enable us to see back billions of years.

The other big contributor to our knowledge of how things began was the discovery in the 1930s that the Universe is expanding, and however far out (and hence back in time) we look, that expansion has been going on. This enables us to work out that the Universe we can see appears to have originated around 13.8 billion years ago, beginning to expand with the so-called Big Bang. The details of how this occurred and what, if anything, ▶

We see the Andromeda galaxy as it appeared 2.5 million years ago, because its light takes that long to reach us

PHOTO: SCIENCE PHOTO LIBRARY

Many cosmologists think the Universe is one of many in a larger multiverse

existed before it are speculative – there are plenty of possibilities. But the basics of the last 13.8 billion years of growth are clearly understood.

So how might the universe end?

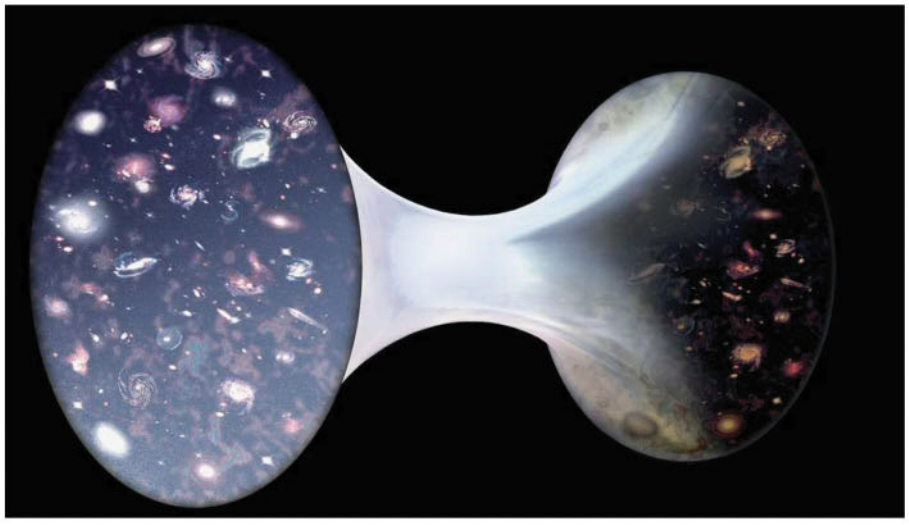
This is where we enter the realm of cosmological speculation. It is possible to produce all kinds of hypothetical outcomes, but there are four broad scenarios that have the most support.

Two of these scenarios involve the Universe continuing to expand, continuously getting thinner and more dispersed, although the final outcomes are very different. The most conventional, the Big Freeze, is simply the ultimate outcome of standard thermodynamics. Everything evens out until there is simply nothing happening in a totally diffuse Universe. The more dramatic version incorporates the observation that the Universe is not just expanding, but that the expansion is *accelerating*. If this accelerating expansion is extrapolated to the extreme, we get the Big Rip, in which all of the matter in the Universe, from planets and galaxies to fundamental particles and space-time itself, is pulled apart as the expansion heads off to infinity.

By contrast, the other two scenarios see the expansion of the Universe eventually reversing. If everything ends in the Big Crunch (sorry about the corny names, but we're stuck with them), we see a reversal of everything we've experienced to date, returning to an infinitely dense point – a 'singularity'. This can then produce a new Big Bang and a new Universe, giving a possibility for a cycle of universes. In the subtly different Big Bounce, the Universe again reaches a peak size and begins to contract, but in this instance, it never gets as far as a singularity before bouncing and expanding again. The difference from the Big Crunch is that some aspects of the earlier Universe can carry over into the next one. In effect, the Big Crunch generates a new Universe, whereas the Big Bounce sees the same Universe repeatedly expand and contract.

What does it depend on?

All these possibilities are devised by taking the observed behaviour of the Universe and then extrapolating some key aspects of physics into the future, notably the General Theory of Relativity. This theory, Einstein's masterpiece describing the relationship between matter, gravity, space and time, can be used to model the entire Universe in a crude fashion. Of all of the factors involved in predicting the future of our Universe, the existence of the accelerating expansion is the most reliable. First discovered in 1998, we now even have a figure for the rate of



The Big Bounce is a scenario in which the Universe will contract, before bouncing and expanding again to form the same Universe

JARGON BUSTER

Brane

Some theories combining quantum physics and gravity require there to be at least 10 dimensions. In such scenarios, objects with fewer dimensions called branes (short for membranes) could float in the multidimensional environment.

Cosmology

The branch of astronomy concerned with the origin, evolution, and eventual fate of the Universe.

Quantum particles

Small particles such as electrons and photons of light obey completely different physical rules to ordinary objects. Such 'quantum particles' respond to the probabilistic rules of quantum theory.

Singularity

Various physical models predict that certain characteristics of cosmic objects – their density, for example – will get bigger and bigger until they become infinite. When this happens, it's called a singularity and current theory breaks down.

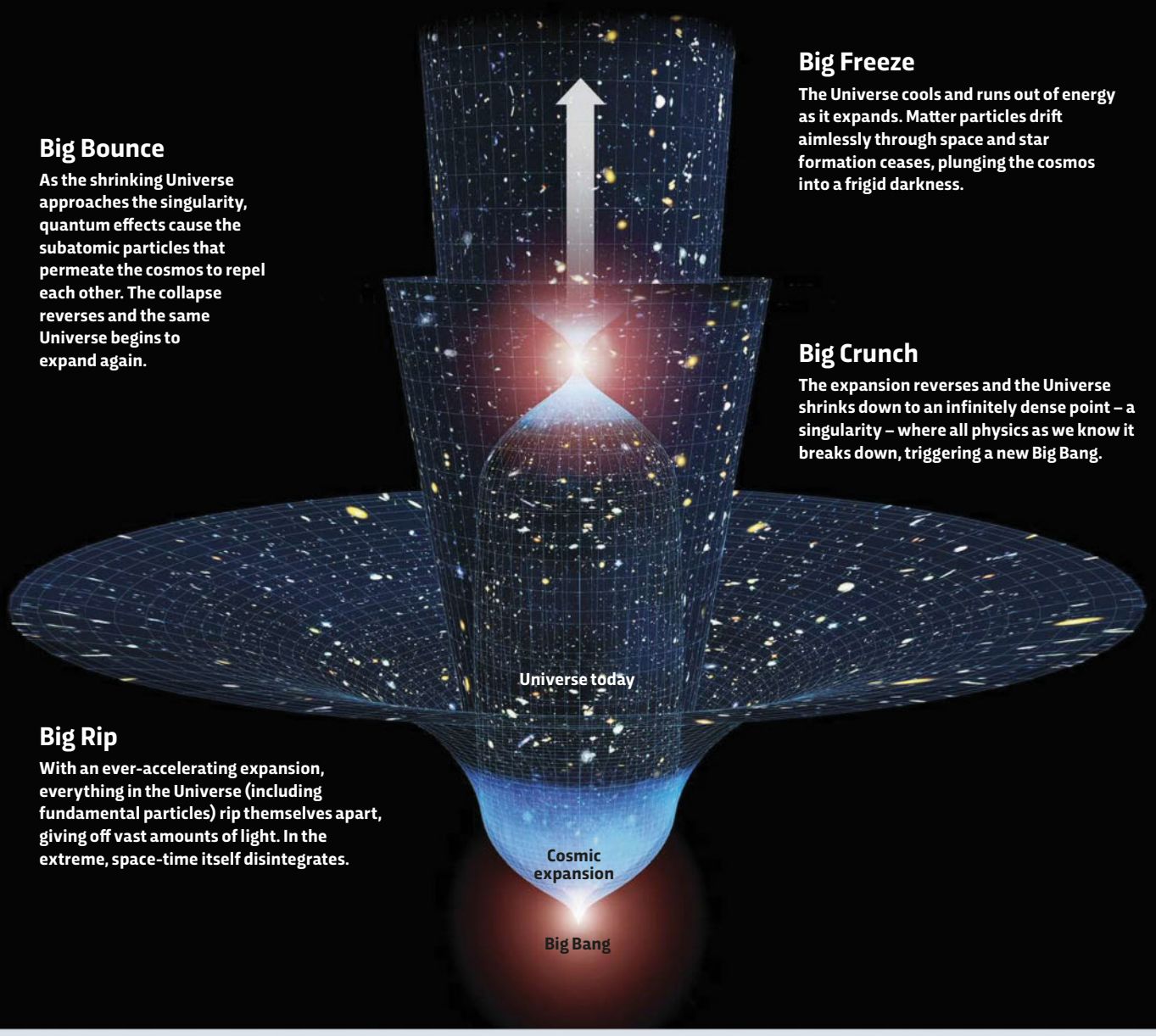
Space-time

Albert Einstein showed that space and time were not separate but linked in a structure known as space-time. This is the underlying framework of the Universe.

PHOTOS: GETTY, SCIENCE PHOTO LIBRARY X2

HOW WILL OUR UNIVERSE END?

There are four popular scenarios...



Big Freeze

The Universe cools and runs out of energy as it expands. Matter particles drift aimlessly through space and star formation ceases, plunging the cosmos into a frigid darkness.

Big Bounce

As the shrinking Universe approaches the singularity, quantum effects cause the subatomic particles that permeate the cosmos to repel each other. The collapse reverses and the same Universe begins to expand again.

Big Crunch

The expansion reverses and the Universe shrinks down to an infinitely dense point – a singularity – where all physics as we know it breaks down, triggering a new Big Bang.

Big Rip

With an ever-accelerating expansion, everything in the Universe (including fundamental particles) rip themselves apart, giving off vast amounts of light. In the extreme, space-time itself disintegrates.

WHAT WE STILL DON'T KNOW

1 HOW TO COMBINE GENERAL RELATIVITY AND QUANTUM THEORY

Many of the scenarios describing the end of the Universe can only be properly assessed if we can combine the impact of gravity with the behaviour of very small things described by quantum theory. At the moment these are incompatible. Approaches like string theory and loop quantum gravity are still a long way from being effective, and a whole new theory may be required before this is possible.

2 WHAT DARK MATTER IS

It is impossible to make an accurate model of the evolving Universe without knowing what's in it. There is five times as much dark matter as ordinary matter in the cosmos, yet we don't even know if dark matter is a single type of particle or a whole family, like the Standard Model of ordinary matter. Many attempts have been made to detect dark matter, but all – most recently the LUX collaboration, one mile under the Black Hills of South Dakota – have failed.

3 WHAT DARK ENERGY IS

Many researchers are looking into better ways to model dark energy. For example, scientists at University College London and the Centro de Estudios de Física del Cosmos de Aragón in Spain recently developed a quicker way to model the Universe which is 25 times faster than previous techniques, enabling them to check many more scenarios. This allows them to see if hypothetical origins for dark energy match observations. But we still haven't a clue what it is.

PHOTOS: SCIENCE PHOTO LIBRARY

In one tweet...

The Universe is dying, pulled apart by dark energy. Don't send flowers – they won't exist at the end and there are billions of years to go.

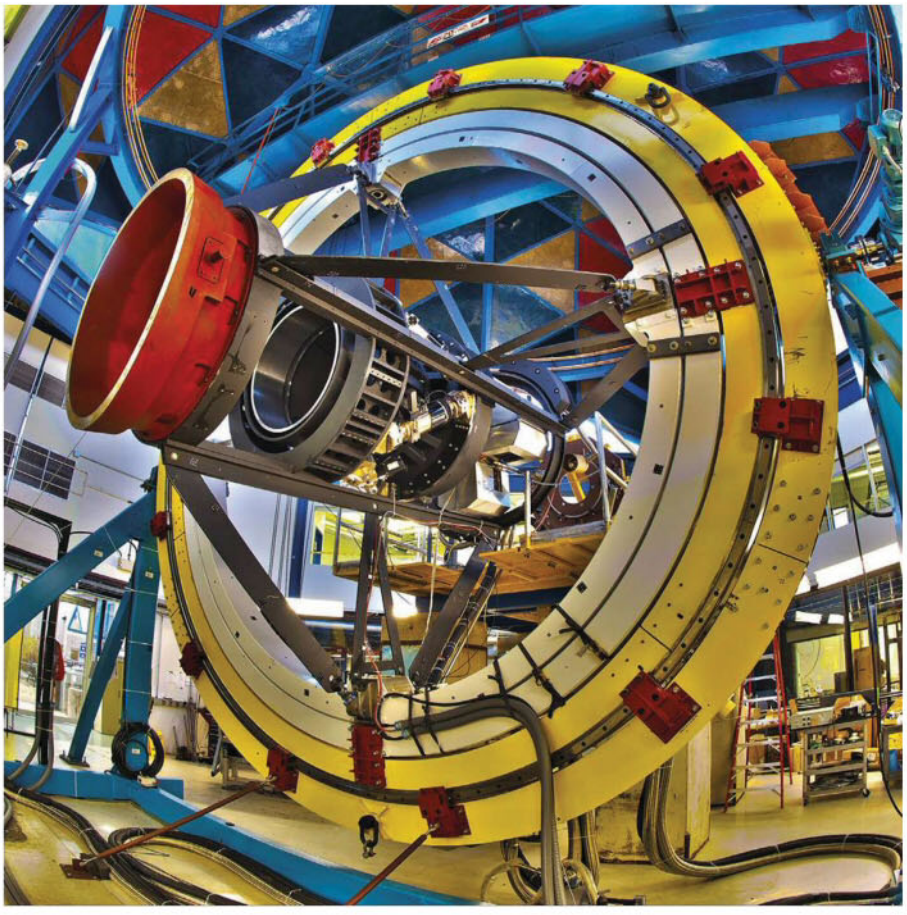
expansion: 73.2 kilometres per second per megaparsec (a megaparsec equals 3.26 million light-years).

The 'extrapolation into the future' part is trickier. We can't experiment with a Universe and try out different scenarios. We only know what has happened so far. There's nothing to say that things will continue in the future the way they have in the past – it's just an assumption. It's a bit like trying to predict the stock market. On the whole there are clear trends, but it's always possible that we'll get caught out in a crash. Perhaps most doubtful is the use of General Relativity. Although Einstein's theory has proved hugely effective in predicting the effects of gravity, it doesn't work at the level of quantum particles – the physics required in most end-of-the-Universe scenarios. Also, using the theory to model the Universe requires vast simplifications, making the model significantly different from reality.

Which theory is the most popular among cosmologists today?

It depends who you ask! The problem with theories like the Big Crunch and the Big Bounce is that models of the Universe suggest that such processes would run out of steam, unable to keep recycling unless there was some external input. The best supported version of the Big Bounce depends on something called 'ekpyrotic theory', a concept based on an unproven advanced version of string theory – an attempt to combine quantum theory and General Relativity. According to this picture, our Universe is a four-dimensional 'brane' (three of space, one of time), floating in a space-time continuum, and the Big Bounce occurs when two such branes collide, providing that external input.

Variants of the Big Freeze, or 'heat death', in which everything runs out of energy and stars finally stop forming in around 100 billion billion years, were most popular among cosmologists for a long time. Now, though, the Big Rip is probably the best supported theory, because dark energy – the entity that's speeding up the expansion of the cosmos – seems to be driven by the size of the Universe, so the bigger it gets, the more powerful the effect. It's an eternal feedback loop. Based on this, our Universe has at least 20 billion years to go, but this is very speculative – we don't know, for instance, if dark energy will continue to have the same effect.



The Dark Energy Camera in Chile is used by cosmologists to probe the expansion of the Universe

What's dark energy?

Though it sounds like the latest comic book villain, dark energy is whatever it is that's causing the acceleration of the expansion of the Universe. The 'dark' bit doesn't mean it's evil and brooding, just that we don't know what it is.

Thinking about an expanding Universe isn't easy because we're used to stuff expanding *within* the Universe. This is the Universe itself – the whole thing – getting bigger. And the effect is dramatic. As the Universe is about 13.8 billion years old, the furthest we could ever see is light that has taken 13.8 billion years to reach us. (In practice, it's more like 13.5 billion years, as the Universe was opaque before that.) Yet the most distant potentially visible objects are thought to be about 45 billion light-years away, because of the expansion of the cosmos.

Without dark energy, General Relativity models predict different final outcomes depending on the curvature of space-time. If space-time is flat, as is generally thought, we would expect some kind of Big Freeze outcome, but with other types of curvature of space-time, gravity could overcome the expansion and produce a collapsing Universe. Add dark

PHOTO: SCIENCE PHOTO LIBRARY

IN A NUTSHELL

1 THERE WILL BE COSMIC DEATH

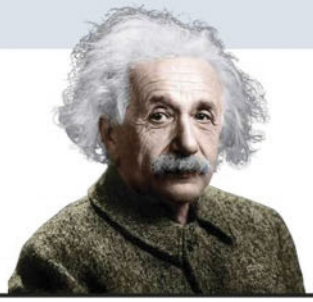
The Universe as we know it can't last forever. It's not just that stars will burn out – the whole cosmos is running down at the same time as it expands faster and faster. Eventually, billions of years in the future, we expect our Universe to come to an end.

2 THERE ARE ALTERNATIVE ENDINGS

Exactly how the Universe will end isn't clear. However, most cosmologists think that the expansion of the Universe will continue to accelerate, ending up with everything ripping apart.

3 THERE ARE KNOWN UNKNOWNS

As yet we still don't understand two fundamental components of the Universe: dark matter, which makes up over 80 per cent of the mass of the Universe, and dark energy, which drives the accelerating expansion. Until we do, which will require us to combine our understanding of gravity and quantum theory, this will all remain speculation.



Albert Einstein established the relationship between matter, gravity, space and time, allowing us to crudely model the Universe

energy into the mix and the acceleration could go on forever.

How is dark energy created?

'Dark energy' is just a label, and there are several possible explanations for its existence. It might be a fundamental property of empty space – a kind of intrinsic energy that's present throughout the Universe. This might come about through strange quantum effects, with the uncertainty of energy levels meaning that particles are constantly popping in and out of existence. Alternatively, dark energy might be a new kind of energy field or fundamental force, filling all of space but having the opposite effects to normal energy and matter. Finally, it might be that Einstein's theory of gravity is incorrect, and that a new theory is needed. The person who solves this mystery will be an instant Nobel Prize-winner.

On the scale with which we're familiar, dark energy is trivially small – unnoticeable. But when taking the Universe as a whole, so much energy is required to accelerate its expansion that dark energy is estimated to make up about 68 per cent of the mass/energy content of the Universe. Whatever it is, it's the dominant ingredient of our cosmos.

Can we predict the end of the universe with computer models?

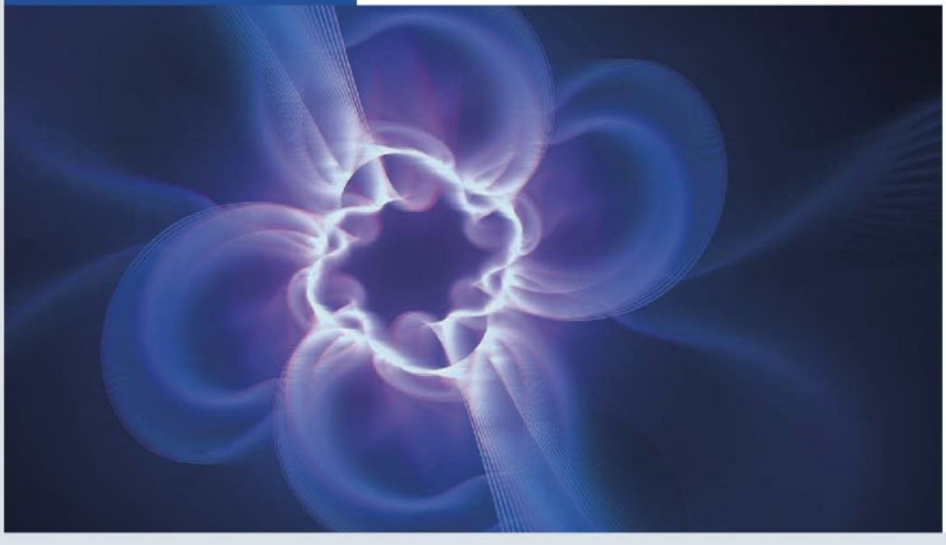
To a degree. Ever since Einstein developed his General Theory of Relativity, scientists have made simple mathematical models of the Universe and how it could develop with time. Over the years, these have become more and more sophisticated. But in the end the models remain far simpler than the thing they're modelling. Bear in mind that we can't even predict the weather more than a few days ahead. Modelling the behaviour of the whole Universe for billions of years to come is far more of a challenge, especially when we don't understand what dark energy is, nor the nature of the 'dark matter' that seems to make up far more of the Universe than ordinary matter.

Could anything survive the end of the universe?

In the favoured scenarios where everything either runs down or splits apart, it's hard to see how this would be possible. In a bounce, though, in principle *something* could survive, though it is more likely to be fundamental properties such as the laws of nature than anything with structure like a living being.

Will another universe be born after ours dies?

If either the Big Crunch or Big Bounce happens, definitely. However, even the more likely ever-expanding options don't mean the end of everything. Most cosmologists believe that our Universe is one of many in a larger 'multiverse', with Big Bangs happening regularly. So even if our Universe comes to an end, the larger multiverse would carry on forever. It's the universal circle of life.



BELOW: Dark energy, as visualised here, is causing the Universe's expansion to accelerate

PHOTOS: SCIENCE PHOTO LIBRARY X2

Brian Clegg is a prolific science writer. His most recent book is *How Many Moons Does The Earth Have?* (£6.99, Icon Books).

DISCOVER MORE

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NEXT MONTH: HOW DO WE KNOW WHAT MATTER IS MADE OF?

PHOTO: ISTOCK

CAN WE IMPROVE THE LIVES OF CAPTIVE ANIMALS?

A TRIP TO THE ZOO CAN BE A FUN AND EDUCATIONAL DAY OUT, BUT DO THESE INSTITUTIONS DO MORE HARM THAN GOOD?

WORDS: DR LORI MARINO

Lori is a neuroscientist and animal behaviour expert at Emory University in Atlanta, Georgia. She is also the founder and executive director of the Kimmela Center for Animal Advocacy, and president of The Whale Sanctuary Project.

Until fairly recently, zoos and aquariums were primarily places to take children for a fun afternoon. Few people gave ethics much thought as they stood in front of a cage watching a tiger pacing back and forth. Today, however, the entire enterprise of displaying wild animals is under intense scrutiny, by both the general public and the scientific community. We now know a lot more about how animals fare in zoos and aquariums (and we therefore understand why that tiger was pacing), and zoos and aquariums have to answer tough questions when they claim, for example, that all of the animals in their collections live long, happy and healthy lives.

A DIFFERENT LOOK

Not so long ago, the collections of unusual and exotic creatures at zoos included humans from other cultures around the world. As recently as the early 1900s, people from Africa were displayed as exhibits. One of the most famous of these individuals was Ota Benga, a Congolese man who was captured by slave traders and taken to the US where he was displayed in the Monkey House with apes. While Benga was eventually freed from the Bronx Zoo, he committed suicide a few years after being released.

Not so long ago, the collections of unusual creatures at zoos included humans from other cultures

In the 1960s and 1970s, zoos and aquariums started to rebrand themselves as places of education and conservation. But in many cases, the change was largely one of appearance. Enclosures and concrete tanks became 'habitats', tricks became 'behaviours', and elephant displays were painted with scenes of Africa. And that is where most zoos and aquariums still are today.

Small cages with bars may have been replaced with larger, more natural-looking areas, but the changes have little to do with what the various animals need to thrive and more to do with the appearance of nature.

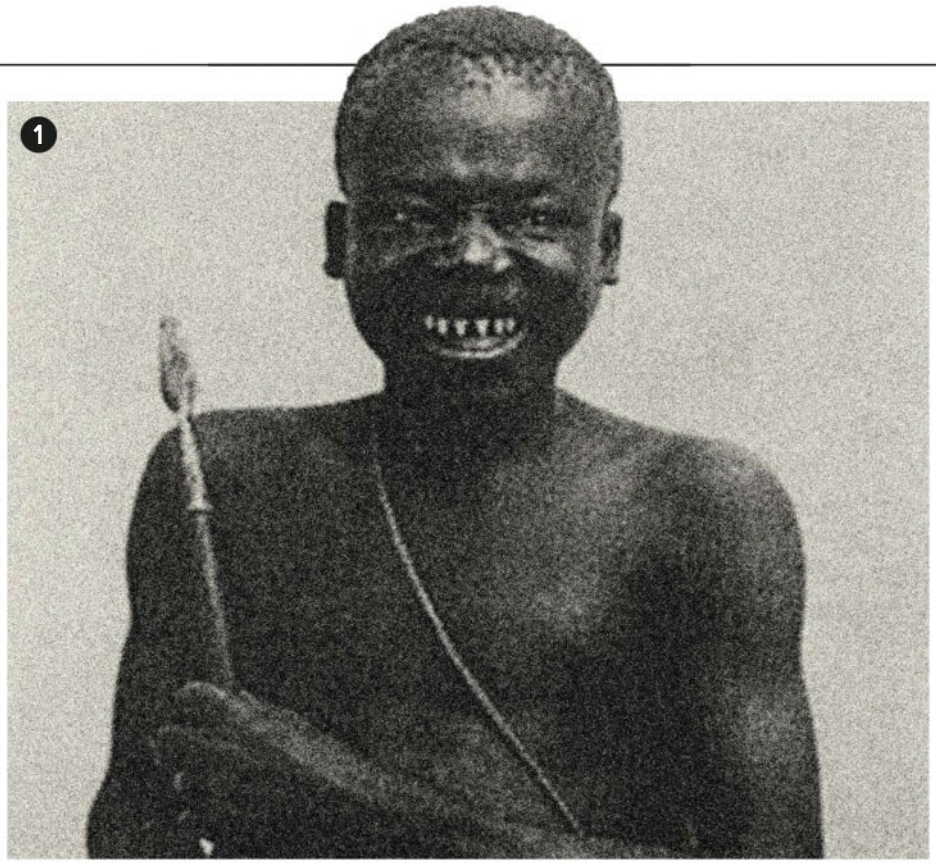
In 2016, zoos and aquariums struggle with the fact that people are more informed about the mental and social complexity of non-human animals and the psychological characteristics they share with us. We've seen dolphins recognising themselves in mirrors, chimpanzees grieving, elephants consoling one another, crows making complex tools, pigs playing video games, and fish enjoying friendships together. Characteristics like these not only allow us to see ourselves in them; they also make it clearer why many animals fare so poorly in captivity.

TRAGIC EVENTS

The last few years have also seen a series of events that have brought to the fore the challenges faced by both animals and humans in zoo and aquarium settings. The 2010 killing of trainer Dawn Brancheau by orca Tilikum at SeaWorld Orlando in 2010 and films like *The Cove* and *Blackfish* have propelled the marine park industry into the spotlight, raising troubling questions about the ethics of holding dolphins and whales in concrete tanks and forcing them to perform. Following Brancheau's death, the USA's Occupational Safety and Health Administration (OSHA) ordered SeaWorld to end human 'water work' with orcas during shows. Furthermore, a study published in the journal *Animals* in August 2016 found that aggressive behaviour in orcas increases when they are trained to perform.

Again in response to public demand, the US-based circus company Ringling Bros and Barnum & Bailey Circus put on its last elephant show earlier this year. Their 11 elephants have now retired to a facility in Florida. In the UK in the 1990s, rigorous welfare regulations were introduced regarding captive whales and dolphins. Existing dolphinaria were incapable of meeting the new standards. They closed, ending the UK's dolphin and whale marine park industry.

More recently, the ongoing news stories about deaths in zoos around the world – Marius the 'surplus' giraffe in the Copenhagen Zoo, Harambe the gorilla in the Cincinnati Zoo, and Arturo the polar bear at ◉



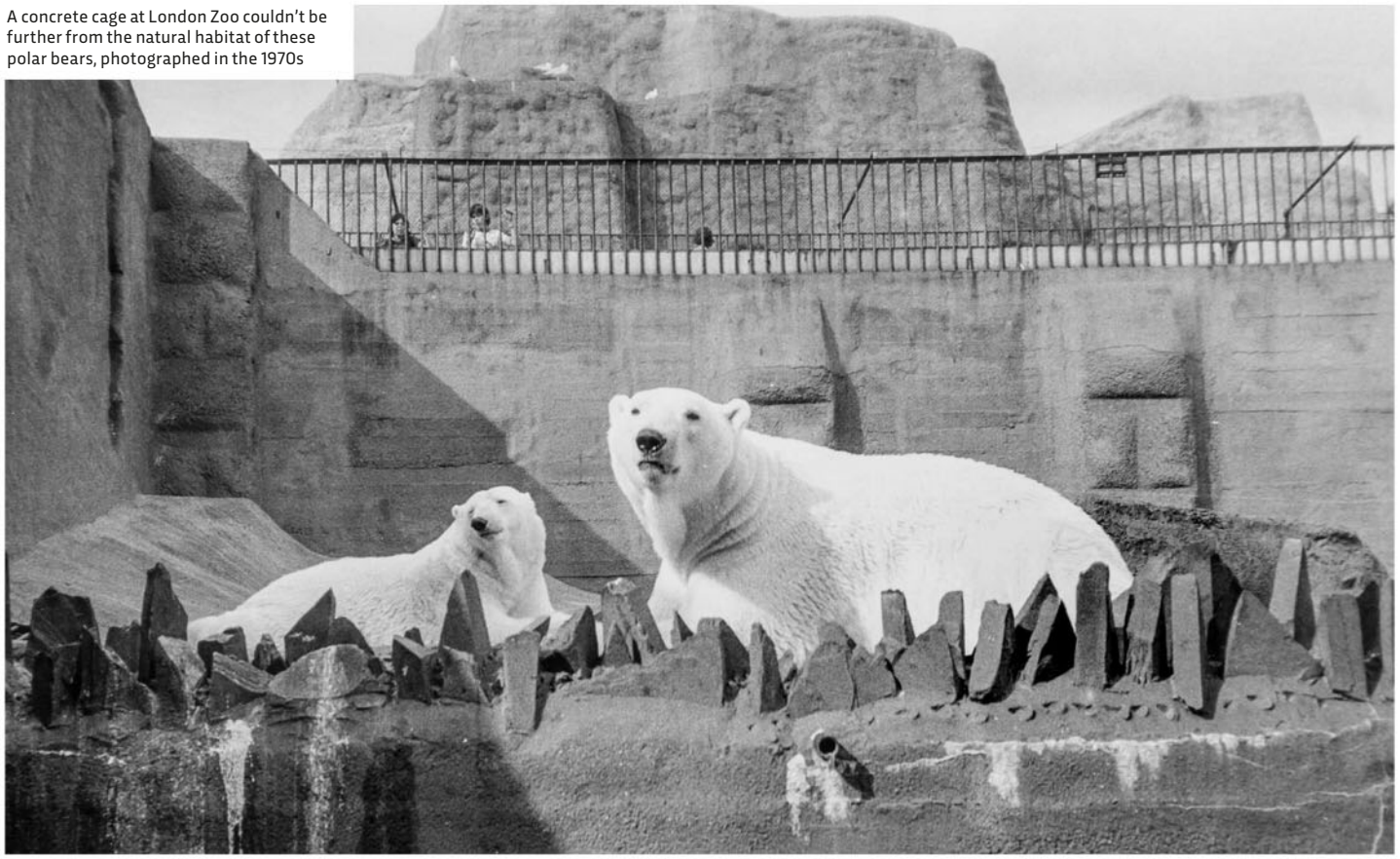
1 Ota Benga was taken from the Congo in the early 20th Century and was exhibited at the Bronx Zoo. He was later released, but pined for his homeland. He committed suicide in March 1916

2 In July this year, Arturo the polar bear died in a zoo in Argentina. A petition to move him to a more suitable habitat in Canada had gathered thousands of signatures

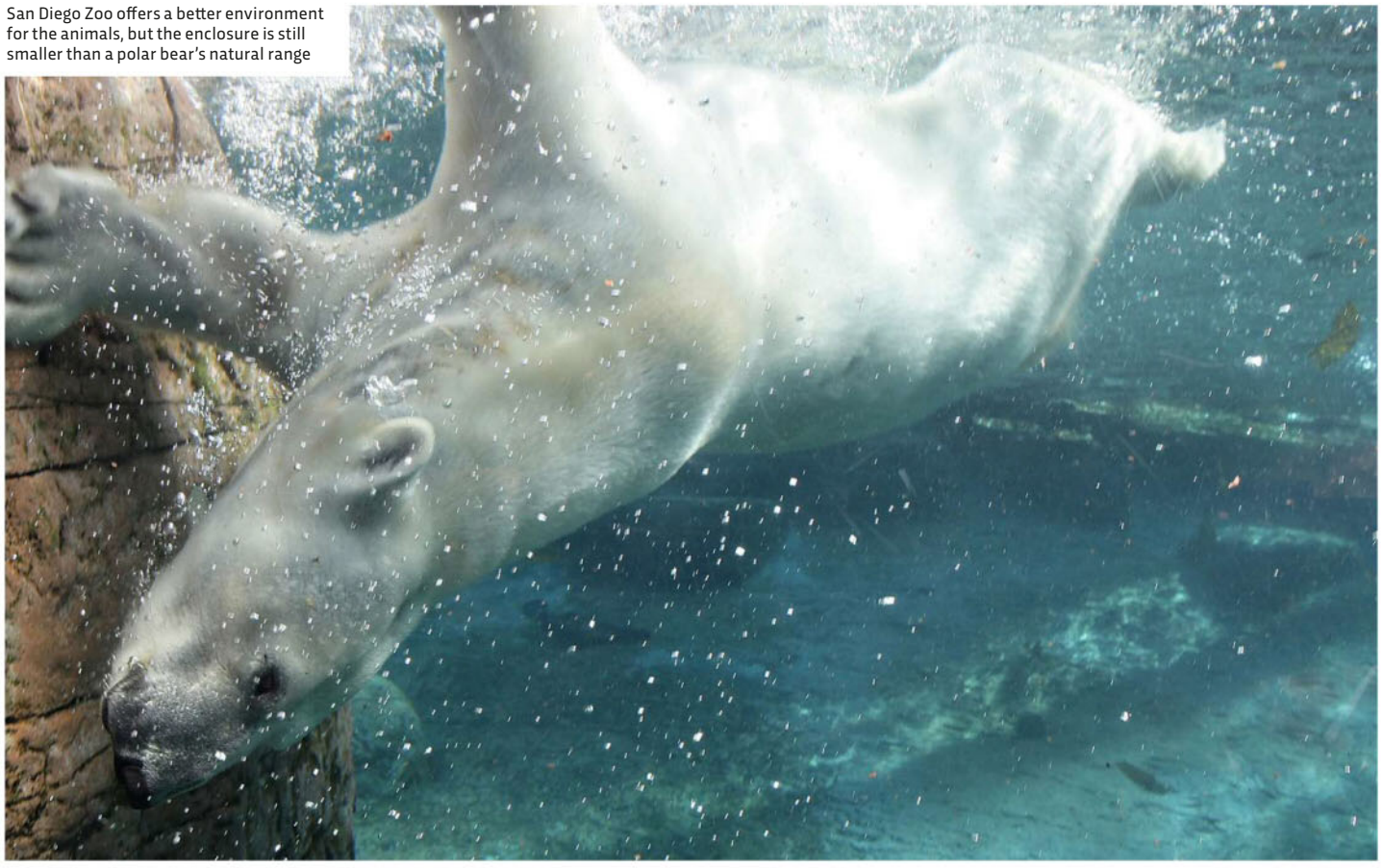
3 SeaWorld trainer Dawn Brancheau was killed by the male orca Tilikum in February 2010. Hers was the third death in which Tilikum had been involved

PHOTOS - PREVIOUS PAGE: GETTY , THIS PAGE: BRIDGEMAN ART LIBRARY, GETTY X 2

A concrete cage at London Zoo couldn't be further from the natural habitat of these polar bears, photographed in the 1970s



San Diego Zoo offers a better environment for the animals, but the enclosure is still smaller than a polar bear's natural range



PHOTOS: ALAMY, GETTY, REX

Argentina's Mendoza Zoological Park – have turned these animals into cause célèbres for good reasons.

Three facts remain central to the future of zoos and aquariums. First, the welfare of many of their captive animals remains poor, especially the larger species like dolphins, whales, elephants, bears and big cats. There is overwhelming scientific evidence that these highly intelligent, socially complex, wide-ranging mammals, who are the 'big ticket' items for zoos and aquariums, cannot thrive in captivity. Elephants and cetaceans live significantly shorter and less healthy lives in captivity. Orcas, who can travel 160km (100 miles) a day in the ocean, chew the bars of their tanks, grinding their teeth down to stubs. Elephants, who are capable of roaming tens of miles a day in the wild, sway back and forth. Gorillas eat their own faeces. And polar bears are offered ice lollies as they waste away in hot, humid climates that are anathema to their very physiology.

Second, the direct conservation efforts of many of the world's zoos and aquariums are minimal. While there have been a handful of successes, such as the California condor, Przewalski's horse, the British field cricket and the Partula snail, these are not 'big ticket' species that bring in high levels of revenue from visitors. Plus, most animals in captivity are never reintroduced to wild populations. The majority of elephants currently in European zoos were caught in the wild, thereby exacerbating, not diminishing, conservation problems for wild populations.

There is evidence that seeing an animal in captivity actually decreases conservation concerns for that animal

Moreover, most successful reintroductions around the world occur in specialised breeding and care centres, not zoos open to the public. For example, the Zoological Society of London engages in numerous global conservation initiatives but it isn't clear that the effectiveness of these programmes is dependent upon it having wild animals on display.

In a lot of countries, there are restrictions on reintroducing certain species into the wild. And the proportion of revenue spent by most zoos and aquariums on actual conservation projects pales in comparison to what is spent on the 'visitor experience'. (Most highly endangered species kept in zoos are too genetically inbred to contribute to the health of wild populations.)

Third, zoos and aquariums continue to maintain that seeing animals on display educates people in conservation values. They promote their facilities as conservation centres that create 'connections' between the visitors and the animals. But we've been viewing elephants in zoos for decades, yet these animals are now on the brink of extin ction. Indeed, despite the fact that hundreds of millions of people have visited zoos and aquariums, we're currently witnessing a global mass extinction event.

There has yet to be published a study providing strong evidence that viewing animals on display has any real long-term educational value. On the other hand, there is evidence that seeing an animal in captivity and in association with humans actually decreases conservation concerns for that animal.

At the same time, attendance at zoos and aquariums is falling. SeaWorld's stock has been shaky since the worldwide showing of *Blackfish* in 2013. The company's stock price dropped precipitously from a high of $39 in May 2013 to a low of $15.80 in December 2014, along with visitor attendance. In 2016 they continue to experience stock and revenue declines.

A NEW MODEL

What, then, can these facilities do to become relevant to a 21st-Century world? More than anything, they will need to reflect our changing relationship with animals from one of objectification and exploitation to one of restoration and reconciliation. First, they will need to stop breeding their captive creatures and stop importing wild animals. Public pressure has forced SeaWorld to announce an end to all orca breeding in its parks around the world, and the US government has already declined Georgia Aquarium's application to import 18 wild-caught beluga whales from Russia. Aquariums will need to end their theatrical shows, which serve no purpose other than to provide spectacle for visitors. Animals should not be imposed upon to perform for food.

Second, these facilities will need to move to a life-enhancing model. Many aquariums already engage in rehabilitation of stranded marine mammals and other animals, and such efforts can become a focal point for real education and conservation. And third, zoos and aquariums need to move toward the only model that can truly justify their existence: they must become sanctuaries.

An authentic sanctuary differs from a zoo or aquarium in one critical way. While the priority of a zoo is to give the human visitor an enjoyable

Elephants at the Performing Animal Welfare Society (PAWS) can enjoy lots of room to roam, along with a more naturalistic environment

experience, the priority of a sanctuary is the health and well-being of its animals. Sanctuaries offer more natural environments, and are places where the goal is to give back to the animals as much as possible of what was taken from them. Sanctuaries can provide real education since they have no need to hide uncomfortable truths from their visitors. And while those who run for-profit zoos and aquariums depend on staying in business, sanctuary owners would like nothing more than to be put out of business as a result of a decline in the kind of abuse and exploitation of animals that makes refuges such as these necessary.

A BRIGHT FUTURE?

Some more progressive zoos have already started the process of evolving from places of spectacle to authentic centres of restoration, education and conservation. In 2005, Detroit Zoo closed its elephant exhibit and moved its two elephants to the Performing Animal Welfare Society (PAWS) sanctuary in California. In 2013, Toronto Zoo did the same thing and moved its three elephants to PAWS. This year, the National Aquarium in Baltimore announced plans to create a sanctuary in Florida or the Caribbean for its eight bottlenose dolphins.

Meanwhile, The Whale Sanctuary Project, a new not-for-profit organisation, is planning the first North American seaside sanctuary for cold-water dolphins and whales, which will provide an option for orcas and belugas currently on show at marine parks. Another example of a successful non-profit wildlife sanctuary is the Marine Mammal Center in Sausalito, California, where seals and sea lions are rescued and rehabilitated in a state-of-the-art facility. When the time is right, the animals are released. At the same time, the Marine Mammal Center offers volunteer and education programmes to engage the general public.

Even as they adopt a model that's no longer rooted in exploitation, zoos and aquariums can still operate as businesses. While the animals thrive in a more natural, sanctuary-based setting, visitors can enjoy engaging and interactive displays that are made possible by increasingly sophisticated computer-generated graphics, immersive technology and virtual reality. Ironically, then, as they give up live animal displays in favour of more technology, zoos and aquariums have the opportunity to actually become more natural and authentic.

The model for the future will likely involve a melding of for-profit corporate expertise and experience with non-profit motives, goals and models of animal care, education and conservation. Far from having a bleak future, zoos and aquariums that shift to this more progressive model will not only thrive, but will become cultural leaders in our relationship with the other animals with whom we share this planet. The choice is up to them.

PHOTO: GETTY

VIEW FROM A ZOO

***Charlotte Corney** is director of the Isle of Wight Zoo. The attraction has a strong focus on providing homes to rescued big cats, and is currently being converted into a charity. She argues that zoos have a vital role to play in conservation*

The time is ripe for a revolution. Humans have been keeping animals in zoos since 1752 (the Tiergarten Schönbrunn zoo in Vienna), and in private menageries since Egyptian times. Since then we've made huge leaps forward in our scientific understanding of animals – but our steps to implement change for their well-being have not progressed at the same rate. Over the last few hundred years, wild landscapes have been desecrated and their inhabitants persecuted at an unprecedented pace, while zoos have failed to convert visitors into passionate conservationists.

So what now? Do we acknowledge our failings and just 'give up', at this most critical time when we're facing a sixth mass extinction? Or do we do things differently and start winning more battles? I'm in the latter camp, despite understanding and acknowledging the scale and scope of work to be done.

Zoos and similar facilities are uniquely positioned to influence the hearts and minds of decision-makers throughout the world. They attract people of all ages and backgrounds – some 700 million annually present themselves as potential recruits for the wildlife cause. That's a phenomenal resource to just throw away should zoos cease to exist, but it's also a phenomenal resource to waste. If people walk out of our gates lacking the understanding and motivation to take action, we will continue to lose the icons of our conservation campaigns, and with them, our planet's vital biodiversity. Should that time come, there would be little point in keeping a living museum of animals, and I'd say 'let them go'.

British people have boycotted circuses with wild animals to such an extent that they are now defunct

In order for us to inspire our audience in favour of conservation, we need to show them our problems and ask for their help. I see the general public's increasingly informed status as a strength to draw on, not something to fear. This may mean they're more likely to support funds that go directly to the animals, rather than visiting artificial environments; they might travel further to visit particular species living in specialised centres; but they may also start to empathise with, rather than condemn, our endeavours to help save the world's wildlife. Our challenges are complex but not impossible, as long as we de-institutionalise, drop egos and are prepared to re-invent ourselves.

The public already vote with their feet: they've told us that it's unacceptable to keep certain species (such as orcas) in captivity, and the British people have boycotted circuses with wild animals to such an extent that they are now defunct. These movements are encouraging.

Zoos are still, on the most part, dependent on commercial revenue, but this should not be an obstacle to making the right decisions about what species they house. If they are smart enough to talk to their visitors, I am sure they will be able to combat the loss of 'big ticket' animals. But this change should not be attempted in isolation: the zoo world must think 'collaboration' not 'competition'.

Some zoos should become sanctuaries for rescued or unwanted animals, but if we take the line that *all* zoos should cease breeding, then we are relying on in-situ conservation efforts alone to protect our planet's wildlife. I, for one, am not ready to gamble on that.

DISCOVER MORE

Do you think that zoos and aquariums are outdated, or do you think they're still valuable? Have your say on our Twitter page, @sciencefocus, or send an email to reply@sciencefocus.com

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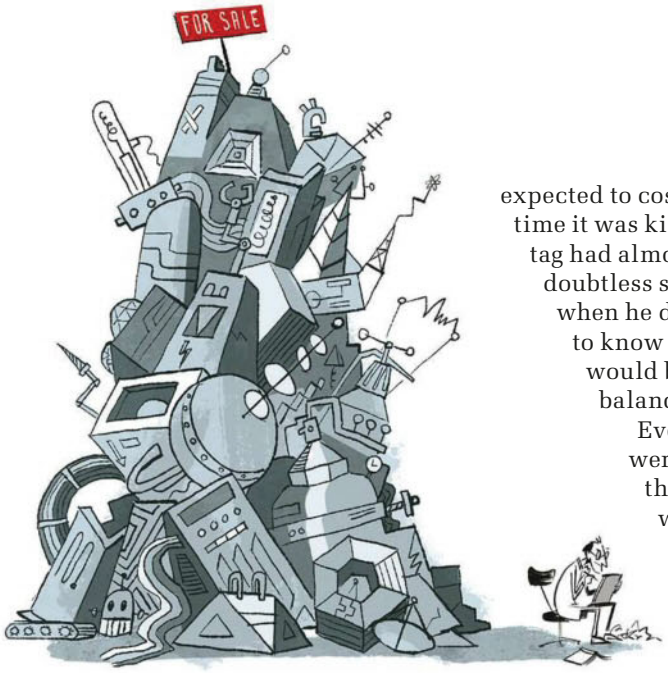
ROBERT MATTHEWS ON... BIG SCIENCE

"HISTORY SHOWS THAT MOST BIG BREAKTHROUGHS COME FROM SMALL BUT SMART SCIENCE"



On a recent trip through the state of Texas, I saw a signpost that directed visitors to the scene of a bitter battle where a band of plucky heroes tried to defend a frontier outpost against a huge army, but lost. No, it wasn't the Alamo, but a town called Waxahachie. And many physicists remember all too well what happened there in the early 1990s.

The outpost took the form of a particle accelerator called the Superconducting Super Collider (SSC), and its role was to push back the frontiers of knowledge about the Universe.

Like today's Large Hadron Collider (LHC), the SSC was designed to smash together particles with energies similar to those that prevailed just after the Big Bang. And to do it, the SSC, like most things in Texas, was going to be big: thousands of tonnes of superconducting magnets and other paraphernalia packed into a tunnel almost 90km round – triple the size of the LHC – buried under Waxahachie.

The SSC promised to answer a whole host of cosmic questions. Was the so-called Standard Model, the best description of subatomic particles, really trustworthy? If so, where was the so-called top quark, the last of the building blocks of subatomic matter predicted by its equations? And did the Higgs Vector boson, needed to explain why particles have mass, really exist?

The prospect of getting answers to these questions sparked huge amounts of excitement among particle physicists. But in 1993, with just 20 per cent of the SSC built, calamity struck. US congressmen, concerned about spiralling costs, took aim, fired and killed the project. Among physicists, the decision was seen as a massive defeat. Morale plunged, and many sought careers elsewhere.

Not everyone was distraught by the decision to shut down the project, however. The SSC was originally expected to cost around $4bn, but by the time it was killed off the estimated price tag had almost tripled. One senator doubtless spoke for many US taxpayers when he declared: "It would be nice to know the origin of matter. It would be even nicer to have a balanced budget".

Even some scientists were glad to see the demise of the SSC. I recall one professor working on less glamorous problems than the quest for the Higgs boson saying it was about time that particle physicists got their comeuppance.

In the end, the scientists got answers to their questions anyway – they just had to wait a bit longer for them. But now it seems that not even the LHC will answer the next batch of questions. What is the 'dark matter' that lurks in our Universe? Where does dark energy come from? And what lies beyond the Standard Model? I have no idea, and I doubt that physicists will be given billions for another Big Science project to find out.

So does that mean the end of the quest for cosmic knowledge? Hardly: history shows that most big breakthroughs come from Small But Smart Science. The nature of the Universe has been pinned down with exquisite precision using orbiting observatories costing far less than the LHC. Dark energy was discovered using multitasking Earth-based telescopes. And in the last few months, key insights into the nature of dark matter have emerged from experiments costing less than £10m a pop.

I suspect that the days of Big Science projects like the SSC and LHC are over. Instead, it's time to seek inspiration from the battle cry of the first atom-smasher himself, Lord Rutherford: "We don't have the money, so we'll just have to think."

Robert Matthews is visiting professor in science at Aston University, Birmingham. His latest book *Chancing It: The Laws Of Chance And What They Mean For You* is out now (£14.99, Profile).

NEXT ISSUE: PERSONALISED MEDICINE

ILLUSTRATION: ADAM GALE

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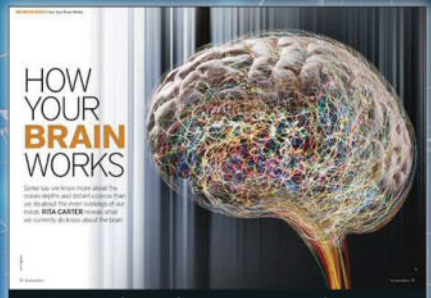

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Q&A

DR CHRISTIAN JARRETT
Christian is a psychology and neuroscience writer. His latest book is *Great Myths Of The Brain*.

DR ALASTAIR GUNN
Alastair is an astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester.

PROF ROBERT MATTHEWS
Robert is a physicist and science writer. He's visiting professor in science at Aston University.

DR PETER J BENTLEY
Peter is a computer scientist and author who is based at University College London. His latest book is *Digitized*.

LUIS VILLAZON
Luis is a freelance science and tech writer with a BSc in computing and an MSc in zoology from Oxford University.

ALEXANDRA CHEUNG
Alexandra has a degree in environmental science, and has worked for CERN and Imperial College London.

YOUR QUESTIONS ANSWERED

OCTOBER 2016 | EDITED BY EMMA BAYLEY

The drought balls in Los Angeles will last for 10 years, and will then be recycled

How do drought balls work?

ANNA KENDAL, TIVERTON

The warmer water gets, the faster its molecules move. This extra energy allows water to evaporate more quickly. By shielding the water from sunlight and keeping it cool, drought balls (also known as shade balls) can slow evaporation from water bodies. In 2014, the Los Angeles Department of Water and Power released 96 million of these plastic balls into the city's main reservoir. Their goal was not to save water but to reduce the growth of microorganisms and prevent the creation of bromate, a carcinogen that forms through a chemical reaction triggered by UV light. The balls did, however, reduce evaporation by up to 90 per cent. **AC**

PHOTO: ZUMA PRESS/KEVINE

NO EASY ANSWER

WHAT IS DARK MATTER?

Over 80 per cent of the matter in the Universe is made up of this stuff, but despite its name it can't simply be made up of dead stars, gas and dust. Dark matter has to consist of something more exotic than standard atomic particles to ensure the Big Bang produces a universe chemically similar to the one we see.

Such observational constraints have forced theorists to focus on a handful of candidates for dark matter.

Leading the pack are so-called weakly interacting massive particles ('WIMPs') and gravitinos, whose existence is predicted by theories aimed at unifying all the fundamental forces and particles of nature.

The other main contenders are axions, predicted to exist by theories of how atomic nuclei hold together. Experiments now underway at the LHC could soon reveal the truth. AC

How did cavemen cut their toenails?

EDWARD SEYMOUR, HOVE

They could theoretically have used a flint edge to trim them, or a rough stone to file them down. However, we don't have any firm evidence of 'cavemanicure' at all, since no fingernails or toenails survive from any Stone Age burial sites. If you spend your day walking barefoot and scraping up roots with your hands, your nails will wear down naturally, which is why they have evolved to keep growing throughout our lives. **LV**

Can your tonsils grow back?

RICHARD MERRIL, LITTLEHAMPTON

Yes. In about 10 per cent of cases in one study, there was some regrowth of the tonsils after four years. This can happen if the surgeon accidentally leaves some of the tonsil tissue behind, but it's quite common to deliberately perform a partial tonsillectomy too. Regrowth is more common after the age of seven and in individuals with diets high in sugar. **LV**

Is sea level rise accelerating?

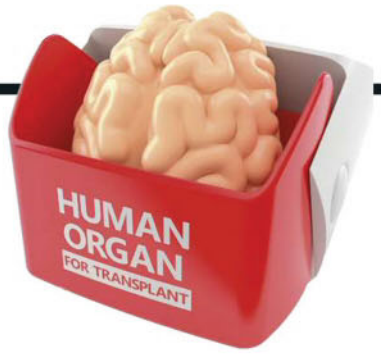
KATIE RYAN, LONDON

Wading through floodwater: still more pleasant than public transport

Global sea levels rose by about 19cm from 1900 to 2010, creeping up by an average of 1.7mm a year.

Since 1993, satellite measurements have allowed us to make more precise measurements of sea level change, showing that between 1993 and 2010, sea level increased by just over 3mm per year, almost double the average pace for the 20th Century. As global temperatures continue to soar, scientists expect that sea level will rise at even faster rates in coming decades, resulting in a further increase in global sea level of up to 80cm by the end of the century. **AC**

PHOTOS: GETTY X2, ISTOCK, SCIENCE PHOTO LIBRARY



If I put my brain in another body, would I feel different?

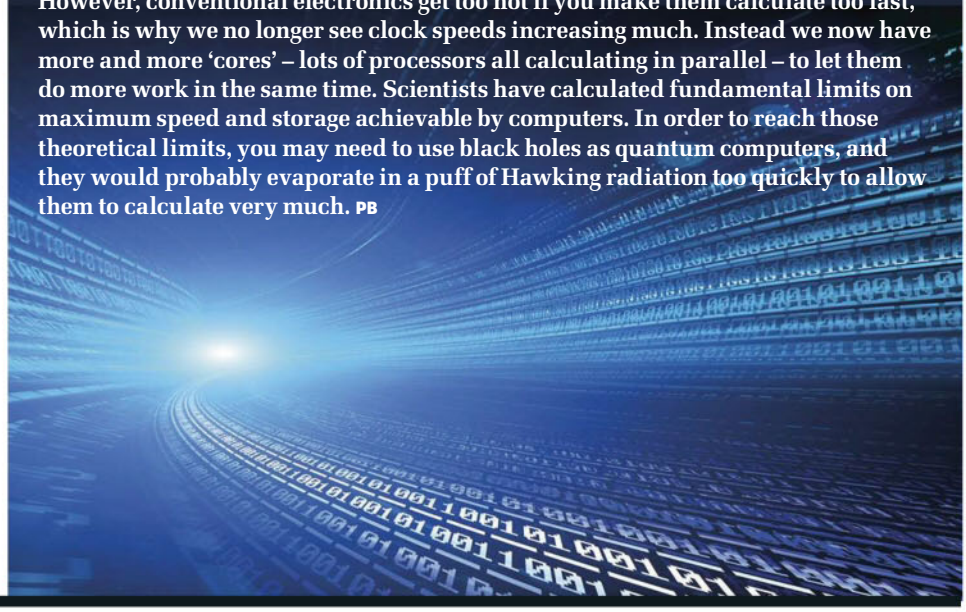
ARTHUR CHAMBERS, EASTLEIGH

You'd feel paralysed! The only time this has been tried was in 1970 when Robert White transplanted the head of a monkey onto the body of another, decapitated monkey. This gruesome hybrid was conscious, but paralysed from the neck down because we can't yet reattach severed nerves. If we ever get past this obstacle, body transplants will still take a lot of getting used to. For one thing, your brain would be exposed to a different cocktail of hormones. **LV**

Can computers keep getting faster?

TOBY KRISTEN, TONBRIDGE

The laws of physics stop computers getting faster forever. Computers calculate at the tick of an internal clock, so for many years manufacturers made transistors smaller and clocks faster to make them perform more computations per second. However, conventional electronics get too hot if you make them calculate too fast, which is why we no longer see clock speeds increasing much. Instead we now have more and more 'cores' – lots of processors all calculating in parallel – to let them do more work in the same time. Scientists have calculated fundamental limits on maximum speed and storage achievable by computers. In order to reach those theoretical limits, you may need to use black holes as quantum computers, and they would probably evaporate in a puff of Hawking radiation too quickly to allow them to calculate very much. **PB**



THE THOUGHT EXPERIMENT

IF A LIFT IS FALLING, WHAT'S YOUR BEST CHANCE OF STAYING ALIVE?

1. SIT TIGHT

Unless the building suffers catastrophic damage, such as during the World Trade Center attacks of 2001, lifts almost never fall. A lift has between six and 12 independent cables and each one is strong enough to support a fully loaded lift. If all the cables fail, brakes will automatically clamp onto rails lining the lift shaft.

2. DON'T JUMP

Jumping up at the last moment, before the lift hits the bottom, only works in cartoons. Even if you were somehow strong enough to leap fast enough to negate your falling velocity, you would just smash your head against the lift ceiling at the same speed you had been falling!

3. FALL FROM THE TOP FLOOR

In 1945 a B-25 bomber crashed into the Empire State Building and damaged the lift cables. Betty Lou Oliver fell 75 storeys, breaking her neck, back and pelvis, but survived. The huge length of steel lift cables hanging beneath the lift car coiled into a springy mat at the bottom of the shaft and this partly cushioned her fall.

PHOTOS: ISTOCK X2. ILLUSTRATION: CHRIS PHILPOT

Q&A

As Jupiter's gravity pulls in so much matter, is the planet growing?

LOUIS GOODWIN, LEWES

Jupiter's large gravitational field makes it prone to impacts from asteroids, comets and other Solar System flotsam. This was spectacularly demonstrated in 1994 when the comet Shoemaker-Levy 9 plunged into the atmosphere of Jupiter, adding at least one trillion kilograms to the planet's mass in a single event. It is estimated that Jupiter's rate of mass increase from impacts or accretion is up to 8,000 times that of the Earth's. Events like Shoemaker-Levy 9 are rare but even adding up the smaller bombardments of Jupiter that continuously rain down on the planet, the increase in mass is still a tiny fraction of Jupiter's overall total. However, this does not mean that Jupiter's mass is increasing. Jupiter's atmosphere is warm; so warm that gas molecules are moving fast enough to escape the gravitational pull of the planet. Furthermore, the solar wind actually ionises many of the atoms in the Jovian atmosphere. Since these atoms become neutrally charged, they can easily escape Jupiter's magnetic field and float off into space. This slow but constant loss of mass from Jupiter's atmosphere is actually greater than the gain in mass from collisions so, overall, Jupiter is shrinking not growing in mass. AG

TOP 10

LONGEST LASTING LANDFILL ITEMS

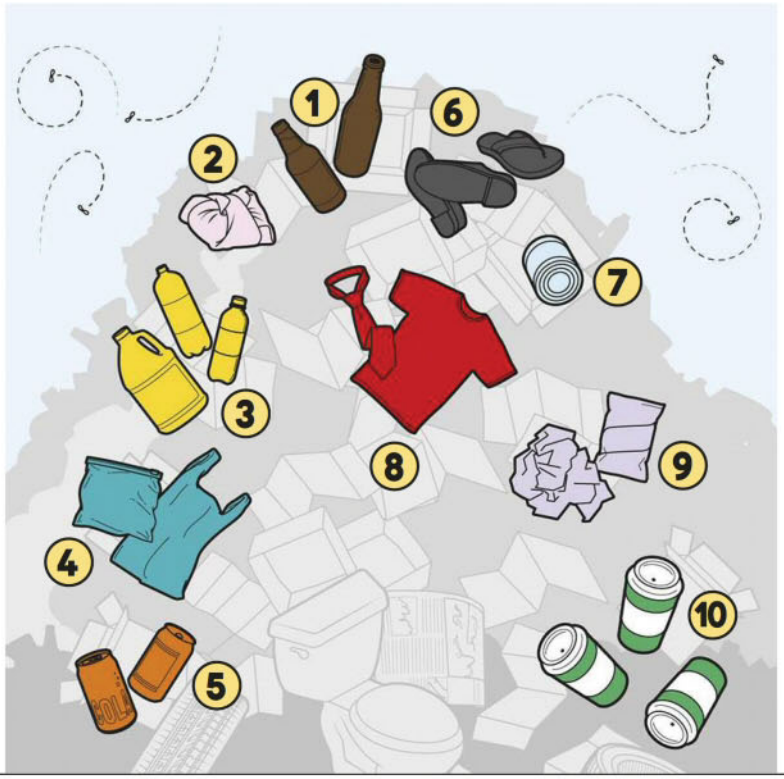
1. Glass bottles
Time to break down: one million years

2= Disposable nappies
Time to break down: 450 years

2= Plastic bottles
Time to break down: 450 years

4. Plastic bags
Time to break down: 200-500 years

5. Aluminium cans
Time to break down: 80-200 years



6. Rubber-soled shoes
Time to break down: 50-80 years

7. Tin cans
Time to break down: 50 years

8. Clothing
Time to break down: up to 40 years

9. Plastic film*
Time to break down: 20-30 years
*clingfilm, magazine wrappers, crisp packets, etc

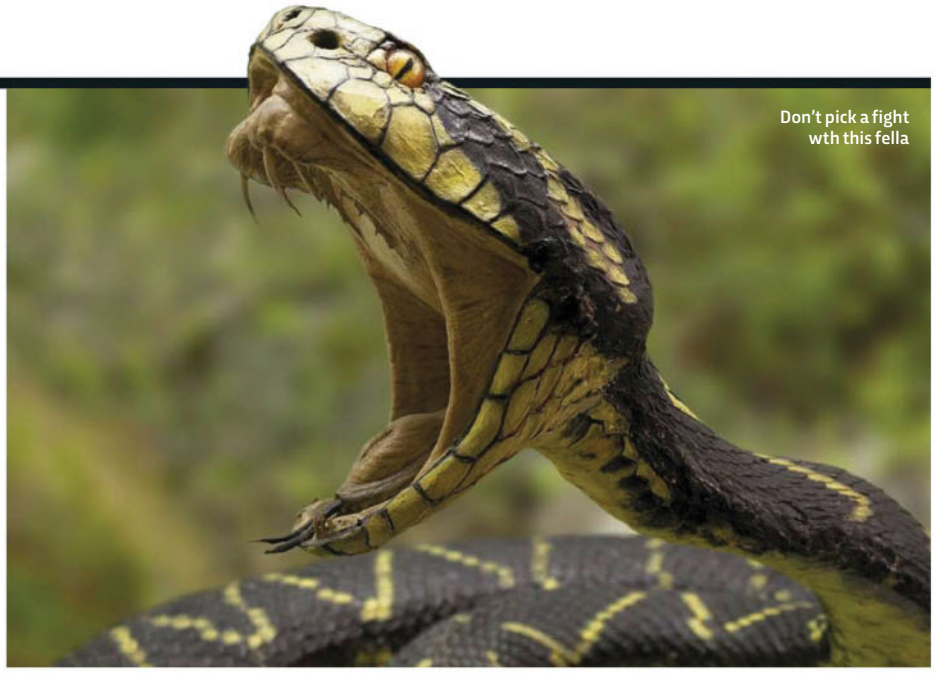
10. Paper coffee cups
Time to break down: 20 years

PHOTOS: SCIENCE PHOTO LIBRARY, ISTOCK X3, GETTY

Why is nail-biting so addictive?

MADISON HUGHES, SHROPSHIRE

There are plenty of theories for why people start nail-biting (or what doctors call 'onychophagia'), including perfectionism and stress. And there's also the Freudian notion that it's to do with being stuck at the oral stage of psychological development! But as to why nail-biting is so addictive (20 to 30 per cent of us do it), there's little research. We can speculate that it is to do with its cost-free ease, practicality and relative social acceptability, and there's the rewarding aspect of getting each nail just how you want it. On a positive note, childhood nail-biters are less prone to allergies, presumably because they're exposed to more germs. **CJ**



Don't pick a fight wth this fella

How does snake venom kill so quickly?

JORDAN SHEMILT, MIDSOMER NORTON

Snakes don't have claws or powerful jaws to pin down their prey. If the venom doesn't kill quickly enough, the victim may escape into a burrow or up a tree and die out of reach of the snake – or, worse, injure the snake in its death throes.

Snakes are in an evolutionary arms race with their prey, which are evolving ever-greater resistance to snake venom. Snakes have adapted to this by evolving venoms that contain a cocktail of several hundred different enzymes and proteins. Some block nerve transmission, others interfere with the beating rhythm of the heart, some break down muscle tissue or cause blood vessels to suddenly become leaky.

Snakes can control how much venom they inject with a single bite and generally use far more than the lethal dose. The black mamba, for example, injects up to 12 times the lethal dose for humans in each bite and may bite as many as 12 times in a single attack. This mamba has the fastest-acting venom of any snake, but humans are much larger than its usual prey so it still takes 20 minutes for you to die. **LV**

Can you die from a nosebleed?

KADIM OLZHAS, KAZAKHSTAN

Most nosebleeds involve superficial bleeding from the capillaries close to the skin and can be stopped with pressure and an ice pack. But nosebleeds can also be caused by a torn internal carotid artery and in that case the bleeding can be fast enough to be life threatening. It's also possible for a milder nosebleed to block your airway and asphyxiate you.
A 47-year-old man from Gravesend, Kent died this way in 2011. **LV**

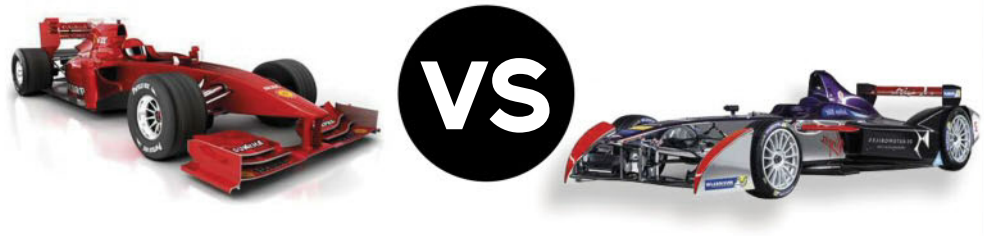
Q&A

Could an asteroid knock Earth out of its orbit?

CHRIS WISNER, SOUTH CAROLINA, USA

No. The Earth has a lot of mass and moves extremely quickly in its orbit around the Sun; in science speak, we say its 'momentum' is large. To significantly change the Earth's orbit, you would have to impart a very great change to the Earth's momentum. Not even the largest asteroids have sufficient mass and kinetic energy to make much of a difference to the Earth's momentum. Even more of an obstacle is the fact that our planet's binding energy is greater than its orbital kinetic energy. This means that any object large enough to change the Earth's orbit is also big enough to completely destroy it! **AG**

HEAD TO HEAD



FORMULA 1		FORMULA E
702kg	WEIGHT (INC DRIVER)	898kg
710kW	MAX POWER	200kW
2.1 secs	0-100KM/H	3 secs
378km/h	MAX SPEED	225km/h
134dB	NOISE LEVELS	80dB

Like Formula 1, Formula E is a racing championship with single-seater, open cockpit cars, but the vehicles are entirely battery-powered. With a top speed of 225km/h and a power-to-weight ratio 35 per cent higher than a Tesla Roadster, they are no slouch. But F1 cars still win – their 1.6-litre petrol/electric hybrid engine has more than three times the power. **LV**

How far can dandelion seeds travel?

LIZ DAWES, PRESTON

A 2003 study at the University of Regensburg in Germany found that 99.5 per cent of dandelion seeds land within 10 metres of their parent. That's because the seed 'parachute' falls at about 30cm per second and dandelions only grow about 30cm high. So that gives each seed just one second of flight time to be blown sideways by the wind to its new home. Higher wind speeds don't really increase the distance the seeds fly, because strong winds tend to blow downwards as well as sideways, so the seeds just land even sooner. The best conditions for dandelion seeds are actually relatively calm, sunny days that generate thermal updraughts. Under these conditions, dandelion seeds can go much further and the study estimated that 0.014 per cent – about one in 7,000, would travel more than a kilometre. **LV**

Poor dandelion seeds. They never get out of their parent's shadow

PHOTOS: SCIENCE PHOTO LIBRARY, ISTOCK, GETTY. ILLUSTRATION: CHRIS PHILPOT

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HOW IT WORKS

SKYDIVING WITHOUT A PARACHUTE

Back in July, 42-year-old US skydiver Luke Aikins set a new record for the highest skydive without a parachute. But how did he do it?

The jump

Aikins leapt out of the plane at a height of 7,620m (25,000ft) without wearing a parachute or wingsuit.

The fall

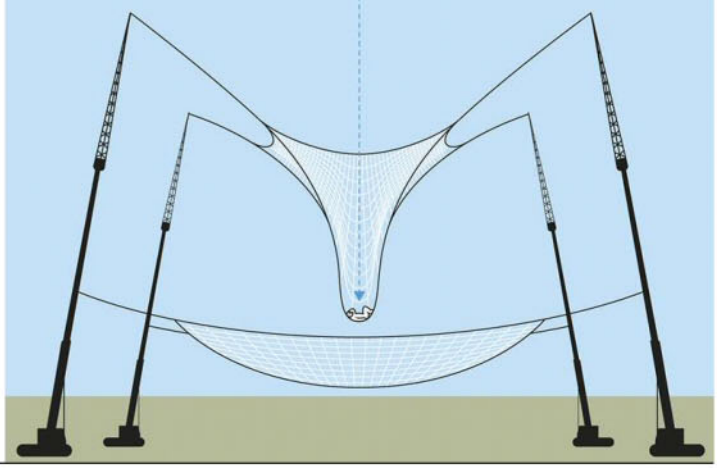
Aikins reached speeds of 193km/h (120mph) during the two-minute fall.

The guidance system

A GPS system on his helmet relayed his position to a guidance system on the ground, which was linked up to the net. The net featured a system of lights that shone red when he was off-target, and white when he was correctly oriented.

The landing

A second before impact, Aikins flipped onto his back. He landed in a polyeth-ylene net measuring 30 x 30m (100 x 100ft) that was suspended above the ground by four cranes.



What is the Interplanetary Superhighway?

TOM NICHOLSON, DERBY

Space agencies like NASA often make use of the gravitational fields of planets to give probes a boost to their final destination. In the late 1970s, mission designers began plotting out the paths between the planets and their satellites that could exploit this fuel-saving effect. The resulting ribbon-like network of celestial routes is known as the Interplanetary Superhighway, and it's now regularly exploited on missions to deep space. **RM**

What happens to a person's online data after they die?

RONG JIE LOO, MALAYSIA

Each company that stores the data may have a different policy. If the person was paying a subscription to a website to store their data, then once the subscription expires, the data will probably be deleted. For free sites, anything can happen. For example, Yahoo! refused to hand over emails of a deceased son to his parents, despite being ordered to do so by a court. However, Facebook has a policy to change the deceased person's profile into a memorial page, if a family member notifies the company. Friends and family can then visit the page to share their experiences, express their sadness, and celebrate the life of the person. **PB**

WHAT CONNECTS...

...X-MEN AND ELEPHANTS?

1. In the Marvel Universe, one of the founding members of the X-Men is the superhero Cyclops, who can shoot powerful beams of energy from his eyes.

2. Although Cyclops has two eyes, he is named after a race of giants in Greek mythology that had a single large eye in the middle of their forehead.

3. Cyclops means 'circle-eyed' and the monster may have been inspired by large fossil skulls found on Crete, Cyprus, Malta and Sicily, which do have a large central hole in the forehead.

4. These are actually skulls of the dwarf elephant, which became extinct around 8,000 years ago. The central 'eye socket' is really the nasal cavity, where the trunk connects to the skull! This feature is also present in modern elephant skulls.

PHOTOS: NASA, ISTOCK, SCIENCE PHOTO LIBRARY, EYEVINE ILLUSTRATION: CHRIS PHILPOT

Hanging gardens
This overpass has been installed over a busy road in the city of Hangzhou in eastern China. Pedestrians are treated to a yellow coloured walkway that features escalators, lifts, gardens and rest areas, instead of having to trudge their way over a bleak concrete structure. The overpass is even outfitted with devices that spray a cooling mist, to refresh weary walkers when the city heat gets too stifling.

WHO REALLY DISCOVERED?

THE NORTH POLE

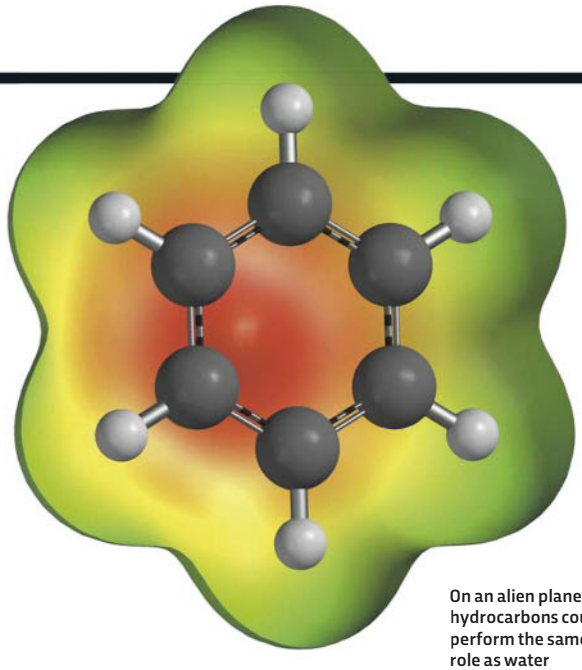
ROBERT PEARY

DR FREDERICK COOK

For many years that accolade went to the US explorer Robert Peary, who claimed to have reached the North Pole on 6 April 1909. Yet even at the time his claim was disputed. Dr Frederick Cook, a rival American explorer, insisted he had reached the pole almost a year earlier. But neither of them could provide definitive proof of their supposed triumph. Cook's own evidence was rejected by an independent commission, while Peary refused to hand over any details at all.

In 1989, the US National Geographic Society announced that an analysis of photographs taken by Peary, together with his records of ocean depths and other data, were consistent with his expedition getting within eight kilometres of the true pole. Cook's claim, meanwhile, has always been dogged by suspicions of fraud.

In the years that followed, the North Pole was reached many times by airborne and submarine expeditions. Surprisingly, the first undisputed expedition to reach the North Pole over the surface did not achieve its goal until 1968, when the American Ralph Plaisted and three companions arrived on snowmobiles. On 6 April the following year, the British explorer Wally – later Sir Walter – Herbert became the first to reach the North Pole the traditional way, on foot. RM



On an alien planet, hydrocarbons could perform the same role as water

Is water always necessary for life?

SARAH HOLLIS, MANCHESTER

All known life needs liquid water to function properly. It's essential in part because water is such a good solvent, readily dissolving and transporting nutrients across a wide range of temperatures. Its molecules also play a key role in ensuring proteins behave properly. But some scientists suspect alien life may have evolved to exploit alternative chemicals like hydrocarbons capable of performing the same roles. **RM**

IN NUMBERS

5,407

The number of threatened species on the IUCN Red List that are imperiled by agriculture alone. These species include the cheetah and the African wild dog.

1,700

The height in metres of an underwater mountain, Anton Dohrn, off Scotland's west coast. In comparison, Ben Nevis is 1,344m high.

10%

The proportion of UK adults that don't read any books at all.

Why does the inside of a shell sound like the sea?

CONNOR DOOLEY, SOUTHAMPTON

The sound has nothing to do with the sea, nor the shell's oceanic origins. It's simply the result of the effect of the shell's shape on air trapped inside. Unable to escape, the air vibrates at frequencies dictated by the size of the shell, creating a mix that sounds a bit like waves on shingle. You can create a similar effect just cupping your hand over your ear. **RM**

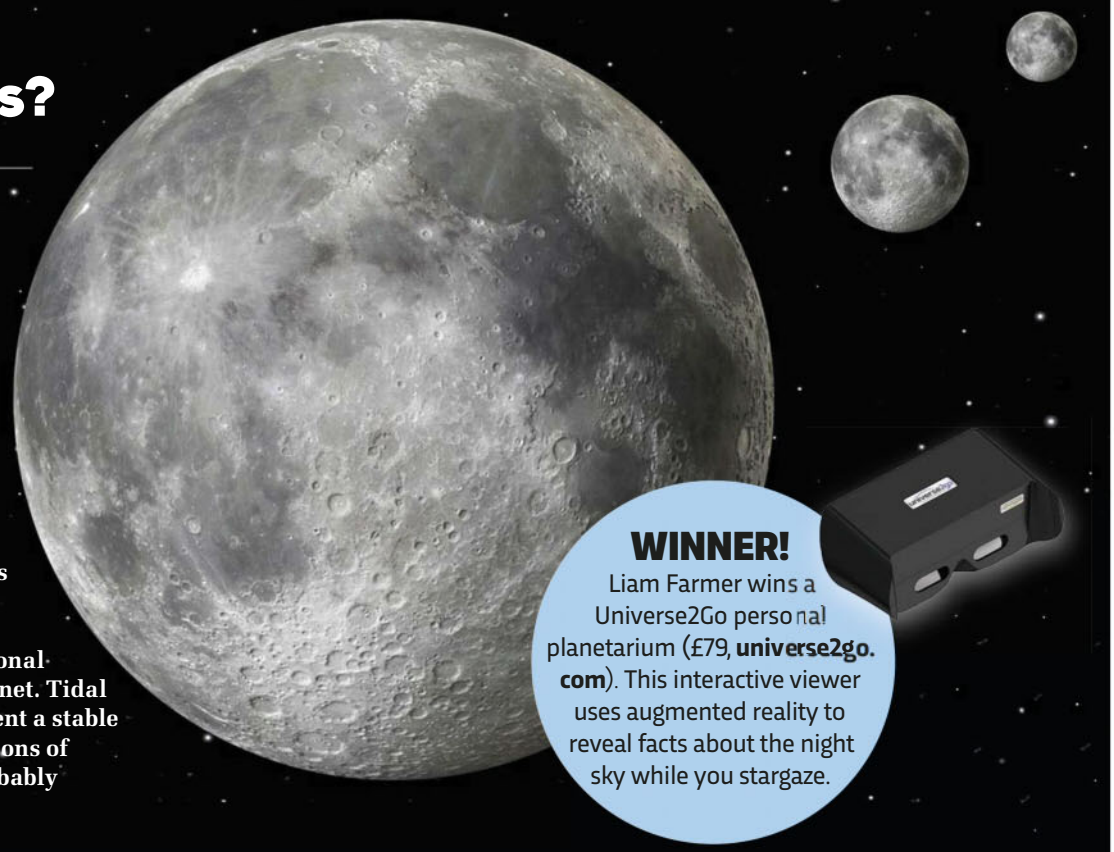
PHOTOS: GETTY X2, SCIENCE PHOTO LIBRARY

QUESTION OF THE MONTH

Can moons have moons?

LIAM FARMER, BIRMINGHAM

There is no reason why a moon could not have a moon. But for such a 'sub-moon' to survive for any length of time, it would require a stable orbit around its parent moon. This generally means that the sub-moon would have to be quite small and orbit quite close to the parent moon. The bigger the sub-moon is and the further it is from the parent moon, the more likely it will be influenced by the gravitational attraction of the parent planet. Tidal forces can also easily prevent a stable orbit being possible. So, moons of moons are possible but probably extremely rare. AG



WINNER!
Liam Farmer wins a Universe2Go personal planetarium (£79, **universe2go.com**). This interactive viewer uses augmented reality to reveal facts about the night sky while you stargaze.

Why do we get 'the meat sweats'?

RHIANNON WELSBY, COLCHESTER

There isn't much hard research specifically into whether meat makes you sweat, but one possibility is the 'thermic effect' of protein. We digest protein less efficiently, and for every 100 calories of meat we eat, 20 to 35 calories are wasted as heat, compared with 5 to 15 calories for fat or carbohydrate. The sweating may be necessary to flush away that waste heat. **LV**

Why do people get hangry (angry when hungry)?

ROB WILKS, LEAMINGTON SPA

Maintaining composure in the face of provocation takes self-control and there's a long-running theory in psychology that states self-control depends on blood glucose levels. When you haven't eaten you have less glucose, meaning that your tolerance is likely to run out sooner. In one study, psychologists gave married participants a voodoo doll to represent their spouse. Each night for 21 nights, the researchers measured the participants' blood glucose levels, and told them to stick as many pins in the doll as they wanted based on how angry they were feeling. The participants with the lowest glucose levels stuck in the most pins. **CJ**

NEXT ISSUE:
Why do joints crack?
Who owns the Moon?
Can fish see in the dark?

Email your questions to **questions@sciencefocus.com** or submit online at **sciencefocus.com/qanda**

PHOTOS: ISTOCK X2

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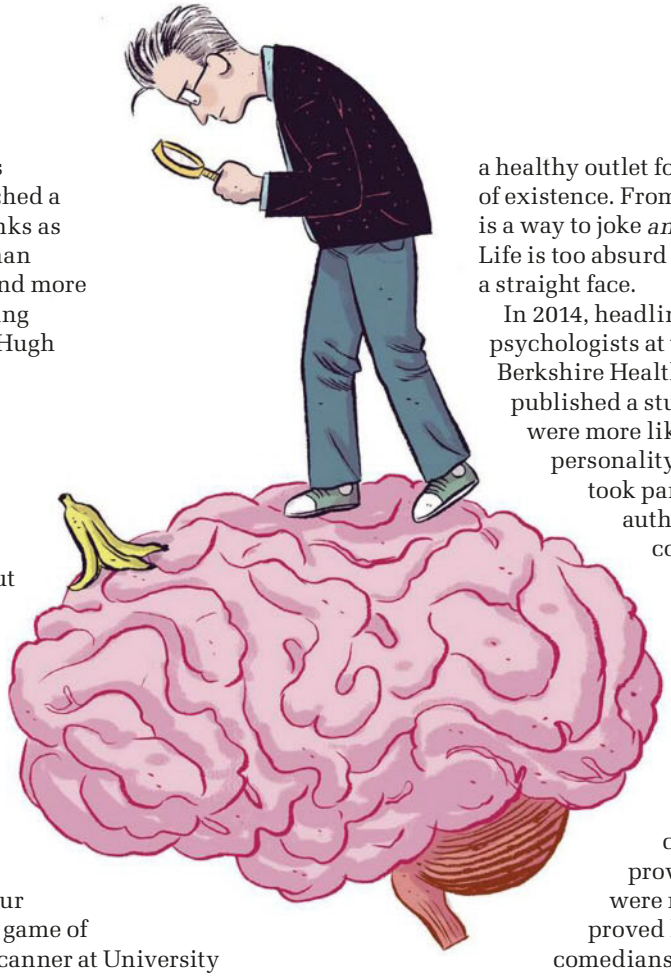
+ Calls will cost 7p per minute plus your telephone company's access charge. Lines are open 8am–8pm weekdays & 9am–1pm Saturday.

ROBIN INCE ON... COMEDY AND MENTAL HEALTH

"SOME BELIEVE THAT IF YOU'RE JOKING ABOUT SOMETHING, YOU HAVEN'T COME TO TERMS WITH IT"



Public speaking is thought so wretched a torture that it ranks as more stressful than moving house, and more horrible than being cooked alive in lard while a drunk Hugh Fearnley-Whittingstall clumsily spatchcocks you with skewer after skewer.

Therefore, those uninfected with the desire to make rooms of strangers laugh often see the comedian as a diseased anomaly.

When I made a documentary about comedians and melancholy a couple of years ago, Jo Brand told me that she didn't necessarily think all the comics she knew were categorically mentally ill, but that most were "damaged people".

Despite the weight of anecdote, there's little hard research. Perhaps one way of finding out how comedians think is to look at our brains. Last year, I played a solitary game of Radio 4's *Just A Minute* in an MRI scanner at University College London as part of research into which areas of the brain light up when a performer improvises. Preliminary analysis suggested that, compared to a control group, comedians have less activity in Broca's area, a region of the brain involved in the basic processes of speech production. This may sound surprising, but the researchers say that it's because comedians find speech less effort. It's called the 'gift of the gab', and it seems that practice has honed that part of our brains.

Unfortunately, neuroscience is less helpful when it comes to finding a link between comedy and more nebulous concepts such as mental health.

Can psychology help? I spoke to two psychotherapists while researching this column. One believed that if you're joking about something, then you haven't come to terms with it yet, suggesting that comedy is an unhealthy coping mechanism. The other saw joking as a healthy outlet for coping with the anxiety of existence. From my perspective, I think there is a way to joke *and* to come to terms with life. Life is too absurd to take all its catastrophes with a straight face.

In 2014, headlines were made when psychologists at the University of Oxford and Berkshire Healthcare NHS Foundation Trust published a study showing that comedians were more likely to have psychotic personality traits. Over 500 comedians took part in the study, with one of the authors, Prof Gordon Claridge, commenting that "the creative elements needed to produce humour are strikingly similar to those characterising the cognitive style of people with psychosis."

Whereas other cultural groups may have blanched at being considered psychotic, comedians were pleased that it proved they were special. Actors were researched too, and they proved less psychotic, giving comedians a quiet moment of pride. More seriously, this study didn't prove a link between comic talent and mental illness – this isn't psychosis in the clinical sense, but rather an ability to make quick associations and connect random thoughts, a thinking style that's often seen in people with schizophrenia or bipolar disorder. Say 'bicycle' to a comedian and they don't just picture a bike, they picture all the things that might make the bike funny.

Ultimately, perhaps comedians are no sadder than the rest: it's just that they publicise their pain. As Billy Crystal said, "stand-up is how comedians process things that are painful." Hopefully, by doing so, they can give a voice to others who process their pain in silence.

Robin Ince is a comedian and writer who presents, with Prof Brian Cox, the BBC Radio 4 series *The Infinite Monkey Cage*
bbc.in/1Lxp3QR

NEXT ISSUE: GHOSTS

ILLUSTRATION: JAMIE COE

OUT THERE

WHAT WE CAN'T WAIT TO DO THIS MONTH

OCTOBER 2016 | EDITED BY JAMES LLOYD

01 PORE OVER PLANTS

PLANT: EXPLORING THE BOTANICAL WORLD
IS OUT 3 OCTOBER (£39.95, PHAIDON).

This beautifully symmetrical image is the work of British artist Lisa Creagh, who painstakingly stitched together individual photos of flowers to create a digital 'garden'. It's featured in a new book celebrating the history, culture and diversity of plants.

***Plant* displays more than 300 botanical works of art, from ancient stone carvings and medieval manuscripts to sculptures and state-of-the-art micrographs. Iconic works by Georgia O'Keeffe and Leonardo da Vinci sit alongside scientific illustrations by the likes of Charles Darwin and Pierre-Joseph Redouté. It might be a bit early, but this one's already on our Christmas list.**

PHOTO: LISA CREAGH

02 GET SNAPPING FOR SCIENCE

With its psychedelic colouring, this fan-throated lizard has every right to look proud. Snapped by Anup Deodhar in India, this image won a silver medal in the 2016 International Images for Science competition, run by the Royal Photographic Society and supported by Siemens. Fan-throated lizards develop their vibrant flaps of skin during the breeding season, using them to woo females and warn other males off their territory.

All of the competition winners, plus 95 shortlisted entries, will be showcased during a five-week exhibition at The Crystal in London from 14 September to 17 October, before going on tour around the country. Entries for the 2017 competition are now open, so you'd better dust off that camera!

RPS INTERNATIONAL IMAGES FOR SCIENCE
RPS-SCIENCE.ORG

03

BEDLAM: THE ASYLUM AND BEYOND
WELLCOME COLLECTION, LONDON,
15 SEPT 2016 – 15 JAN 2017
WELLCOMECOLLECTION.ORG/BEDLAM

EXPLORE BEDLAM

Bedlam has long been a synonym for madness and chaos. But rewind to the 15th Century and the word was originally used as a nickname for the Bethlem Royal Hospital, probably the world's oldest, and most famous, psychiatric institution.

A new exhibition at the Wellcome Collection tells the story of this asylum, exploring how its history reflects changing attitudes to mental health and psychiatry over the centuries. More than 150 objects and archival materials will be on show, including artwork from patients and works by contemporary artists.

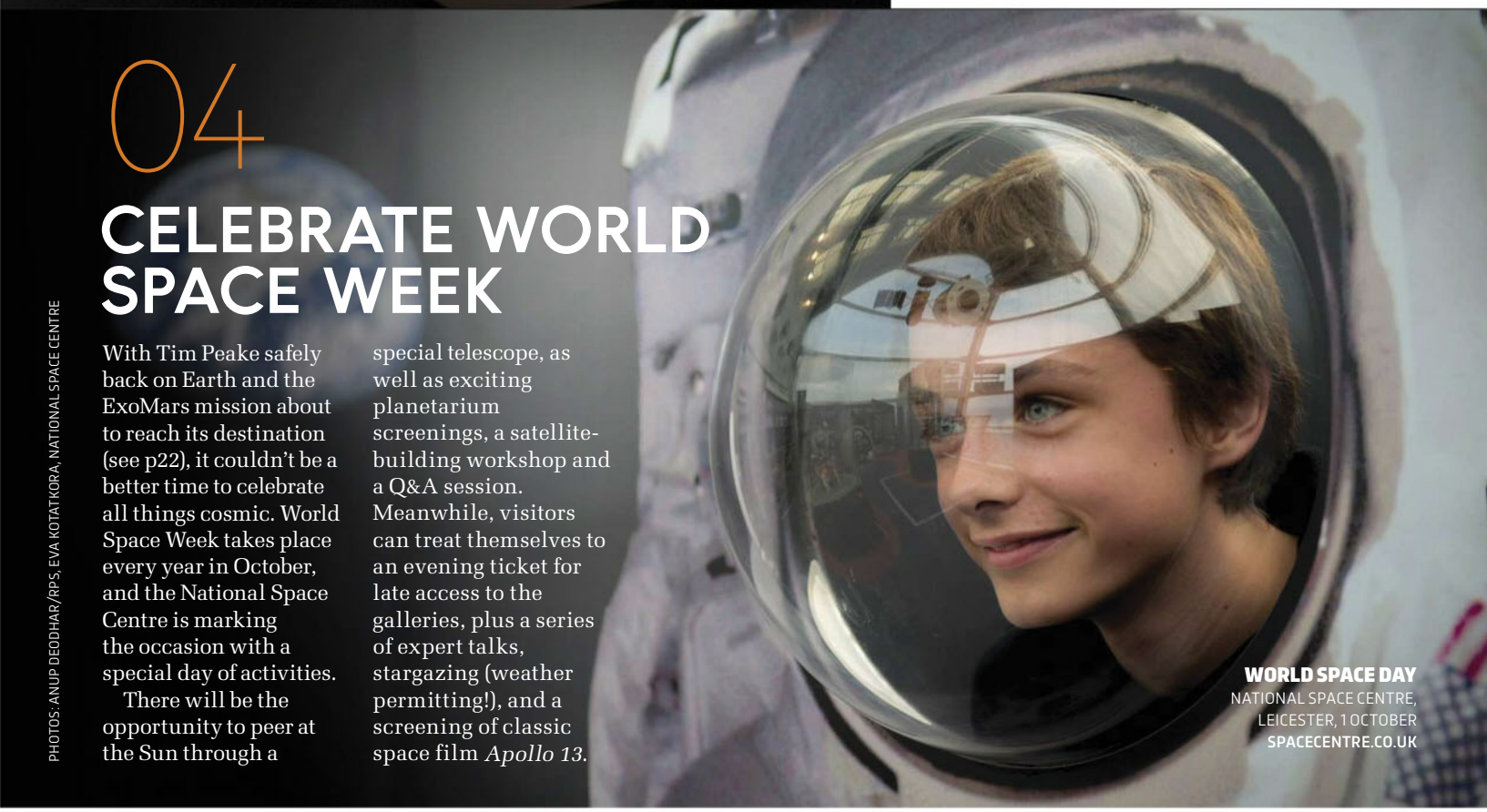
The exhibition also takes a look at the ever-expanding range of treatments and therapies on offer to patients in the modern world. Asylums are now largely consigned to history, but what can we learn from them, and how can we improve places of sanctuary and care for those in distress today?

04

CELEBRATE WORLD SPACE WEEK

With Tim Peake safely back on Earth and the ExoMars mission about to reach its destination (see p22), it couldn't be a better time to celebrate all things cosmic. World Space Week takes place every year in October, and the National Space Centre is marking the occasion with a special day of activities.

There will be the opportunity to peer at the Sun through a special telescope, as well as exciting planetarium screenings, a satellite-building workshop and a Q&A session. Meanwhile, visitors can treat themselves to an evening ticket for late access to the galleries, plus a series of expert talks, stargazing (weather permitting!), and a screening of classic space film *Apollo 13*.



WORLD SPACE DAY
NATIONAL SPACE CENTRE,
LEICESTER, 1 OCTOBER
SPACECENTRE.CO.UK

PHOTOS: ANUP DEODHAR/RPS, EVA KOTATKORA, NATIONAL SPACE CENTRE

05
HACK OUR LIVES WITH SCIENCE

Want to get ahead in life? *The Geek Guide To Life* offers scientific advice on everything from dating and dancing to sleeping and stone skimming. Co-author COLIN STUART shares five tips to get you started...

1. SUCCEED AT ONLINE DATING
Unsurprisingly, your photo is key – people say they draw more information about someone's personality from their photo than their words. A 2016 study found that an open posture is important, so those leaning back or spreading their arms were more likely to receive romantic interest. With the words, stick to a 70:30 ratio of who you are to what you're looking for.

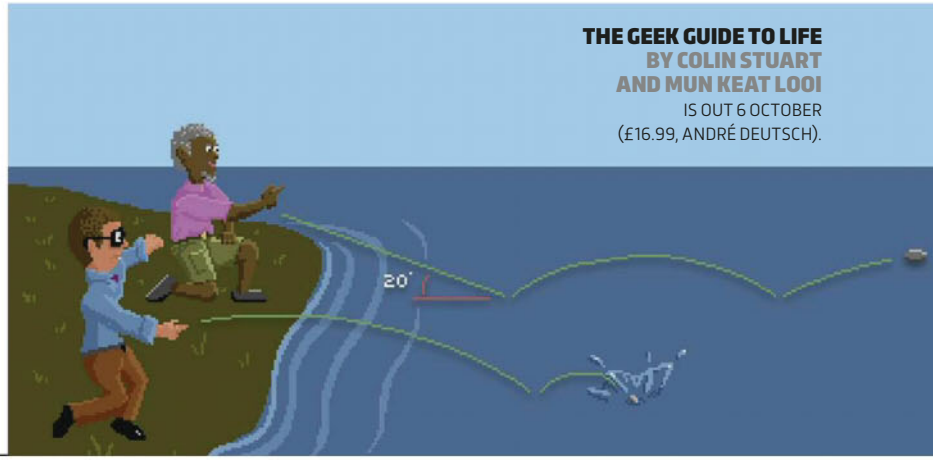
2. CHOOSE YOUR CAR COLOUR
If you're buying a new car, avoid black. An Australian study of 850,000 accidents over a 20-year period found that black cars were 12 per cent more likely to be involved in a crash than white cars, rising to 47 per cent at dawn or dusk when the light is low. Research has also shown that black cars are some of the most likely to be stolen.

3. TAKE THE PERFECT NAP
The ideal napping time is six to seven hours after waking, around 2pm for most people. This is far enough away from bedtime not to interfere with your sleep cycle. It

may sound counter-intuitive, but try downing an espresso before taking your 20-minute snooze. The caffeine will enter the brain just as you're waking up, boosting your energy levels.

4. MAKE FOOD TASTE BETTER
According to the work of 'gastrophysicist' Prof Charles Spence, meals are tastier if eaten off round, white plates with heavy cutlery. In another Spence study, 700 volunteers were played music while eating takeaway. Indian food was rated more highly when indie music was playing, whereas Thai and Japanese food tasted better with jazz. Justin Bieber's music consistently lowered the enjoyment of almost every food group (seriously!).

5. BECOME A MASTER STONE SKIMMER
The magic number here is 20°. According to a study published in *Nature*, that's the angle at which your stone should hit the water. Pick a flat, round stone approximately five centimetres (two inches) in diameter. Use your finger to set it spinning as it leaves your hand, aiming for a launch speed of at least 2.5 metres per second (5.6mph).



THE GEEK GUIDE TO LIFE
BY COLIN STUART AND MUN KEAT LOOI
IS OUT 6 OCTOBER (£16.99, ANDRÉ DEUTSCH).

DAME FRANCES ASHCROFT SHARES HER FAVOURITE SPOTS IN OXFORD

Oxford may be a city, but it is full of trees, parks and gardens. It's also home to beautiful buildings, both ancient and modern – and numerous bicycles! It's a stimulating place to live and work, humming with the excitement of new discoveries. The half-heard conversations on the walk from the science labs to the city centre can be extraordinary.

In early summer, I visit the **MUSEUM OF NATURAL HISTORY** ❶ to see the swifts that nest in the tower (there is a live webcam on their nests). Hidden at the back of the building is the Pitt Rivers Museum, which is crowded with fascinating items. My favourites include the shrunken heads, a Hawaiian cloak made of red and yellow feathers, a lantern fashioned from a puffer fish, and a set of nested ivory balls, made from a single lump of ivory.

I love the **MUSEUM OF THE HISTORY OF SCIENCE** ❷, where you can see the equipment that was first used to purify penicillin. Contrary to popular belief, it was Howard Florey and Ernst Chain in Oxford (and not Fleming) who developed penicillin into a useful antibiotic. The bedpans in which they grew the mould are displayed here. I also like the model of penicillin by Dorothy Hodgkin, who solved its structure and is still the only female British scientist to win a Nobel Prize.

My favourite place to eat is **PIERRE VICTOIRE** ❸, a vibrant, family-run French restaurant with a terrific ambience. But if I want a quick lunch then I head to the **THE ASHMOLEAN CAFÉ** ❹ for homemade soups and salad – and often take a look at the Chinese ceramics on the way out.

Just outside the city lies **WYTHAM WOODS** ❺, which is a wonderful mix of semi-wild woodland and grassland that was given to the university over 60 years ago. You can apply for a permit to walk there, provided you don't disturb the experiments.

And then there are the college gardens – all lovely and all different. In spring, I never miss the rare and beautiful wild fritillaries in the Magdalen College meadows, or the flowering bulbs in their Fellows' Garden that make you feel as if you've slipped into an impressionist painting. My favourite gardens are those at **TRINITY COLLEGE** ❻ – but I'm biased as this is my own college. Ⓕ

ILLUSTRATION: TONWEN JONES

❶ MUSEUM OF NATURAL HISTORY
This museum features the world's most complete dodo remains.
Parks Road, OX13PW
oum.ox.ac.uk

❷ MUSEUM OF THE HISTORY OF SCIENCE
Here you'll find an enchanting collection of oddities, including a blackboard bearing Einstein's chalked scribblings.
Broad Street, OX13AZ
mhs.ox.ac.uk

❸ PIERRE VICTOIRE
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trinity.ox.ac.uk

Dame Frances Ashcroft is a professor at the University of Oxford. She leads a research team focused on diabetes and how it can be treated.

THE NUMBER GAMES

GIVE YOUR BRAIN A WORKOUT

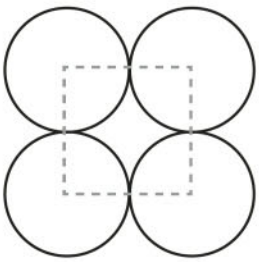
WHAT IS MATHSJAM?
MathsJam is a chance for maths lovers to get together in a pub and swap puzzles over a drink. Matt organises the London and Guildford MathsJams, and colleague Katie runs the Manchester one. Visit **mathsjam.com** to find your closest gathering.

This month, I was able to use the sentence "Don't worry, I'm a mathematician". I have never been in a such a super-position of delight and embarrassment.

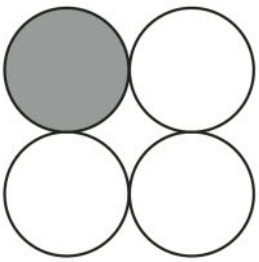
The backyard of my house is on a serious gradient, and I'm keen for it not to get any ideas about becoming the front yard. So I had someone around to give me a quote on how much holding back the gravitational potential energy could potentially cost. They took some measurements, drew some diagrams and then expressed regret that they couldn't measure the exact height of the back of the yard. It'd be nice to know this, they said, but getting a surveyor in would be too costly.

Which is where we came in: some string, a home-made inclinometer and a bit of trigonometry later, I emailed them the exact height and gradient of the yard. It seems landscaping calculations are more complex, because I've not heard back from them yet.

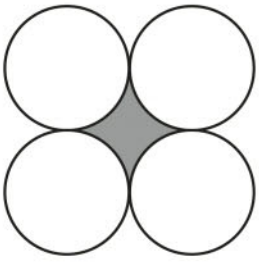
My joy at using Pythagoras and trig ratios in a practical situation reveals the shameful secret of maths: most of the content will be of little to zero use in your normal life. This case was an anomaly, an enjoyable outlier. Like many people I enjoyed doing calculations with angles and side-lengths in school; like sudoku, but with more satisfying chains of logic. Now I look enviously at my phone as it effortlessly crunches through GPS calculations, doing all the fun work and delivering only the final answer to me.



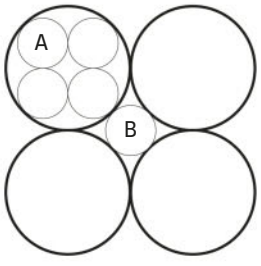
Four circles on a square



Space inside a circle



Space between the circles



Which is bigger: A or B?

PUZZLE 1

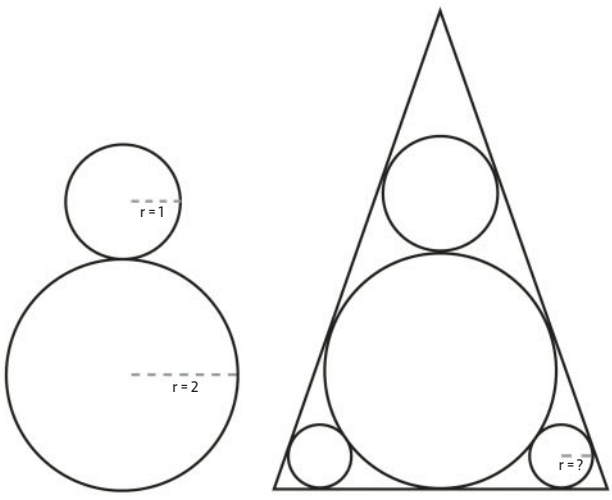
So I've decided to forget waiting for the chance to calculate a side-length to crop up and I've sought out some Pythagorean puzzles. Like me, you can embrace the fun of geometric gymnastics!

The first puzzle is my favourite, and relies on a bit of Pythagoras flexibility. You have four identical circles arranged in a square just touching each other. This produces two types of spaces: the inside of the circles and the region between all four circles. We now put in two new small circles: Circle A is the biggest circle of which four, arranged as a square, can fit inside one of the original circles; Circle B is the biggest circle which can fit between the original circles. The challenge is simple: which is bigger, Circle A or Circle B?

The second puzzle is nice because it's brand new. Some people will have seen the first puzzle before, but this second one was created in 2016 by Canadian maths enthusiast John Barsby (and member of the Winnipeg MathsJam). So unless you competed in the 2016 Manitoba Mathematical Contest it was originally written for, or came across it when it spread through the MathsJam, this should be all new.

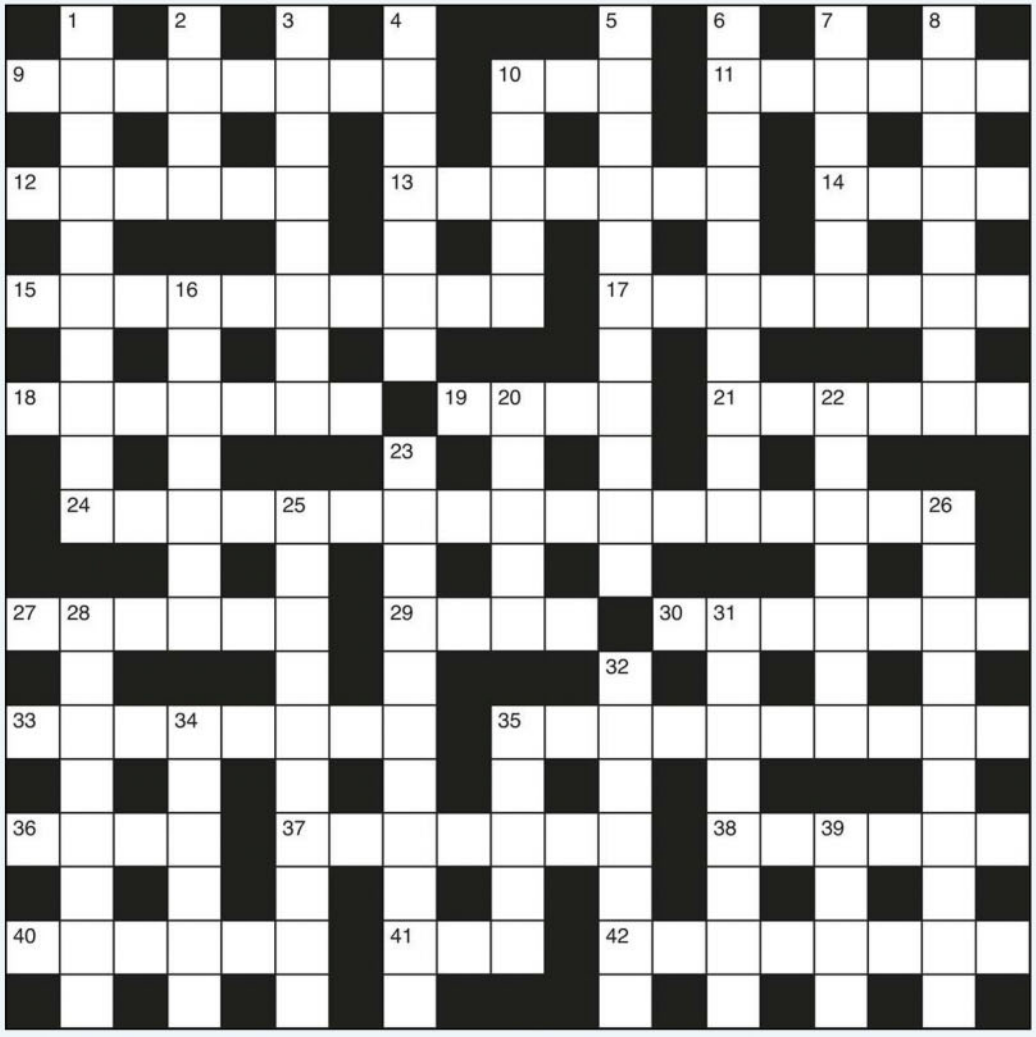
Circle 1 and Circle 2 have radii 1 and 2 respectively, and are placed in a snowman formation. A triangle is drawn around them, fitting as snugly as possible. What we want to know is: how big are the two identical circles that fit in at the bottom?

Matt Parker is a stand-up comedian and mathematician. He is a regular on BBC Radio 4's *The Infinite Monkey Cage*, alongside Brian Cox and Robin Ince.



PUZZLE 2

THE *BBC FOCUS* CROSSWORD
BACK BY POPULAR DEMAND



ACROSS

9 Second relative has nothing more sleek (8)
10 Meteorologist originally has a pressure chart (3)
11 LP that's unsurpassed (6)
12 Holiday in an alcove (6)
13 Wild lion removed from print (7)
14 Fletcher's groove (4)
15 Prisoner with complaint points to church merging (10)
17 Family member's account (8)
18 Land worked on a site (7)
19 Hit a gastropod (4)
21 Flexible game (6)
24 Cancel emails, like a solution to a complaint (6-4,7)
27 Reassessed balm as something similar (6)
29 Sway to some music (4)
30 Yours truly has a terribly neat aquatic mammal (7)
33 Brilliant old bird (8)
35 Stop directors getting building material (10)
36 Stallion, hard-working, promises to leave (4)
37 Owls set off, not the most speedy (7)
38 Duration of amount of trouble (6)
40 Long-legged creature running to cave (6)
41 Leave daughter of Zeus, say (3)
42 Work properly as a 10A (8)

DOWN

1 Simple soap derived from woody vine (10)
2 Spy some substance (4)
3 A hirsute hybrid of dictionaries (8)
4 Father gets right range of confectionery (7)
5 Colourful picture makes grocer stamp about (11)
6 Plant car lot enlivened by song (10)
7 Emphasise dialect (6)
8 Soft cure – refined sugar (8)
10 Chap, say, back in disorder (5)
16 Followers endlessly about to get America down (7)
20 I call out for some shade (5)
22 Lamb played with hesitation with old fish (7)
23 Mark puts gold into branch in resort (11)
25 Wearing my lion suit shows brilliance (10)
26 Bear forced to share in anomaly (10)
28 Move via table, in case (8)
31 A student swimming in lake that's not acidic (8)
32 Pope quietly takes on argument (7)
34 Doctor joins one old family (6)
35 Money for food (5)
39 Observe a sound (4)

ANSWERS

Please visit **bit.ly/TheNumberGames** for the answers to this month's puzzles and crossword.

PHOTOS: GETTY

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MEDICINE

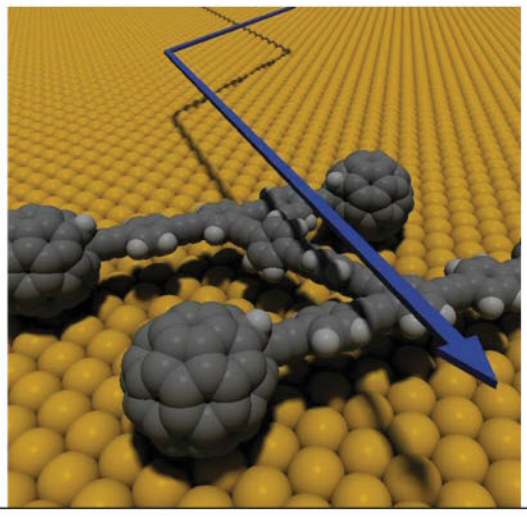
Can we beat cancer?

A report by Macmillan Cancer Support has revealed that cancer survival rates have doubled since the 1970s. We look at the latest advances, and find out how close we are to beating the disease.

PHYSICS

NANOCARS ARE GO!

Take your seats for the first ever NanoCar race, which will see single-molecule cars competing on a nano-sized track in Toulouse. We meet some of the teams bidding for glory.



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WEIRD THEORIES

THE 10 STRANGEST IDEAS IN SCIENCE

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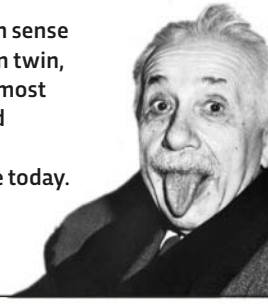

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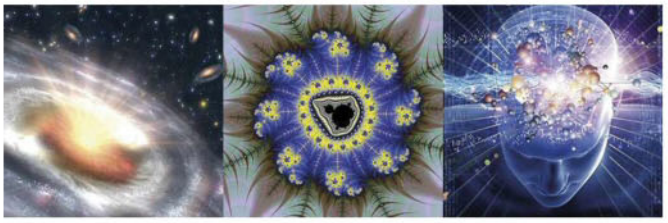

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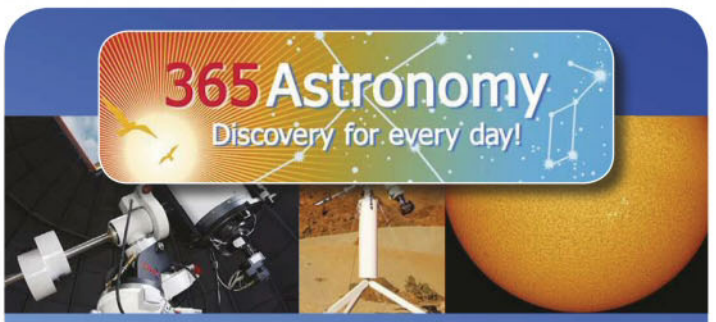

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"No one knows what a 'ghost' is, so it's tricky to set up studies to look for them"

Caroline Watt is professor of parapsychology at Edinburgh University. This Halloween she explains to **Helen Pilcher** why there's more to parapsychology than 'ghostbusting'!

Half of the population say they believe in some sort of paranormal phenomenon. I've never experienced one.

My work examines the evidence for psychic abilities, like mind reading. I'm also interested in the psychology of ghostly experiences. I get sent loads of photos of supposed 'ghosts' and 'evil faces' but more often than not, I can't see the 'thing' that I'm meant to see.

No one knows what a 'ghost' is, so it's tricky to set up studies to look for them. Some people run around with meters that detect electromagnetic activity, then when they get a blip they say they've found a ghost. But plug sockets, fridges and other things emit electromagnetic activity. It's a big leap for these people to say they have detected a ghost.

We've run experiments in Hampton Court Palace and the vaults in Edinburgh, both places that are said to be haunted. We found that people were more likely to experience unusual sensations – like the hairs rising on the back of their neck or a general feeling of unease – in places that were relatively large and poorly lit. It makes sense from an evolutionary perspective as these are places where you might feel vulnerable. But it isn't evidence for ghosts.

I suspect that when people think they've seen or 'felt' a 'ghost', they are primarily responding to normal but subtle physical cues in the environment, then they misattribute these feelings to something else. There's also a psychological phenomenon called 'pareidolia', where the mind perceives faces and figures in random or ambiguous patterns. If you're in a place that's misty or poorly lit, it doesn't take much to imagine a face in the gloom. This could explain some ghostly experiences.

We've done experiments to see if dreams can predict the future. In one study, we asked participants to try and dream about a randomly chosen film clip that they were going to be shown in the morning, and recorded their dream reports. The experiment found no evidence to support the idea of dream precognition. Other researchers, however, have found the opposite.

So do psychic abilities exist? Some parapsychologists say the matter is already settled, that well-designed experiments have shown they do. But I don't think we have a definitive answer. I think the standard of evidence isn't high enough. That's something we're trying to sort out.

I love communicating what I do to the public. I've written a book, run an online course, and did a show at 2015's Edinburgh Fringe where we opened the unit to the public – there were queues down the street.

I've been at the Koestler Parapsychology Unit for 30 years and was recently appointed professor. It feels like an achievement, not just because it's a controversial area, but also because I've raised two sons, went to a comprehensive, and was first in my family to go to university.

Caroline Watt is a founding member of Edinburgh University's Koestler Parapsychology Unit.

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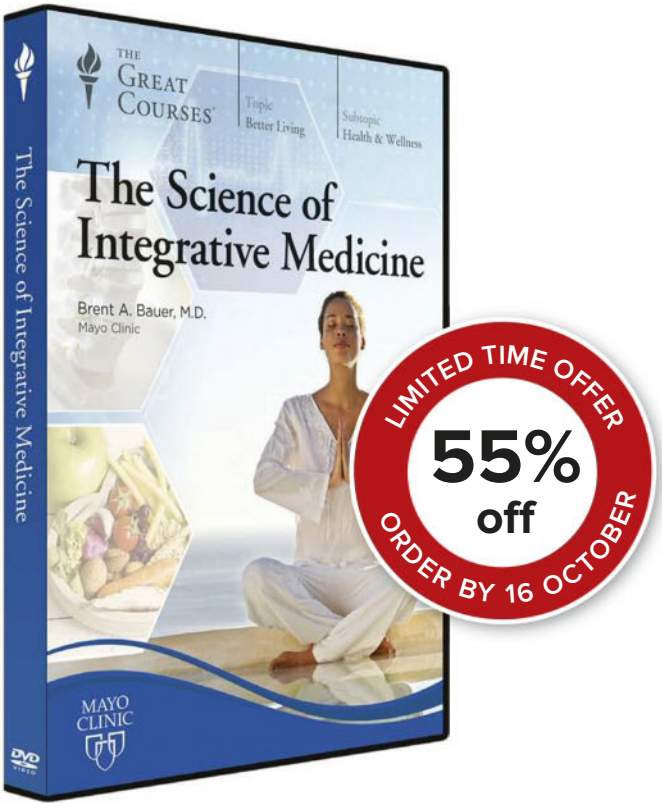

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