BBC

GET THE TRUTH! EXTRACT A CONFESSION LIKE THE CIA

# FOCUS

SCIENCE AND TECHNOLOGY

WHY THIS CAR WILL CHANGE THE WORLD

SCIENCEFOCUS.COM ISSUE 281 / JUNE 2015

# FREE WILL

## THE GREATEST ILLUSION?

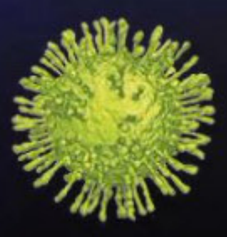
How science is discovering that you're not really in control

22 OF YOUR SCIENCE QUESTIONS ANSWERED

**REVEALED!**
THE SECRET WORLD BENEATH YOUR FEET

**NEW DISCOVERY!**
OLDEST HUMAN FOSSIL FOUND

WHAT'S THE EVIDENCE FOR BLACK HOLES?



THE MICROBES YOU LEAVE EVERYWHERE

WHAT 5G PHONES WILL DO FOR YOU

Renault ZOE

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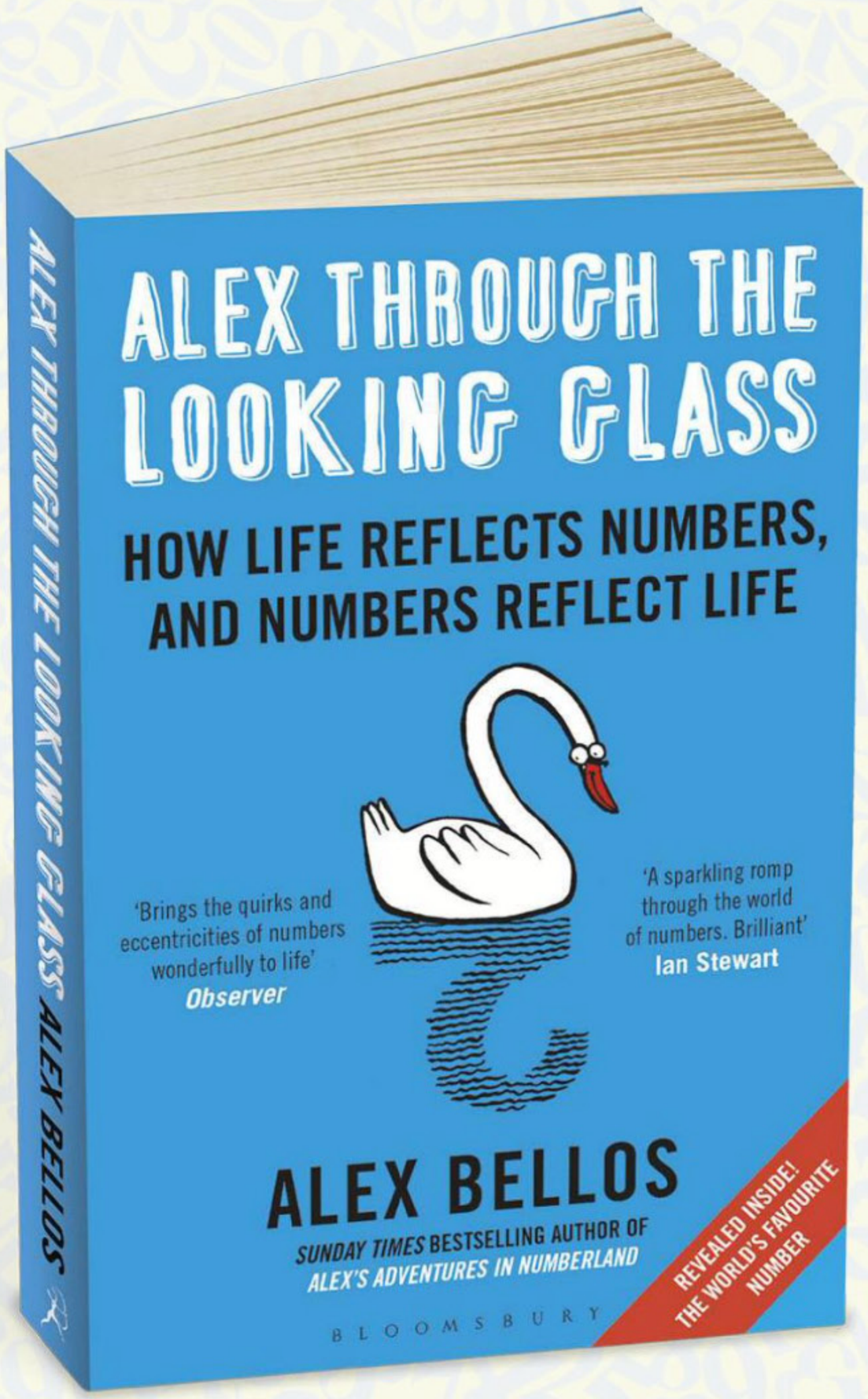
FROM THE *SUNDAY TIMES* BESTSELLING AUTHOR OF *ALEX'S ADVENTURES IN NUMBERLAND*

'Bellos has a fantastic knack of making you feel as if you're sharing a room with these mathematical explorers'
***New Scientist***




'Brings the quirks and eccentricities of numbers wonderfully to life'
***Observer***

REVEALED INSIDE! THE WORLD'S FAVOURITE NUMBER

**OUT NOW IN PAPERBACK**

BLOOMSBURY

# WELCOME

WE HAVE FREE will. You decide who to talk to, what to say and where to buy lunch. It's obvious, right? Yet certain studies suggest our brains make some decisions before we're even aware we've made them. So are we really in control? Turn to p32 to find out.

It's hard to make a decision if you think you're being misled. But if you want to get someone to tell you the truth, what's the best way to go about it? On p53, Jo Carlowe asks a former CIA operative for some practical tips to use in everyday life.

The CIA must surely be grateful for the invention of Kevlar. The fibre, best known for its ability to stop bullets, was developed 50 years ago by Stephanie Kwolek at DuPont. Turn to p42 for the science of body armour and the new technologies that could save lives in future.

Nothing would save you from certain death if you were ever sucked into a black hole. But I've often wondered why scientists are so sure they exist when we can't see them. Top science writer Brian Clegg rounds up the evidence on p86 and reveals the mystery that hasn't entirely gone away.

And there's much else besides, including a look at what's beneath your feet – as featured in an upcoming BBC programme. Enjoy the issue!

Graham

**Graham Southorn**, Editor

**PS Don't miss our July issue, on sale 28 May 2015**

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## THIS MONTH WE...

**...tried out the new Audi TT** as part of our feature on eco-friendly cars. Find out how we rated it on p80. We love the button that makes the spoiler go up. Go-Go-Gadget spoiler!

**...caught up with author Nick Lane** about the development of complex life. Read a review of his book *The Vital Question* on p98, and listen to the interview at sciencefocus.com/podcast

**...got on the phone to 'psychological magician' Marc Paul** to learn how he and his fellow entertainers rely on the illusion of free will to pull off dazzling tricks. All is revealed on p32.

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## APPEARING IN THIS ISSUE...

**Jo Carlowe**

Jo writes for numerous titles, including the *The Guardian*, *BBC Good Food* and *Cosmopolitan*. She speaks to a former CIA agent about how to get someone to tell the truth on p53.

**Simon Crompton**

Simon, a former health editor for *The Times*, was always going to write for *BBC Focus* – it was inevitable. Or was it? Simon examines the war against free will on p32.

**Christine Evans-Pughe**

Christine is a science and technology writer who has written for *The Independent*, *The Guardian* and *The Economist*. On p42, she looks at the future of bulletproof materials.

**Tom Ireland**

Tom is the managing editor of *The Biologist*, the magazine of the Society of Biology. On p60, he looks at the personal colony of microbes that follows us everywhere we go.

COVER: ANDY POTTS

**WANT TO SUBSCRIBE?** Turn to p30 to save **40%** on the shop price of *BBC Focus*

**SUBSCRIBER BONUS** On p30, **Dr Jan Zalasiewicz** delves into the history of Earth and finds there is much we still don't understand

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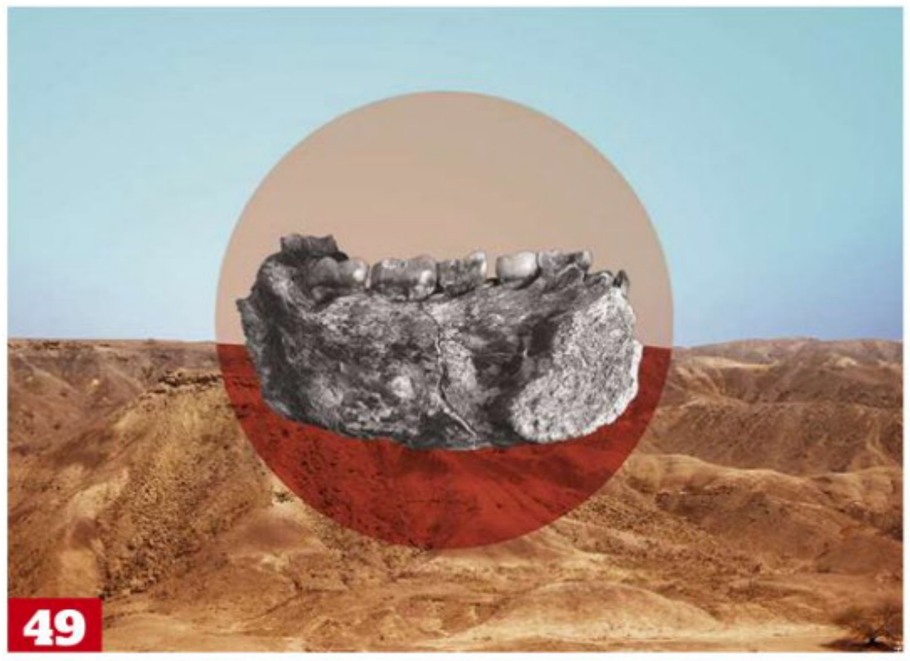

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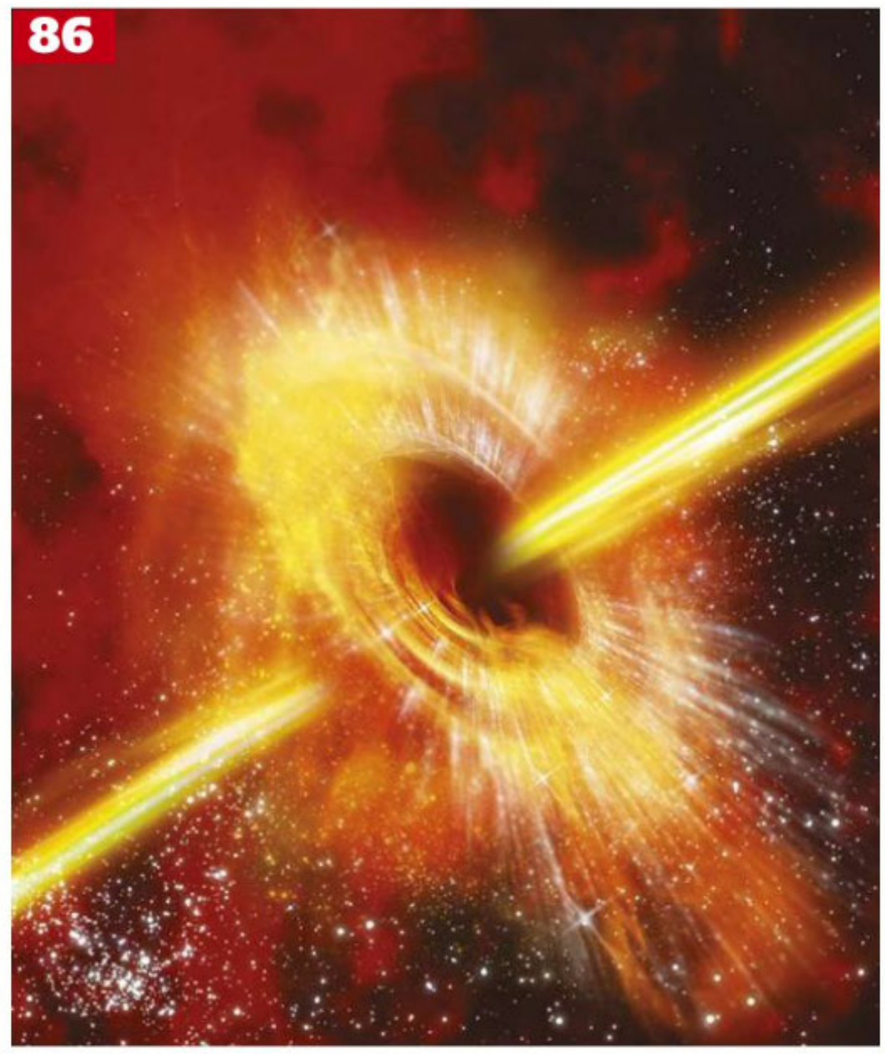
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Awe-inspiring images from the world of science

# MegaPixel

## Toxic beauty

IN CENTRAL POLAND, coal ash leaks from the Bełchatów power station through outlets into nearby clear waters, painting the surface with sinister grey veins. Bełchatów is the largest coal-fuelled plant in Europe and emits more than 30 million tonnes of $CO_2$ every year, more than any other in the continent.

The shot was taken from a paraglider by Polish photographer Kacper Kowalski, as part of a project named 'toxic beauty' that features images of chemical plants, mines and landfill sites taken from a bird's-eye perspective.

"Coal-fired power generation comes with significant costs to the environment and human health," says Chukwunonye Ezeah, a researcher in waste and environmental management at the University of Wolverhampton. "Water run-off from coal washeries carries heavy metals that contaminate groundwater, rivers and lakes, affecting aquatic flora and fauna.

"Most importantly for human health," he adds, "the combustion of coal releases emissions of harmful gases such as sulphur dioxide, nitrogen oxides and carbon monoxide, and various trace metals like mercury, into the air through stacks that can disperse this pollution over large areas."

PHOTO: KACPER KOWALSKI/PANOS PICTURES

MegaPixel

# Making waves

SLIDING DOWN THIS 30m-tall wall of water as it cascades towards Praia do Norte beach in Nazare, Portugal, is the tiny figure of Garrett McNamara, a thrill-seeking surfer famous for riding monstrous waves.

The colossal swells begin when storms arising in the North Atlantic during winter push vast quantities of water towards the European coast. The unique features of the Praia do Norte coastline then transform this mass of water into the spectacular breakers pictured here.

"A deep water canyon offshore of Nazare allows the wave to travel towards the coast without losing too much energy along the way," explains Matthew Lewis from the School of Ocean Sciences at Bangor University.

"When a wave approaches the shoreline, the bottom of the wave starts to 'feel' the seabed, which slows its speed, resulting in energy loss. The headland also focuses the energy," says Lewis.

"The wave starts to slow down as it reaches shallower water, which changes its direction and focuses the mass of water and energy together, resulting in very large waves."

PHOTO: CORBIS

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**MESSAGE OF THE MONTH**

Ian Waddington isn't keen on the idea of a cashless world

## Cash-free catastrophe

BILL THOMPSON'S ARTICLE 'A cash-free world' (April, p79) states that one of the reasons for the move to cashless payments is "simply that the technology is now available to replace cash... the banking system likes this". Of course they do – never mind the customers who still like the option of using cash! An electronic money expert explains that criminals and tax avoiders like cash. But they also like technology. On the opposite page was a feature about keyless car entry, which explains how many keyless cars are being stolen and that thieves have devised processes that hack the car's entry system.

Using technology simply because it is available is never a good idea and there are many examples of how criminals can – and do – take advantage of the digital world. Cashless payment systems will be a great incentive for them to sharpen their hacking skills. Don't say I didn't warn you!
**Ian Waddington, Chester**

*Personally, I'm in favour. A cashless world would save bus drivers from having to fiddle about with change and would stop coins making holes in my pockets. And of course, you can't put the genie back in the bottle. Even as far back as 2009, the proceeds of cyber crime in the US exceeded the money stolen in physical bank robberies. Plus, I keep finding fake pound coins in my change. Grrr! – **Ed**.*

### Write in and win!

The writer of next issue's Message of the Month wins a pair of Sennheiser Momentum In-Ear earphones worth £89. Made from stainless steel with chrome detailing, the earphones have a powerful bass response and and are supplied with a set of ear adapters for a perfect fit. **en-uk.sennheiser.com**

Exoplanet Kepler-22b

## Habitable planets

I was very interested in the article 'Why there's an Earth-like planet around every star' (April, p24). However, it continues what to my mind is the arrogant assumption that we are the only intelligent civilisation in the Universe. It has taken billions of years for us to evolve as intelligent humans on this planet, yet it is less than a century since we became capable of transmitting anything meaningful into space. Assuming that advanced societies do exist out there, the vast distances involved could mean hundreds, if not thousands, of years before we detect any evidence of them. In any case, why would they choose this small planet around this small star as their objective?
**Lawrence Smith, Dorset**

*If intelligent life even exists elsewhere, it could be rare. If that's the case, alien beings might well take an interest in us. – **Ed***

## Why we need engines

I read the letter by Steve Jones in the April issue with interest. However, the internal combustion engine does not have to operate exclusively on fossil fuels. Instead of being banned, internal combustion engines can actually enable a zero-net-carbon energy economy.

Fully-renewable liquid fuels can be made by recycling $CO_2$ already in the atmosphere. Instead of relying on being paid a relatively small amount to put $CO_2$ in the ground, the high value of transport energy is more likely to make it viable to use the air-extracted carbon to fix hydrogen as 'electrofuel'. With such

PHOTO: ISTOCK, NASA, CERN, GETTY

plants operational, some of the $CO_2$ could be sequestered [captured and stored].

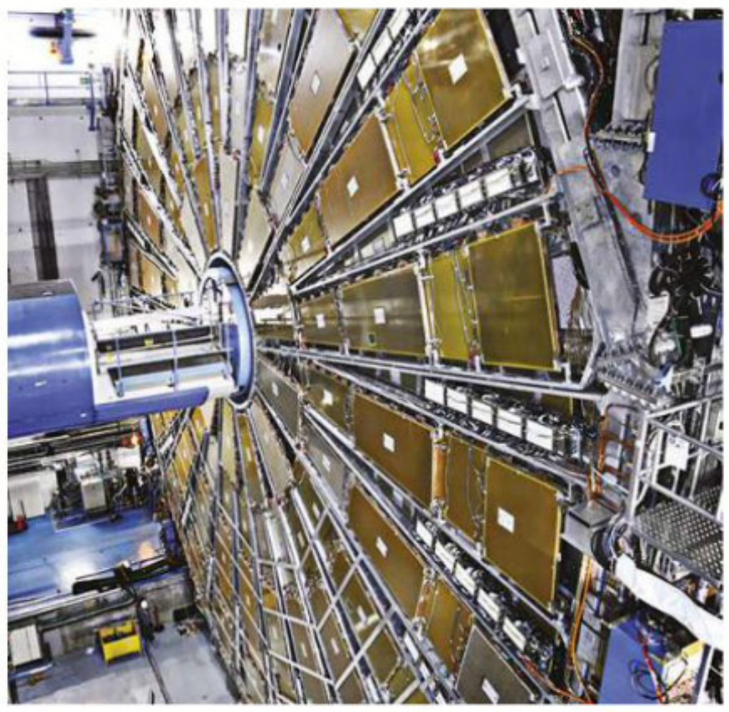
This process can in turn promote the development of solar energy in many of the poorer regions on Earth. Developing nations would then have an opportunity to build their economies by exporting what developed nations crave: energy. Long-term, this is likely to be far more valuable than relying on aid.

All over the world there are researchers working on making such processes a reality, and pilot plants already exist that demonstrate this possibility. The internal combustion engine allows the gradual changeover to renewable hydrocarbons.
**Prof James Turner, University of Bath**

## Conscious robots

The quest for a conscious robot (April, p114) has been going on since the first computer was built. There are, however, two human abilities that are not in any way mimicked by expert systems: the ability to solve problems that do not have a precedent, and the ability to find unprecedented solutions to existing problems. A good example of the latter is that in the early 1700s, Cornish mine owners were going ever deeper to find tin, and they had a problem with pumping water out of their mines. The established technology was to use horse gins and windmills. An expert [computer] system would have come up with a better scheme using these existing technologies. Instead, Thomas Newcomen invented the atmospheric steam engine in 1712. A conscious robot/artificial intelligence system would have to find a way of mimicking these human abilities.
**Paul Jeffels, Derby**

Robots would not be able to come up with Thomas Newcomen's atmospheric steam engine, says Paul Jeffels



What will the LHC find this time round?

## LHC: back in action

For some years I have followed the Large Hadron Collider and the search for the Higgs boson. I was delighted to read the excellent 10-page summary on this work in the April edition, which helped to bring the material together. Due to the complexity of the technology, it has taken nearly 50 years since the Higgs was first predicted to its actual discovery. Now that the LHC has been upgraded to run at higher energies, I look forward to reading about developments in future.
**Roger Collison, West Yorkshire**

'The standard model explained' (April, p92) was outstanding in its clarity. It enabled me to get a reasonable understanding of the atom – at least enough to follow with interest the happenings at the LHC. Perhaps an article on quantum physics would help me to follow this more clearly too.
**Jean Foot**

I read the article about the LHC in the April issue and there appears to be no mention of black holes being formed. Supposing the creation of a runaway black hole is not the preserve of science fiction but a possible reality... what then? Astronomers tell us that there are probably millions of Earth-like planets in the Galaxy, so why have we never heard from them? Could it be that they too had their very own LHCs? Perhaps SETI should be concentrating on locating small black holes orbiting in the Goldilocks zones of their yellow stars...
**David Storer, Totton**

*The Earth's atmosphere is constantly being bombarded by cosmic rays at energies far exceeding that of the LHC, and nothing bad has happened. For more, see Dr Tony Padilla's video at https://youtu.be/KETtEHX3pwo* – ***Ed***


# FOCUS
SCIENCE AND TECHNOLOGY

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# DISCOVERIES

## News and views from the world of science

EDITED BY
**JASON GOODYER**

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**TURNING UP THE LHC**
The Large Hadron Collider has doubled its power. What will we find this time?

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**THE MOON'S NEW FRIEND**
NASA has plans to tow an asteroid towards our Moon in the next decade

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**T-1000 3D PRINTER**
Inspired by the Terminator. Created for medicine

THE BIG STORY

# DARK MATTER MAY NOT BE SO 'DARK'

DARK MATTER makes up a whopping 85 per cent of matter in the Universe, but no one knows exactly what it is. It is called 'dark' because it is thought to interact only with gravity, making it invisible to telescopes. It can, however, be detected indirectly due to the distorting effect of its mass on the light from background galaxies, via a technique known as gravitational lensing.

Galaxy clusters are helping researchers to study dark matter

PHOTO: NASA/ESA/D HARVEY/EPFDL/R MASSEY/HUBBLE

The Hubble Space Telescope allows astronomers to view collisions of distant galaxies

Now, an international team of astronomers, led by researchers at Durham University, believes they might have observed the first signs of dark matter interacting with another kind of force.

It is currently thought that all of the Universe's galaxies exist inside clumps of dark matter. Without the constraining effect of dark matter's extra gravity, galaxies such as the Milky Way would fling themselves apart as they spin.

The research team used the Hubble Space Telescope to view the simultaneous collision of four distant galaxies at the centre of a cluster of galaxies 1.3 billion light-years away. They noticed one such clump of dark matter appeared to be lagging behind the galaxy it surrounds by 5,000 light-years. To put this in context, it would take NASA's Voyager craft 90 million years to travel that distance.

Computer simulations run by the researchers show that this lag can be explained if dark matter interacts, even very slightly, with forces other than gravity. The extra friction caused by such interactions would make the dark matter slow down, and eventually begin trailing behind its parent galaxy. Exactly what force this could be, however, is unclear.

"We used to think that dark matter sat around, minding its own business," explains lead author Dr Richard Massey. "But if it slowed down during this collision, this could be the first dynamical evidence that dark matter notices the world around it. Dark matter may not be completely 'dark' after all."

There is more work to be done in determining exactly what is happening. Similar observations of more galaxies and further computer simulations of galaxy collisions are under way to confirm the interpretation and to investigate it further. And if the observations are confirmed, the work could lead to the emergence of new physics, the researchers say.

"Our observation suggests that dark matter might be able to interact with more forces than just gravity," says team member Prof Liliya Williams. "The parallel universe going on around us has just got interesting. The dark sector could contain rich physics and potentially complex behaviour."

## TIMELINE
### A history of dark matter

**1933**
Swiss astronomer Fritz Zwicky proposes dark matter's existence after noting a discrepancy between the mass of visible matter and the calculated mass of the Coma galaxy cluster.

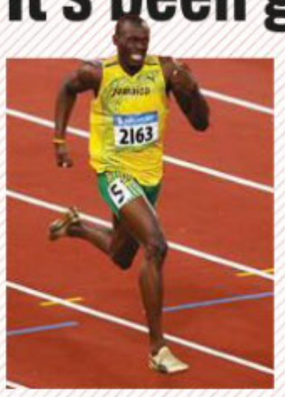
**1970**
Cornell University's Vera Rubin notices that galaxies at the edge of the Universe move faster than expected. She suggests that dark matter could be causing this.

**1981**
Physicist Mordehai Milgrom (right) disagrees. He says the measured mass is correct, but Newtonian mechanics needs updating. He dubs the theory Modified Newtonian Dynamics.

**2009**
Construction on LUX experiment begins in South Dakota. It aims to detect weakly interacting massive particles (WIMPs), a hypothetical particle candidate for dark matter.

# GOOD MONTH/ BAD MONTH

## It's been good for:



### FAST FOOD LOVERS
USAIN BOLT confessed to eating 1,000 chicken nuggets throughout the Beijing Olympics. But he might be on to something. Small amounts of fast food can be just as effective as sports supplements in restoring muscle energy stores after a workout, according to a study at the University of Montana.

### ARTSY TYPES
IF YOU ENJOY painting or sewing, you may be helping your memory. In a study carried out by the Mayo Clinic, those who engaged in arts in both middle and old age were 73 per cent less likely to develop mild cognitive impairment than those who did not.

## It's been bad for:

### SHORT PEOPLE
AS WELL AS being denied rollercoaster rides, it seems short people are also more at risk of heart disease. A team at the University of Leicester analysed genetic data from 200,000 people. They found that for every 6.35cm (2.5 inches) difference in height, the risk of coronary heart disease increases by 13.5 per cent. Compared to a 168cm (5ft 6in) person, a 152cm (5ft) person has a 32 per cent higher risk, on average. The exact reasons still remain unexplained.

### NIGHT OWLS
RISE AND SHINE! Night owls are more likely to develop diabetes and degenerative muscle loss than early risers, even when they get the same amount of sleep, Korean researchers have found. The effect could be due to unhealthy behaviour or poorer sleep quality.

PHOTO: NASA, PRESS ASSOCIATION, ISTOCK, WEIZMANN INSTITUTE OF SCIENCE

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# The LHC: playing the long game

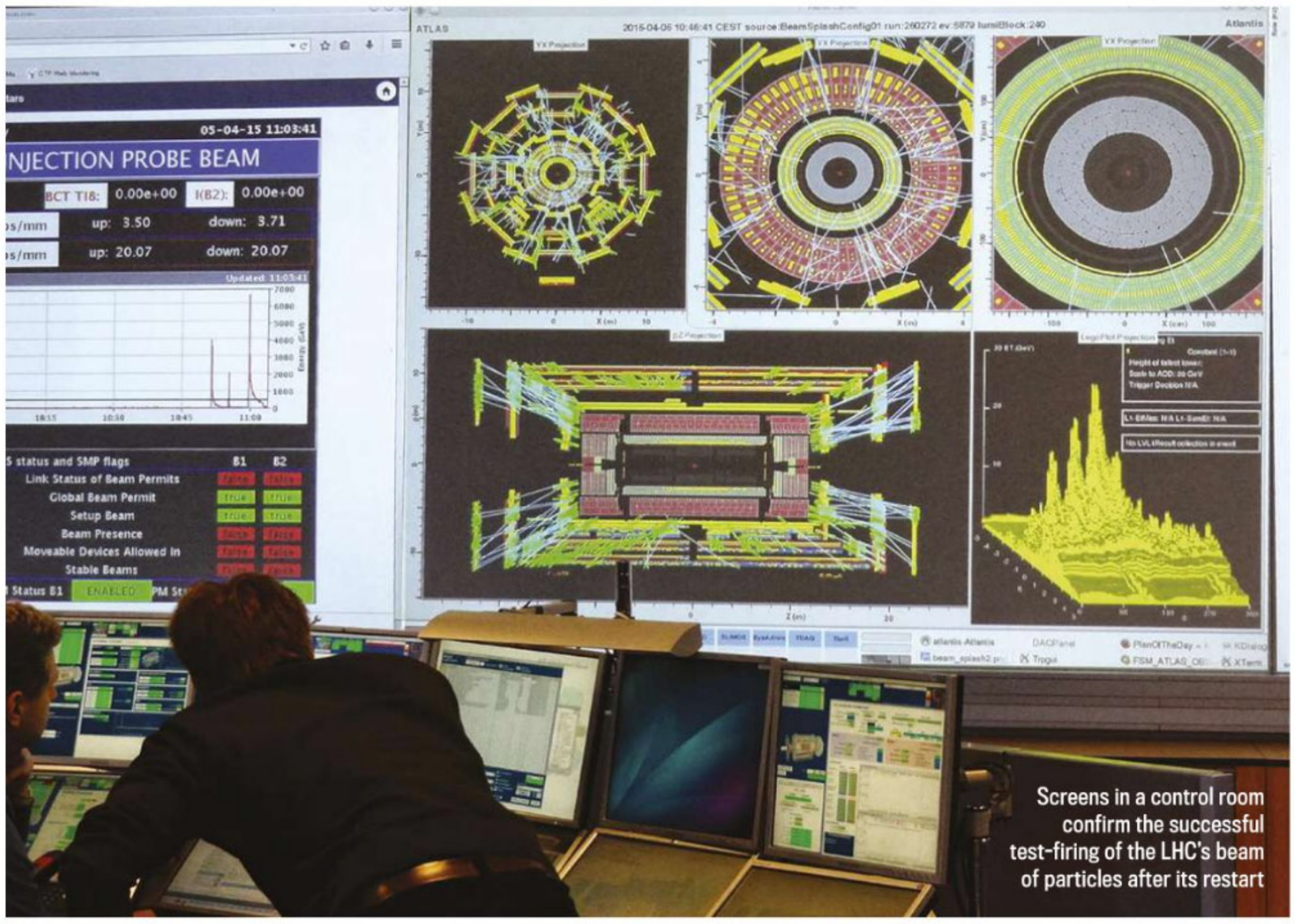
## DAVID SHUKMAN
The science that matters

BACK IN 2003, when I first visited the atom-smashing lab at CERN in Geneva, there was a frenzy of construction going on, as the Large Hadron Collider was in the process of being installed.

Journalists are no good at being patient, and the prospect of the place unearthing anything useful seemed impossibly distant. Still, my cameraman and I were shown the cathedral-sized voids where the giant detectors were soon to be installed. We strolled through the empty tunnels that would later house magnets that would guide beams of protons. And we interviewed half a dozen scientists and engineers about their hopes for the project. Frankly, it all felt more like a science fiction film set than a research centre.

A few years later, we returned for a day of live broadcasts from the site of the CMS detector. We provided hourly updates as a 1,000-tonne component the size of a large house was gingerly lowered underground. But the notion of the gigantic machines achieving hard results still seemed very far off.

On another assignment, I was offered the chance to ride a bike through part of the tunnel. By now, all of the collider's equipment was in place and I worried about crashing into something delicate. Even then, the scene seemed surreal.




Screens in a control room confirm the successful test-firing of the LHC's beam of particles after its restart

In 2008 the big switch-on, when it eventually came, was quickly overshadowed by a blast in one of the magnets – *not* an explosion, insisted the CERN press team. All the same, it was a serious setback and meant further delay. Back in the newsroom, where colleagues are geared for breaking news and instant reactions, the LHC's timescale seemed grindingly slow. So when confirmation of the existence of the Higgs boson finally arrived in 2012, we had to remind everyone why it was major news.

Now the LHC, given nearly double the power it had before, is embarking on a new round of exploration. And once again the timing of any outcome is utterly unpredictable. So a venture dreamed up in one decade, funded in the next, and built in a third is only now bearing fruit – and we in the media continue to keep watch with a mix of disbelief and admiration.

**DAVID SHUKMAN is the BBC's Science Editor. @davidshukmanbbc**

## WHO'S IN THE NEWS?

### Gabriele D'Annunzio

Italian poet and WW1 soldier

**Who's he?**
D'Annunzio was Prince of Montenevoso, a member of Italy's elite Arditi regiment (think the SAS or Navy Seals) and a prominent figure in Italian literature of the late 19th and early 20th Centuries. He's also known as 'the John the Baptist of Italian fascism' thanks to his far-right political ideology and influence on Benito Mussolini. He died of a stroke in 1938.

**So why's he in the news?**
Well, strictly speaking it's not actually D'Annunzio that's in the news, it's his DNA. Italian scientists have reconstructed his genome from semen found on a hanky he gave to his lover, Countess Olga Levi Bruner.

**Lovely! What are they planning to do with that, then – clone him?**
Calm down... no one wants to do that. The point is that DNA reconstruction usually requires the exhumation of the deceased's physical remains, so the experiment was simply a proof of concept exercise. However, the technique could end up being used in reopening cold cases to catch criminals.

PHOTO: CERN, GETTY

JOHN COOPER WORKS

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# THE FRONT SPOILER.
# OR THE SPORTS EXHAUST.

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MINI

Official Fuel Economy Figures for the MINI John Cooper Works Hatch (Automatic): Urban 39.2 mpg (7.2 l/100km). Extra Urban 57.6 mpg (4.9 l/100km). Combined 49.6 mpg (5.7 l/100km). $CO_2$ Emissions 133 g/km. Figures may vary depending on driving style and conditions.

# 10 DISCOVERIES THAT WILL SHAPE THE FUTURE

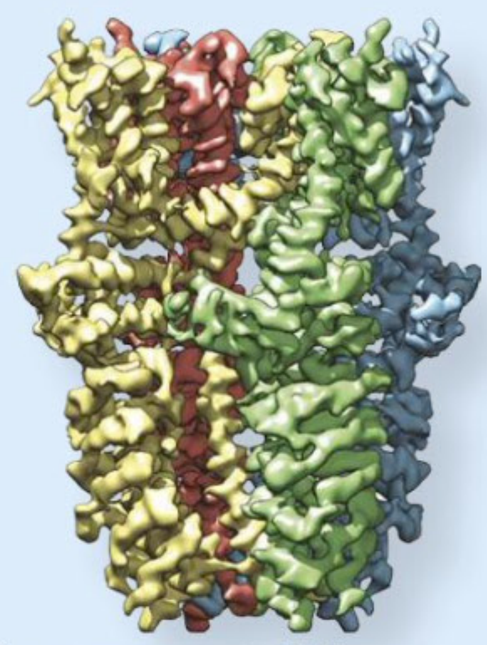
## 10 Screens from genes

Soon, you might be able to pick up a copy of the *DNA-ly Mail* (sorry!)

THE SCREEN FOR your next tablet computer may be made of DNA. Researchers at Tel Aviv University have created a naturally fluorescent material capable of emitting a full range of colours in a single flexible pixel layer, as opposed to the several rigid layers that make up today's screens. It could be used in flexible displays that can be rolled up when not in use. The material is made from peptides and DNA – two of the most basic building blocks of life.

## 9 New class of painkiller

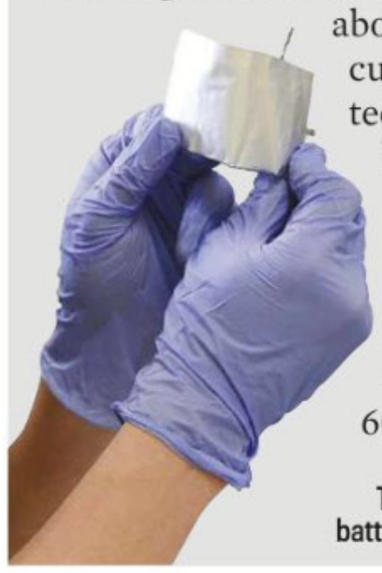
IF YOU'RE A fan of the spicy green condiment used in sushi, chances are you've been giving your 'wasabi receptor' a thorough workout. TRPA1 is a protein located in nerve cells and is triggered by wasabi, garlic and even tear gas. Now, by mapping the protein's atomic structure, a team at the University of California has found it is also involved in transmitting several types of pain signal. The finding could lead to the development of a new class of painkillers, they say.



TRPA1 receptors are comprised of four parts and are located in nerve cells

## 8 Battery that charges in one minute

FED UP OF your phone running out of juice? Well, help may be on the way in the form of an aluminium-ion battery developed at Stanford University that could replace lithium-ion technology in powering everything from smartphones to laptops. The device generates 2V of electricity, about half of current lithium technologies, but it is flexible, durable and can fully charge a device in just 60 seconds.



The first aluminium-ion battery is safe and flexible

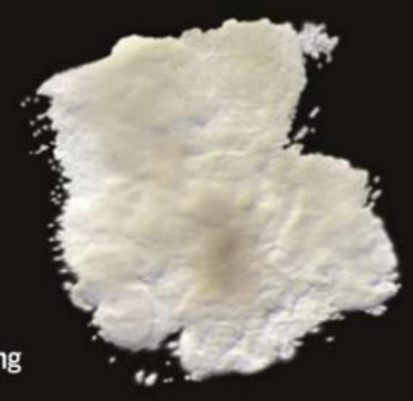
## 7 Non-slip shoes

GET A GRIP! A material that may help pedestrians stay on their feet in icy conditions has been created by Canadian researchers. Made from glass fibres embedded in rubber, the material acts the same as regular rubber on dry surfaces but provides significantly better traction on ice.

Tiny glass fibres act like minuscule studs to grip slippery ice

## 6 Lab-grown lungs

BREATHE EASY. SCIENTISTS at the University of Michigan have used stem cells to grow self-organising mini lungs, complete with the bronchi and alveoli that are found in the human organs. Though the lung structures lack blood vessels, they represent an important step in moving away from animal testing to more effective drug trialling and medical research, the team says.

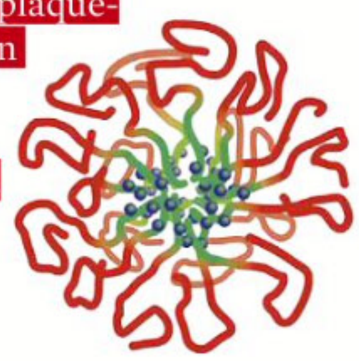


Stem cells were coaxed into growing into tiny lungs

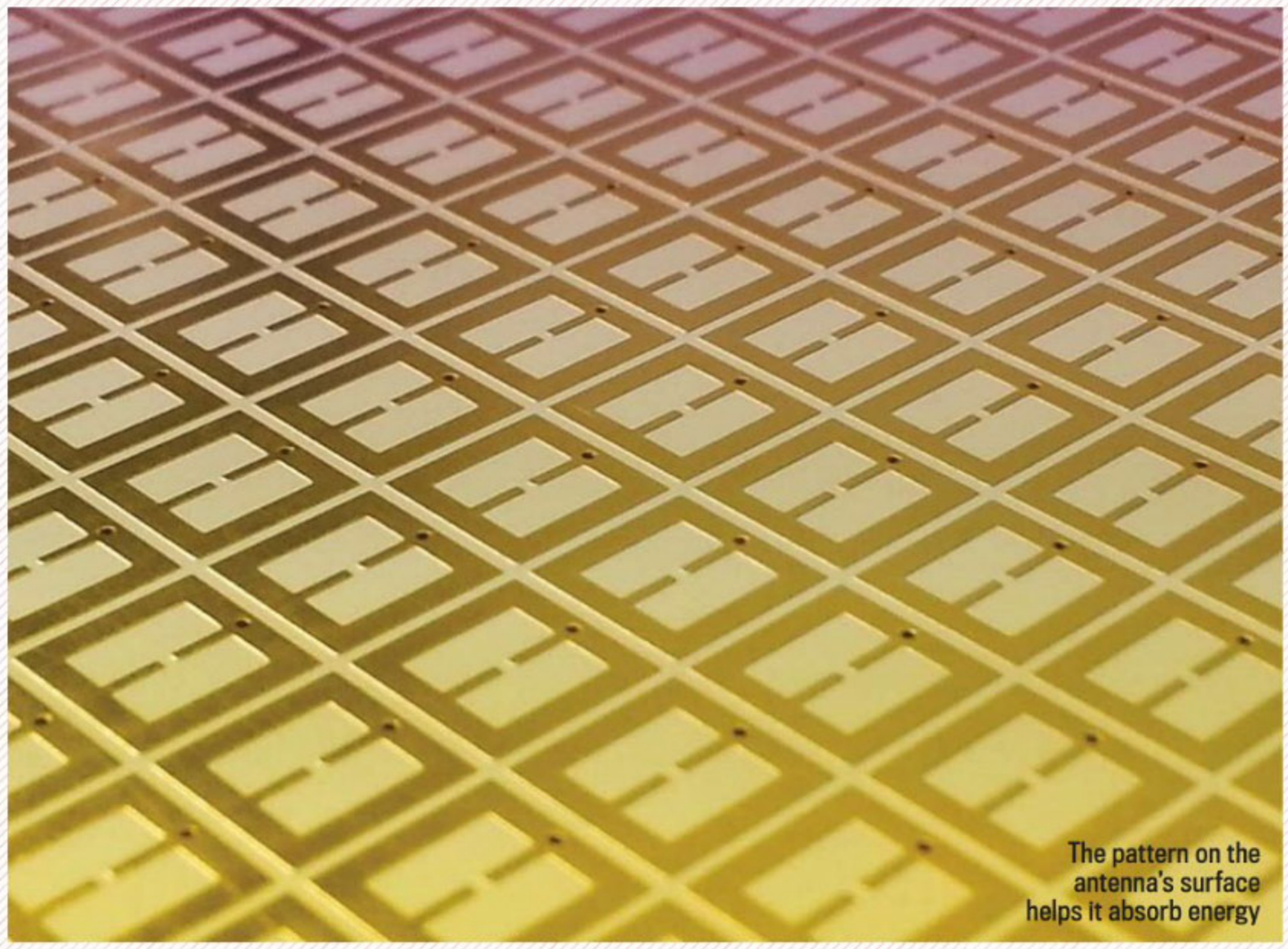
PHOTO: ISTOCK, O RAMAHI/U WATERLOO, GETTY, UC SAN FRANCISCO, MARK SHWARTZ/PRECOURT INSTITUTE FOR ENERGY, REZA RIZVI/YUE LI/SHARON RAVINDRAN

## 5 Nanotech gnashers

NANOTECHNOLOGY MAY SOON save you from a trip to the dreaded dentist's chair. Researchers at Queen Mary University have developed tiny spherical particles that transport a payload of antibacterial drugs to the surface of the teeth to fight plaque and tooth decay. The particles could be put into toothpastes and mouthwashes or used to combat other plaque-like substances, known as biofilms, such as those that form on orthopaedic implants.



The nanoparticles cling to the tooth surface and are not washed away by saliva



The pattern on the antenna's surface helps it absorb energy

## 4 Plastics from eggs

YES, THEY TASTE great with bacon, but eggs could now be used for making antibacterial plastics. Scientists at the University of Georgia made the material by blending albumin, a protein found in eggs, with glycerol, a traditional plasticiser.

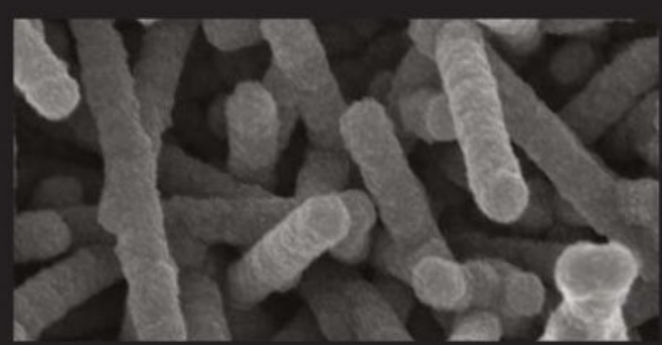
## 3 Energy-harvesting surface

EVERY DAY, THE Earth is bombarded with electromagnetic radiation. Now, team at the University of Waterloo has created a 'metasurface' antenna that can potentially harvest this energy and make it useful. It is much better at capturing energy than traditional designs. The antenna could be sent into space to collect energy and beam it back to Earth. The surface has a special pattern engraved into it that can be tuned to absorb specific frequencies of radiation.

## 2 Viruses heat up water

A tobacco leaf with the characteristic patterning caused by the mosaic virus

VIRUSES CAN GIVE us humans a burning fever, but now a team at Drexel University has found a way of using viruses to make water boil three times more quickly. The technique works by covering a heating element with a virus found in tobacco plants. The coating decreases the size and number of bubbles that form around the element, which in turn increases the heat transfer to the liquid. The technique could be used in everything from power stations to cooling systems for electronic devices.



The nanostructure of the virus-based coating is helping researchers to understand and improve heat transfer

## 1 BO bacteria identified

AS ANYBODY UNFORTUNATE enough to spend time in a packed gym changing room can attest, body odour is bad news. Now, researchers from the University of York have discovered that enzymes in the bacterium *Staphylococcus hominis* are the guilty party. They break sweat down into thioalcohols, the smelly compounds found in armpit aroma. The findings could lead to deodorants that specifically target this particular bacterium, leaving us smelling sweeter for longer.

Nobody likes a stinky gym buddy

# PATENTLY OBVIOUS with James Lloyd

Inventions and discoveries that will change the world

We'd rather do our own dishes than deal with a droid like C-3PO

## Affable androids

AS THE DAWN of robot butlers comes ever closer, maybe it's time to think about how they'll behave. Google has revealed plans to create downloadable robot personalities, meaning that we'll be able to choose our perfect computerised companion. The personalities will be stored on a remote server, and different personalities will see the robots adopting different speaking styles, stances and facial movements. You might choose to model your robot on a celebrity, a friend or even yourself.

Google's robots will also be able to tailor their actions based on your mood. If the robot knows you're not a morning person, it might gently wake you up with a fresh coffee; if you're caught in a storm, it might jovially offer an umbrella and play some uplifting music to cheer you up. Let's just hope they're not all as annoying as C-3PO.

Patent number: US 8,996,429

## Drowning sound

IF YOU'VE EVER put out a fire, it's a good bet a fire extinguisher was involved, spraying messy, toxic chemicals everywhere. Now, two US engineering students have invented a no-mess alternative that douses fires with sound. It's based on the simple principle that sound waves are pressure waves. When directed at a blaze, the waves separate burning material from the oxygen that's fuelling it, starving the fire. The effect only works at low frequencies, though, so you might need to get out that old Barry White album.

Patent pending

## Windows of wisdom

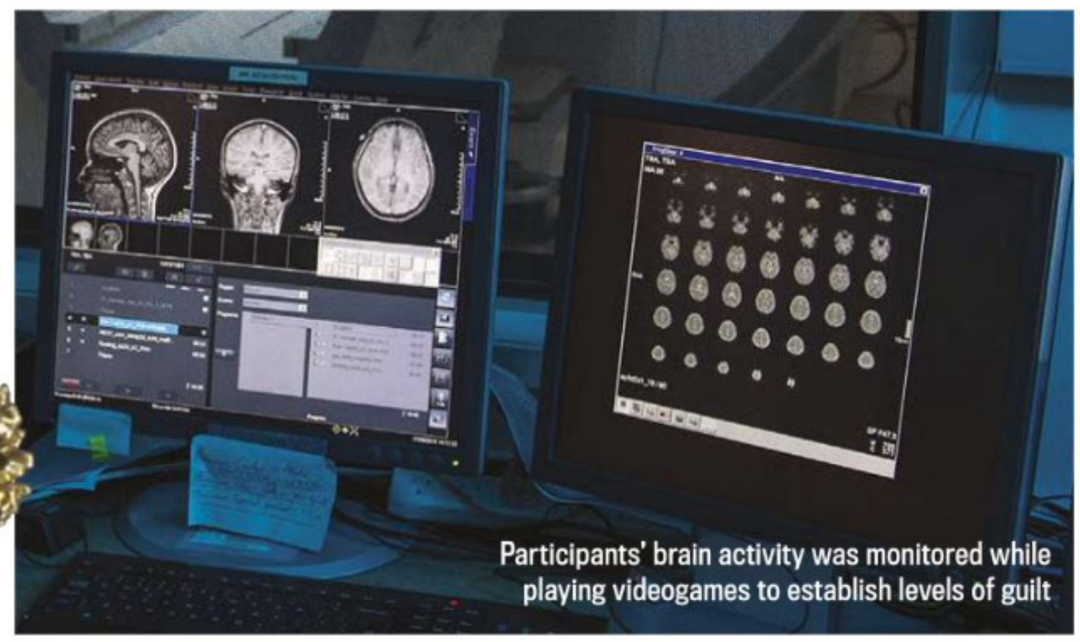
YOU'RE FLYING OVER a city and you spot an unusual landmark below. Intrigued, you point at it through your cabin window, and a display pops up telling you what it is. This is the scenario dreamt up by Airbus in a recent patent application. Their interactive, touchscreen window will detect where you're pointing at and offer up information about it onscreen. You'll be able to swot up on your destination, learn about the landscape below or even identify constellations in the night sky.

Patent publication number: US 20150077337

PHOTO: LUCASFILM/KOBAL COLLECTION, MONASH UNIVERSITY

GENETICS

# Brain scans reveal how killers justify violence



Participants' brain activity was monitored while playing videogames to establish levels of guilt

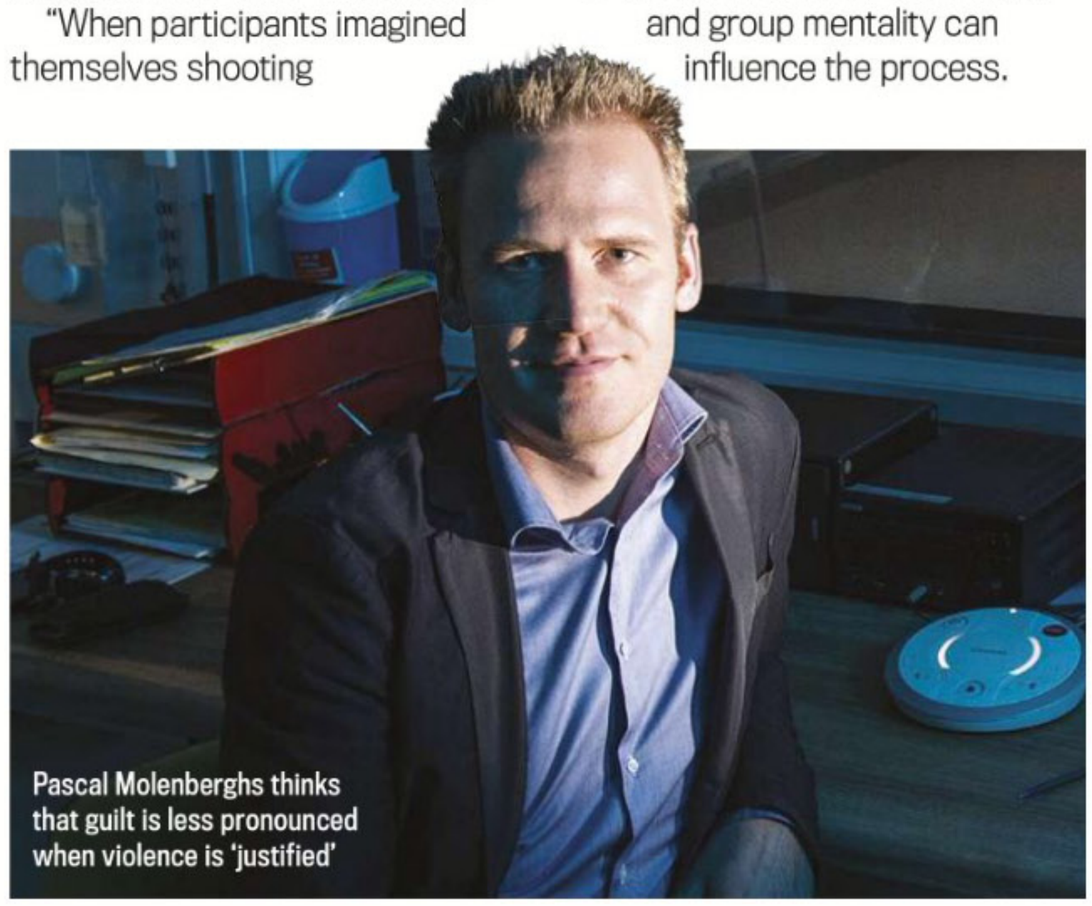
HOW DO YOU spot a killer? Are their eyes too close together? Do they have crooked teeth and poor personal hygiene, perhaps? Well, it might not be as easy as all that, but a study at Monash University looking into the neuroscience behind violent acts has found that brain activity varies according to whether or not the perpetrator sees their actions as justified. The findings could shed light on how the brains of killers differ from those of other people.

Participants in the study played videogames in which they imagined themselves to be shooting innocent civilians or enemy soldiers. Their brain activity was recorded via functional magnetic resonance imaging (fMRI) while they played.

"When participants imagined themselves shooting civilians compared to soldiers, greater activation was found in the lateral orbitofrontal cortex (OFC), an important brain area involved in making moral decisions," said researcher Pascal Molenberghs. "The more guilt participants felt about shooting civilians, the greater the response in the lateral OFC. When shooting enemy soldiers, no activation was seen in the lateral OFC."

The findings show that the neural mechanisms that are typically associated with feelings of guilt become less active when the violence against a particular group is seen as justified.

In the future, the researchers plan to further investigate how people can become desensitised to violence, and how personality and group mentality can influence the process.



Pascal Molenberghs thinks that guilt is less pronounced when violence is 'justified'

INSIDE SCIENCE

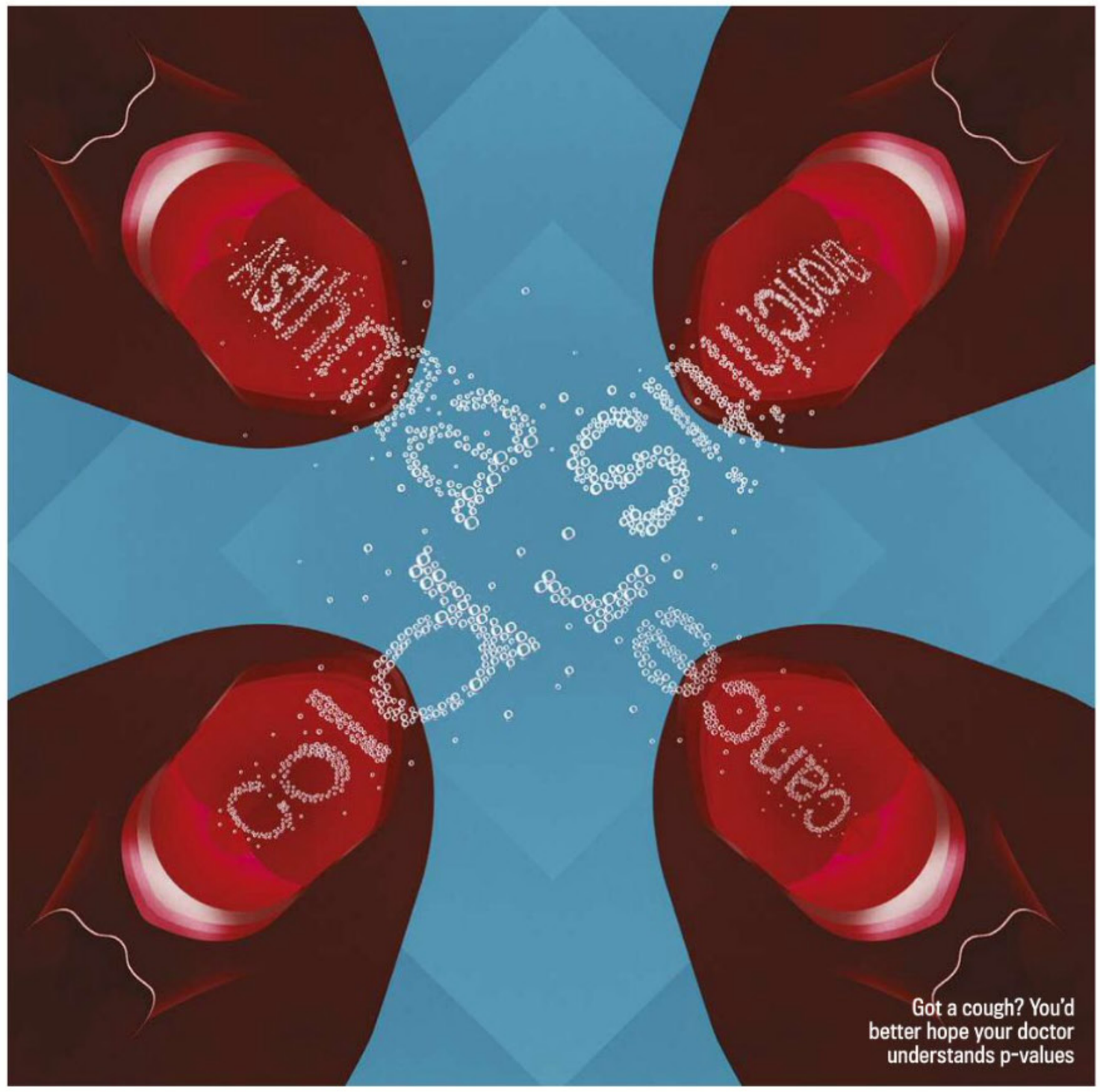
# ROBERT MATTHEWS

## The perplexing number that leads some scientists to get things wrong

SOMEONE WITH A cough walks into a doctor's surgery. The doctor knows that the chances of patients having a cough if they've got lung cancer are high. So the doctor breaks the bad news to the patient: "You've got cancer." That's clearly a blunder, because you don't need a medical degree to twig that a nasty cough doesn't always mean someone has lung cancer. Many other conditions are far more likely to cause a cough, and more questions need to be asked – such as does the patient smoke?

Our fictional doctor's mistake is not too tricky to spot. It lies in the thinking that because it's very likely that patients have a cough if they have lung cancer, it's okay to flip that statement around and conclude that anyone with a cough is very likely to have cancer.

This is merely a made-up situation, but it's an example of a blunder that underpins a scientific scandal involving something called 'p-values'. Scientists use p-values as a 'litmus test' to tell whether a new finding is a genuine result or just a fluke. However, one academic journal, *Basic And Applied Social Psychology*, no longer allows researchers to submit findings that make reference to p-values. Chances are that means little to you. Among scientists, this has provoked a huge controversy. That's because it's a bit like an academic journal banning submissions that mention litmus paper because a lot of researchers don't understand how it works.




Got a cough? You'd better hope your doctor understands p-values

The scientific scandal surrounding p-values has been brewing for years. And here's why. Researchers use formulas that turn their data into a p-value – the probability that the result is a fluke. If this is below 1 in 20, the result is deemed 'statistically significant', and worth publishing.

**"If you've often thought many research findings are twaddle, now you know at least part of the reason"**

Or at least, that's what many researchers think a p-value means. But they're wrong. What a p-value *actually* gives are the chances of getting results at least as impressive as those observed, assuming fluke is their real cause. But hang on... who cares about that? Surely what we want to know is simply the chance of our results *not* being a fluke.

The bad news is that p-values simply can't tell us what those chances are, but many researchers think that they can. If you're struggling with this, don't worry – you're in good company. Many, if not most, researchers couldn't give you the correct definition of p-values, despite using them all the time. But it matters. When using p-values, working scientists routinely make the same blunder as that doctor at the beginning of this column. The researchers flip them around and conclude that there's no more than a 1 in 20 chance their finding is a fluke. That's a big mistake, just as it's a big mistake for our fictional doctor to assume that everyone with a cough has cancer. The chances they don't have cancer are far higher, because other causes are much more likely.

And it's the same with many of those 'statistically significant' results: their sheer implausibility means they're much more likely to be flukes than the p-values suggest. If you've often thought many research findings are twaddle, now you know at least part of the reason.

By banning research papers that use p-values, the editors of *Basic And Applied Social Psychology* are doing their bit to cut the amount of nonsense in the scientific literature. And anyone who pays for research (which means all of us) should hope that other scientific journals follow their lead. ■

**ROBERT MATTHEWS is Visiting Reader in Science at Aston University, Birmingham**

ILLUSTRATOR: MATT MURPHY

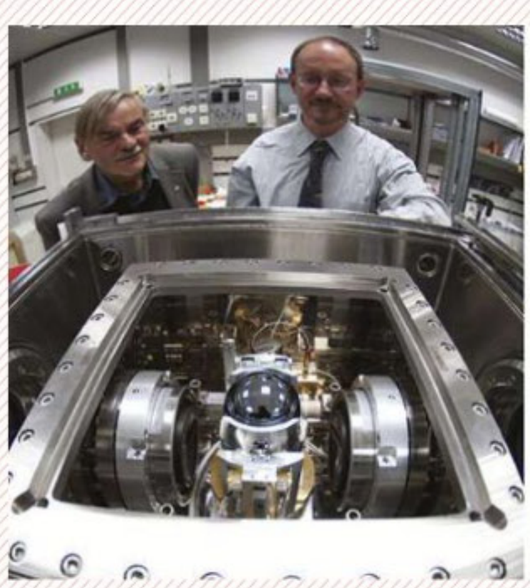
# 1 MINUTE EXPERT
## The IPK

**What's that?**
Since 1889, the mass of a kilo has been defined as that of an object known as the International Prototype Kilogram (IPK). It is made from 90 per cent platinum and 10 per cent iridium and is kept in a pair of bell jars under lock and key in Sèvres, Paris.

**So it's like the daddy of all kilogrammes?**
Right. The problem is that it's slowly losing mass. Over the last century it has shed 100 micrograms.

**That doesn't sound like much. What's the problem?**
It may not make any difference if you're making a Victoria sponge, but when it comes to sensitive experiments, scientists demand as much precision as they can get.

**I guess. So what's the solution?**
A group at the German National Metrology Institute has come up with a method that involves growing a silicon crystal. A silicon atom has a mass of 28 atomic mass units, and silicon has a very regular structure, so by growing a silicon crystal with 2.15 x $10^{25}$ atoms, they can produce the most accurate physical kilogram so far. They hope to produce the crystal by 2018, to an accuracy of one in 100 million atoms.



A model of the new IPK can be seen as a shiny, grey-coloured ball in this image

Capturing a boulder from the asteroid's surface will be the first stage of the mission

SPACE

# NASA wants to give the Moon a moon

IT COULD BE NASA's craziest idea yet: the agency is planning to drag an asteroid into a stable orbit around the Moon. Once there, it will be visited by astronauts who will test technology being developed for future human expeditions to deep space, including to Mars.

Dubbed the Asteroid Redirect Mission (ARM), the project will involve guiding an unmanned spacecraft to a near-Earth asteroid. Robotic arms on the craft will then capture a 4m-wide boulder from the asteroid's surface, before moving the whole shebang into orbit around the Moon. The craft won't physically tow the asteroid: instead, it will use its own mass, combined with that of the boulder, to exert a gravitational attraction on the asteroid and alter its path. In space, gravitational attraction can have a significant impact, even on fairly small objects. The journey is expected to take several years.

"The Asteroid Redirect Mission will provide an initial demonstration of several spaceflight capabilities we

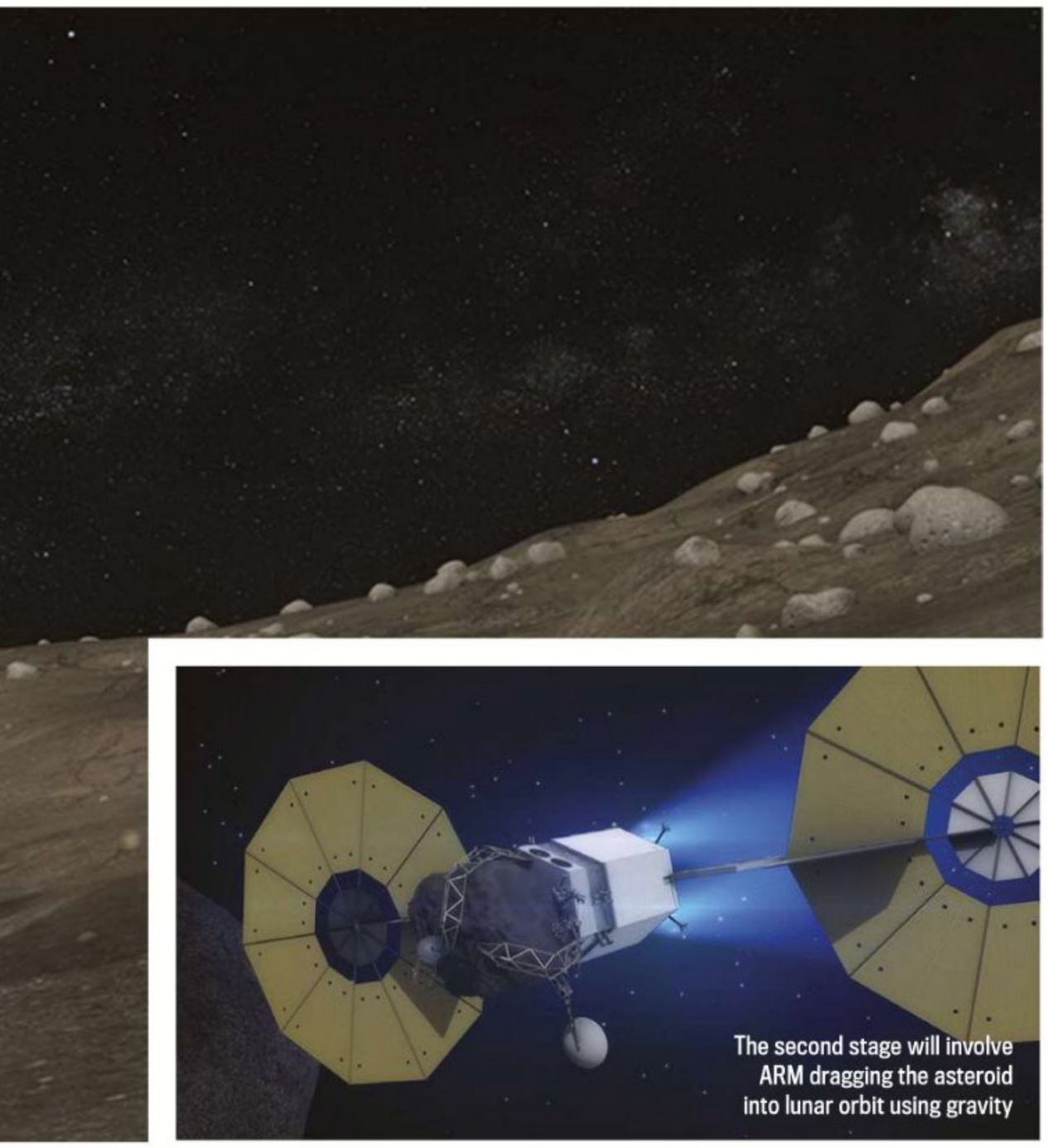
# THEY DID WHAT?!
## Neuroscientists record mouse songs

**What did they do?**
Mice make ultrasonic vocalisations that lie outside our hearing range, but the purpose of these noises has always been unclear. Now, Duke University has found that male mice make the sounds to serenade females.

**What did they find?**
Males sang louder, more complex songs when they could smell a female's urine, but could not see her. The songs were longer and simpler when the males

"Ooh, a female. Better get out my throat lozenges"

PHOTO: NASA X2, ISTOCK, CAMERA PRESS



The second stage will involve ARM dragging the asteroid into lunar orbit using gravity

will need to send astronauts deeper into space and to Mars," says NASA's Robert Lightfoot. "The option to retrieve a boulder from an asteroid will have a direct impact on planning for future human missions to deep space and begin a new era of spaceflight."

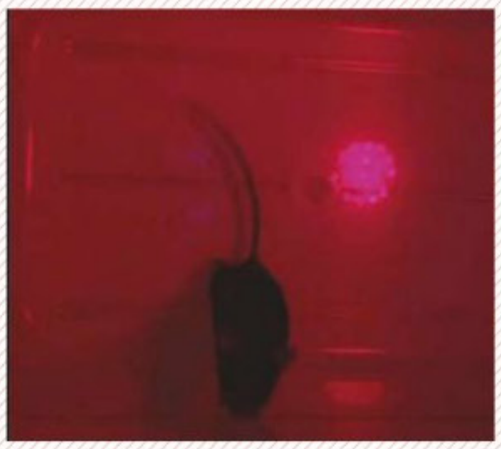
Once the asteroid is in place, NASA's Orion spacecraft will carry a team of two astronauts on a 25-day mission to explore it. They will test sensor and docking technologies and collect samples wearing new spacesuits specially designed for deep space missions.

As part of the mission, NASA will also test ways to deflect asteroids, in case one were ever to enter a collision course with Earth.

The $1.25bn project is targeted for lift-off in December 2020 and the agency has so far identified three potential targets for the mission: Itokawa, Bennu and 2008 EV5. However, it says it won't make a final decision until 2019.

sang directly to the female. Females preferred to listen to the more complex songs – evidence that the songs carry important meaning.

**Why did they do all this?**
Determining the brain circuits involved with different communication patterns may be important for the study of autism, the researchers say.



Male mice sing complex songs when they can smell a female but can't see her

# CLICK HERE

New websites, blogs and podcasts

## SUBMARINE CABLE MAP

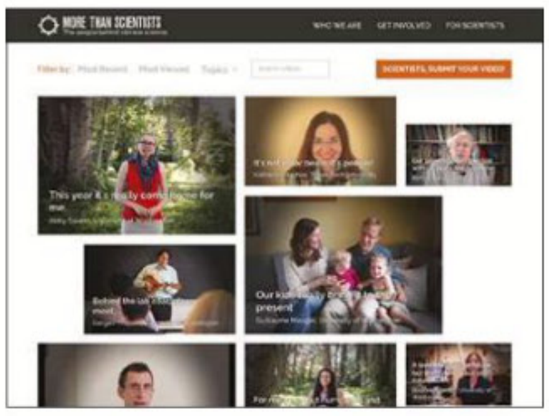
*submarine-cable-map-2015.telegeography.com*

When you're using the internet, you don't often think about the mechanics of it. This site encourages you to do just that, showing you the network of cables on the seabed which make transoceanic communication possible. It resembles an antique map stylistically, but is fully clickable and zoomable – and strangely fascinating.

## ZOMBIE TOWN

*http://mattbierbaum.github.io/zombies-usa/*

Scientists have made a disease dynamics simulator to model how a zombie infection outbreak would spread across the US, and you can play with it here! Click on the map to start an outbreak, then sit back and watch it wreak havoc. It may sound fantastical and frivolous, but this kind of model can be used for real diseases, too.



## MORE THAN SCIENTISTS

*morethanscientists.org*

If you're sick of hearing about the 'debate' on climate change and just want to know what actual scientists think about it all, visit this website. Scientists from a diverse selection of disciplines and backgrounds step out from behind their laboratory benches and use videos to share their stories about what climate change means to them.

## MIKULSKI ARCHIVE FOR SPACE TELESCOPES

*mast.stsci.edu*

Hubble has been exploring the Universe for over 25 years and has amassed a whole load of data – and you can find it all here. If you're looking for a handpicked gallery of gorgeous space photos, you're in the wrong place. But if you want to dig into the actual source material, start with the example searches on this site. Soon you'll be exploring Hubble images like a pro.

KELLY OAKES is Science Editor at BuzzFeed. She tweets from @kahoakes

MATERIALS SCIENCE

# 'Terminator'-inspired 3D printer turns liquids into personalised prosthetics

THE SHAPE-SHIFTING T-1000 was one of the most iconic villains in SF movie history. Now, a team from the University of North Carolina has used the character as the inspiration to create a 3D printer that creates fully formed objects from a pool of liquid.

Standard 3D printing technology works by building up materials layer by layer, fusing them together as it goes. But this new technique – dubbed CLIP, or Continuous Liquid Interface Production – works by using light and oxygen to solidify a liquid resin. It can create objects with a level of detail just 20 microns across: that's less than one-quarter the thickness of a piece of paper. It is also 25 to 100 times faster than conventional methods, say its inventors. CLIP enables a wide range of materials to be used to make 3D parts with novel properties, including nylon-like, ceramic and biodegradable materials, expanding 3D printing's range of potential applications.

Biodegradable coronary stents are one item which CLIP is ideally suited to producing

A model of the Eiffel Tower being produced by CLIP. Wonder if they've noticed it's upside down?

"In addition to using new materials, CLIP can allow us to make stronger objects with unique geometries that other techniques cannot achieve, such as cardiac stents that have been personally tailored to meet the needs of a specific patient," said Joseph M DeSimone, who led the CLIP research team. "Since CLIP facilitates 3D object fabrication in a matter of minutes instead of hours or days, it would not be impossible, within the next few years, to enable personalised coronary stents, dental implants or prosthetics to be 3D printed on-demand."

SEISMOLOGY

# Can animals predict earthquakes?

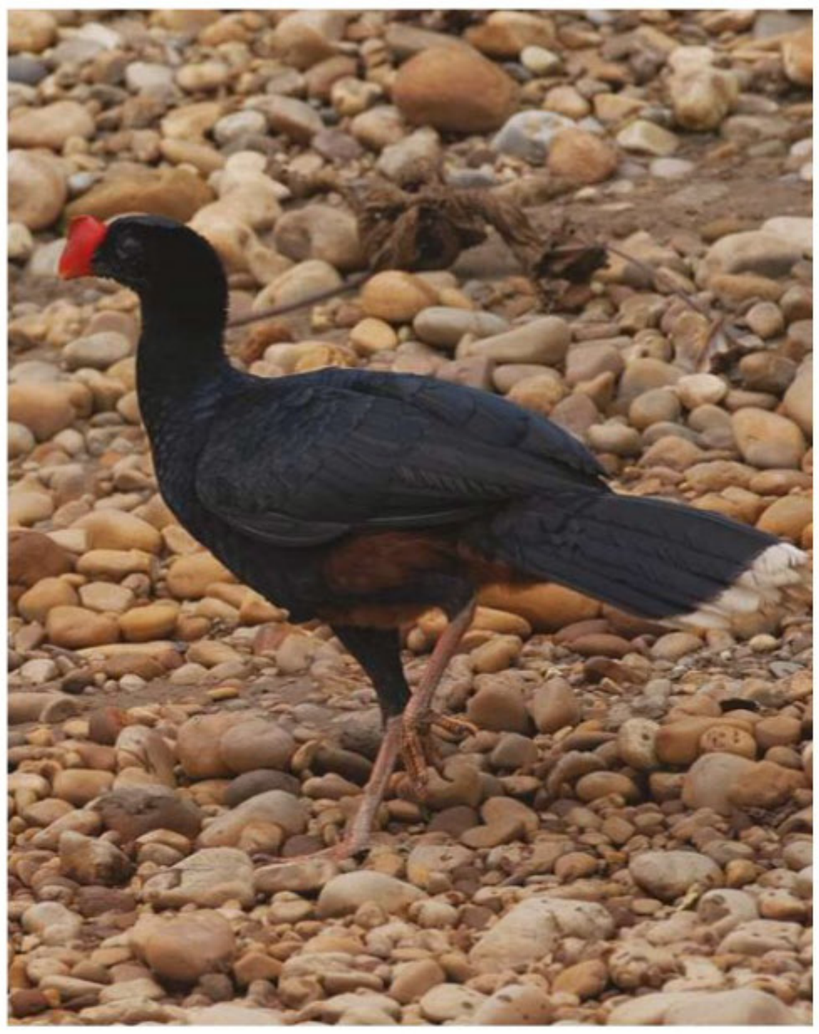
IF YOU'RE EVER out and about and notice an eerie lack of animals scurrying around, you might want to turn on your heels and scarper – an earthquake may be on its way.

A team led by Anglia Ruskin University's Rachel Grant has used motion capture cameras to discover that animals in Peru's Yanachanga National Park have a tendency to hunker down in their nests and burrows several days before an earthquake hits. They suspect this behaviour could be due to the effect of charged particles sent into the air by seismic activity.

On a typical day, the cameras spotted 5 to 15 animals, such as razor-billed curassows. However, in the 23 days before the magnitude 7.0 Contamana earthquake struck in 2011, they saw no more than five on any given day, and for five of the seven days immediately before the earthquake, no animal movements were recorded at all. These findings corresponded with disturbances in the ionosphere, an area in the upper atmosphere that contains a high number of ions, or charged particles.

Furthermore, it is known that a high density of positive ions in the air can lead to side effects in animals and humans. For example, it can cause an increase in the animals' serotonin levels, which can lead to symptoms such as restlessness, agitation, hyperactivity and confusion.

"We believe that both of these anomalies arise from a single cause: seismic activity causing stress build-up in the Earth's crust, leading – among other things – to massive air ionisation. We hope our work will stimulate further research into this area, which has the potential to help with short-term seismic risk forecasting," says Grant.



If there's a quake coming, you won't see many razor-billed curassows

PHOTO: LARS SAHL, CARBON3D INC, MURRAY COOPER/MINDEN PICTURES/FLPA

EVERYDAY SCIENCE

# HELEN CZERSKI

## How can milk foam hold up a spoon when it's only made of water and air?

THE CAPPUCCINO LOOKED all right to me, but then I'm not much of a coffee drinker. It had a pretty pattern in the foam on top, and it had apparently been made using fairly swanky coffee beans. But that wasn't good enough for the friend I was with. She picked up the accompanying metal teaspoon and placed it flat on top of the foam, with the handle of the spoon resting on the side of the cup. We watched in silence as the spoon sank slowly beneath the bubbles. "Rubbish," she sniffed. The waitress returned with my hot chocolate, which was more than half milk foam, and we repeated the test. The spoon sat there quite happily, and apparently this foam passed the test. Isn't that odd? Spoons fall through air and they fall through milk. So how is it that when you mix those two things together, they make something that behaves like a solid and can hold up a spoon?

I have a small milk-frothing device at home, and it's always hot chocolate o'clock, so the next day I roped my in neighbour to assist and we did some experiments. We tried cold semi-skimmed milk first. Milk contains both protein and fats, and as the air was whisked in, the cup filled up with foam really quickly. The secret to a foam is a molecule with both a water-loving and a water-hating end. These coat the surface of each bubble, making a sort of cage around it. In the cold milk, the fats were playing that role, but there weren't very many of them. As we watched, the bubbles joined together to make bigger bubbles, and these eventually burst. The foam vanished almost as quickly as it arrived.

Then we tried heating the milk. Cold protein molecules are wound up into little balls, with their hydrophobic (water-hating) ends tucked safely away inside. But as the milk was warmed, the proteins unwound to reveal those ends. Suddenly, there were far more molecules that could act as a coating. The foam grew just as quickly, but this time it stayed put because there were lots of stable little cages for the bubbles. But it doesn't tell us why the mixture could hold up the raisins that we scattered over the surface.

**"I'm still not a coffee drinker, but I love the thought that you can build a solid structure out of a liquid and a gas"**

In really smooth milk foam, the bubbles are too small to see – each one measures about one-tenth of a millimetre in diameter and the coating stops them from joining together. These foams are quite wet, and the bubbles are spherical squishy packages that pack together just like ping-pong balls in a bucket. Pushing on them just squashes the bubbles a bit, so they'll push back and can hold an object up. But if you push a bit harder, the bubbles squish enough to start sliding past each other. The more liquid there is between the bubbles, the less hard you have to push to get them to shuffle around. This was the issue with the failing cappuccino. There was too little air and the bubbles could easily move out of the way of the spoon.

Like richer hot chocolate? Full-fat milk isn't so good for foam, because the fats and proteins stick to each other and not to the bubbles. But add a bit of cream, and fat takes over from protein to make even more decadent foams. So, to finish the experiments, we made some more milk foam using our most successful technique, and turned it into hot chocolate.

I'm still not a coffee drinker, so I'm not going to turn into a coffee snob. But I love the thought that you can build a solid structure out of a liquid and a gas. And even more, I love the idea that you can add this structure to chocolate and drink it. ■

**DR HELEN CZERSKI is a physicist, oceanographer and BBC science presenter whose most recent series was *Super Senses***

ILLUSTRATOR: ANDREW LYONS

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INTO THE FUTURE

# STEPHEN BAXTER

## Habitable planets may turn up in surprising places

THE STUDY OF planets orbiting distant stars is revolutionising our understanding of the Universe. This year is the 10th anniversary of the first discovery of a 'super-Earth', orbiting a star called Gliese 876. The planet's mass is larger than the Earth's, but smaller than that of Neptune or Uranus. Such worlds and the other 'exoplanets' present new opportunities to find life.

It used to be thought that a liveable world had to orbit in the 'habitable zone' (HZ) of a Sun-like star, at a distance that would allow liquid water to gather on the planet's surface. This seems plausible if you look at the Solar System. Venus is an inferno just inside the HZ. Mars, just outside, is frozen, while Earth seems just right.

But a rule-breaker, whose plausibility has been recently confirmed by astrobiologist Rory Barnes of the University of Washington, was shown in the movie *Avatar*. Pandora is a moon of the gas giant Polyphemus, which orbits a star of the Alpha Centauri system just outside the traditional HZ. But Pandora is kept warm by complex effects that include tidal heating from its parent world.

Even in our own Solar System we have found liquid water far from the HZ. Jupiter's moon Europa has a crust of ice; beneath this lies an ocean, which is kept liquid by tidal effects. There may be as many as six of these 'roof worlds' among the outer planets' moons. Future space probes will determine whether these dark and briny seas are capable of hosting life.

On the other hand, the exoplanets show us that having liquid water is no guarantee of habitability. The super-Earth GJ 1214b, 42 light-years from the Sun, may have an ocean thousands of kilometres deep. The ocean floor is comprised of an exotic kind of ice, which is made solid by high pressure rather than cold. It's not clear if life could evolve cut off from the minerals of the world's rocky core.

Could aliens be living on the moons of exoplanets?

**"Since 70 per cent of stars are red dwarfs, this model multiplies the potential number of habitable worlds in the Galaxy"**

Meanwhile, we no longer even think the parent star has to be like our Sun. Red dwarf stars like Proxima Centauri (as featured in my novel *Proxima*) are small and dim. A habitable planet would have to huddle so close that it would be 'tidally locked', like the Moon is to Earth, with a single face perpetually presented to the star. But since 70 per cent of stars are red dwarfs, this model multiplies the potential number of habitable worlds in the Galaxy many times over.

The habitability of a given world can also change with time, and can be affected by life itself. The film *Jurassic World*, out in June, shows us creatures from an age when Earth was warmer and more oxygen-rich – an ideal environment for huge land animals. More dramatically, Earth was once perfectly habitable for anaerobic (oxygen-hating) bacteria. The evolution of photosynthetic bacteria, which released oxygen into the atmosphere, changed all that. According to James Lovelock's 'Gaia' model, over the five billion years since its formation, the Sun has gradually increased its power output. Its HZ has therefore shifted across space, from well within Earth's orbit to its current position. And yet Earth's surface temperature has remained stable, thanks to the action of immense flows of mass and energy which act like natural thermostats. Life is intimately involved in these systems – in other words, life itself may maintain habitability.

So the definition of a 'habitable' world is more tricky than it first appears. But the Universe as a whole looks a lot more hospitable to life than it did mere decades ago. ■

**STEPHEN BAXTER is a science fiction author who has written over 40 books. His latest is *Ultima*, published by Orion**

ILLUSTRATOR: ANDY POTTS

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# FREE WILL THE GREATEST ILLUSION?

Neuroscientists peering into our brains are becoming ever more convinced that free will is an illusion; simply a creation of our mind that allows us a sense of control. **Simon Crompton** delves into the science to find out more...

YOU WERE ALWAYS going to start this article. It was theoretically predictable from the moment of the Big Bang. You were always going to read this sentence. And this one – each act the inevitable result of everything that preceded it. Every bumping together of atoms and molecules, the exact structure of your DNA, the precise combination of chemical and electrical signals that make you do what you do has been determined by the laws of science from the beginning of time.

That is what is known as 'determinism', and it cuts through traditional ideas of free will like a knife. In the past 30 years, discoveries in neuroscience have freshly stoked the fires of debate about determinism versus human free will that have been crackling among scientists, philosophers and religious figures since at least the days of Socrates. And determinism, most famously advocated by Sir Isaac Newton, currently seems to be gaining the upper hand.

The reason for this is a sequence of brain experiments stretching back to the 1980s,

ILLUSTRATOR: ANDY POTTS

which have indicated with increasing authority that our brains make decisions before we even become aware of them. Scientists today can wire you up to a computer and predict what choice you are going to make many seconds before you believe you make it. If we're not conscious of our decision-making, how can we be said to be acting voluntarily, to be 'willing' our every deed? And if we're acting consciously, exactly what is determining what we do?

Scientific inquiry, it seems, is killing the very idea of free will. Or is it?

## DECISIONS, DECISIONS

Imagine looking at a clock on a computer with a rapidly rotating hand, and being asked to push a button at any point decided by yourself. You have to note the position of the hand on the clockface at the moment you decide to move your finger. All the while, your brain's electrical activity is monitored using an electroencephalogram (EEG).

This was the experiment carried out by American neurologist Benjamin Libet in 1983 which caused a free will re-think. Libet calculated participants' precise conscious decision time, using the times they noted as their decision time and the time the button was actually pushed. Then he compared this decision time with a surge of brain activity that earlier research had shown indicated decision-making. He found that the brain activity started, on average, 300 milliseconds *before* subjects were conscious of making the decision. This change in brain activity that precedes conscious decisions, called readiness potential, has been deemed a blow to free will, suggesting that the brain prepares to do something well before we 'decide' to do it.

Libet's experiments were simple, but his findings have been elaborated on by his followers. In 2010, neurosurgeons and neuroscientists from UCLA and

**Steven Pinker, psychologist**

Speaking in 2011
youtu.be/VQxJi0COTBo

> I don't believe there's free will in the sense of a spirit or soul that reads the TV screen of the senses and pushes buttons and pulls levers of behaviour. Behaviour is the product of physical processes in the brain. But when you have a brain consisting of 100 billion neurones connected by 100 trillion synapses there's a vast amount of complexity, so human choices will not be predictable in any simple way from a given set of stimuli. We also know the brain is set up so that there are at least two kinds of behaviour: choosing how to move a chess piece is different from your iris closing if I shine a light in your eye. It's that kind of behaviour, that has a mental model of the world which can predict the consequences of certain behaviours, that carves out the realm of behaviour that we call free will.

PHOTO: UNIVERSITY OF MELBOURNE, D WEGNER/T WHEATLEY, MAX GERBER

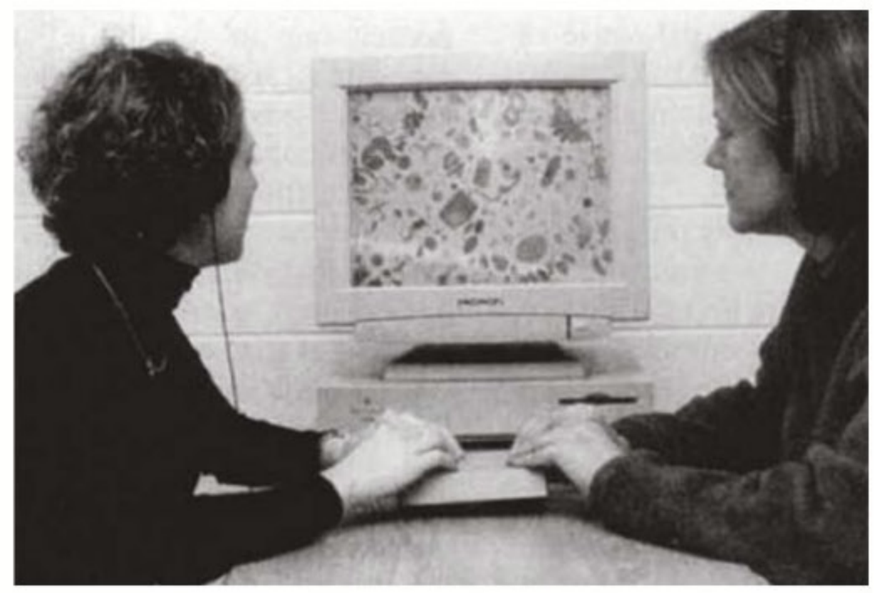
A volunteer undergoes an EEG during an experiment at The University of Melbourne's Decision Neuroscience Laboratory

Harvard repeated Libet's experiment, this time inserting electrodes into the brain to record activity from individual neurones. They detected readiness potential up to 1.5 seconds before a decision.

What's more, brain-scanning research by Berlin neuroscientist John-Dylan Haynes in 2007 showed that some decisions we make can be predicted up to seven seconds in advance. He placed study participants into a brain scanner and asked them to push a button to their left or right side – whichever they wanted, whenever they wanted. The patterns of brain activity leading up to 'right' decisions were found to be different from 'left' decisions, and became clear seconds in advance of the button being pushed.

Perhaps most controversial are the experiments and views of American psychologist Daniel Wegner, who before his death in 2013 argued that our sense of control over what we do is self-delusion. He pointed out that there were constant examples of us being mistaken about being the authors of our own actions.

Sometimes we do things but don't think we're doing them: for example, moving a glass around a ouija board, twitching a stick when divining water or accomplishing tasks under hypnosis. On the other hand, sometimes we aren't doing anything when we think we are. Wegner demonstrated this with a kind of reverse seance. He fixed a small board on top of a computer joystick, and asked two participants to sit on either side with their fingers on the board, causing a cursor to roam over pictures on a screen. They were told to stop the cursor whenever they liked. After the cursor stopped, the participants were asked how strongly they felt that they, individually, had chosen the stopping place. Invariably, participants believed they had controlled the landing place. The trick was that one of the two participants was, in fact, an experiment coordinator who had complete control of the cursor all the time. The movements of the true test subject didn't control the cursor at all.



In Wegner's famous experiment, volunteers believed they were controlling the movement of a cursor on a screen – even thought their input actually had no effect whatsoever on the cursor's movement

In other words, said Wegner, we fool ourselves constantly and have what he called "the illusion of conscious will". This has led to other psychologists and neuroscientists taking the idea further – saying that the feeling of intention is something humans always attribute to their actions after the fact. We make up stories so that we can take ownership of actions that would have happened anyway.

Even for the most pragmatic of scientists, this sounds like a troubling vision of humans as programmed automata, our deeds the products of unconscious processes rather than thought. But that is by no means the whole story. If

In Patrick Haggard's lab, muscle activity in the hand is measured as part of an experiment to determine if we have free will

> Free will is our capacity to see probable futures in time to take steps so that something else happens instead. What happens is determined, but it isn't as important as people have thought: it doesn't imply inevitability. We have to recognise that there are varieties of free will. The traditional varieties – who cares if we've got them? The varieties that matter, the varieties worth wanting, are perfectly compatible with determinism.
>
> Do we have to give up something? Yes, we have to give up some of our ideas and ideology about freedom and blame and responsibility. That will scare some people, who want to be absolutist about responsibility. I mean, the idea of 'in the eyes of God, that's a sin'... that has to go. What we replace it with is still a very rich and familiar concept, and that is: we are not deluded about our own capacity. We are *determined* to be masters of our fate, to a surprising and gratifying degree.

**Daniel Dennett, philosopher**

Speaking in 2014
youtu.be/joCOWaaTj4A

science has taken debates about free will beyond the traditional arenas of 'independent' action, the new understanding it has brought about human consciousness is revealing the inadequacies of talking about 'free will' in the first place. As a result, scientists and philosophers alike are now engaged in framing new ways of looking at what it might actually mean to be 'free'.

## THE GREAT DEBATE

Patrick Haggard is a British neuroscientist who has collaborated with Libet and examines issues of free will and voluntary action as a professor at the Institute of Cognitive Neuroscience, University College London. Until recently characterised as 'anti-free will', he acknowledges his views have evolved as traditional debates seem increasingly irrelevant. One thing is clear, says Haggard: a scientific outlook can no longer accommodate dualist ideas – the belief held by religions and philosophers such as René Descartes that a soul or mind can exist separately from the brain and body.

"A neuroscientist has to believe that all our thoughts, feelings and experiences are the result of electrical and chemical events in the brain," he says. That throws out of the window the idea that there is an 'I' telling the brain what to do.

But at the same time, he believes that ideas that we simply deceive ourselves into believing we have conscious will are going too far. He points to recent work by Aaron Schurger in France, which has

PHOTO: MARTIN POPE CAMERA PRESS, PRESS ASSOCIATION, UCLA

The 'dress illusion' (above and below) showed how neural noise leads to different conclusions about the dress's colour scheme

> Free will as a concept is so incoherent that it can't be mapped onto any conceivable reality. Many people agree that free will doesn't make any sense, and that it's some kind of illusion, but they think that nothing important changes, and in my view that is untrue. Most people imagine that a belief in free will is necessary for morality and it's necessary therefore for getting what we want out of life. I think that's clearly untrue.
>
> The popular conception of free will rests on two assumptions. The first is that each of us is free to think and act differently than we did in the past. The second assumption is that you are the conscious source of your thoughts and actions. Now, unfortunately, we know that both these assumptions are false. We live in a world of cause and effect. Everything that could possibly constitute your 'will' is either the product of a long chain of prior causes, and you're not responsible for them, or it's the product of randomness, and you're not responsible for that.

brought into question whether the 'readiness potential' that Libet identified in the brain actually represents the brain planning what to do next. For some it has brought free will back into the neurological picture. Schurger developed earlier research indicating that when we make a decision based on, say, visual input, groups of brain cells start assembling evidence in favour of various outcomes. When this neural noise rises to a peak, it crosses a threshold and tips into a conclusion. The famous dress optical illusion that took the internet by storm in March, for example, shows that different brains tip over into different conclusions on the basis of ambiguous evidence.

Schurger proposed that this constant neural noise is involved in all decision-making. He created a computer model of electrical activity as the brain assembled information, and found it

**Sam Harris, neuroscientist and author**

Speaking in 2012
youtu.be/_FanhvX09Pk

# A WORLD WITHOUT FREE WILL

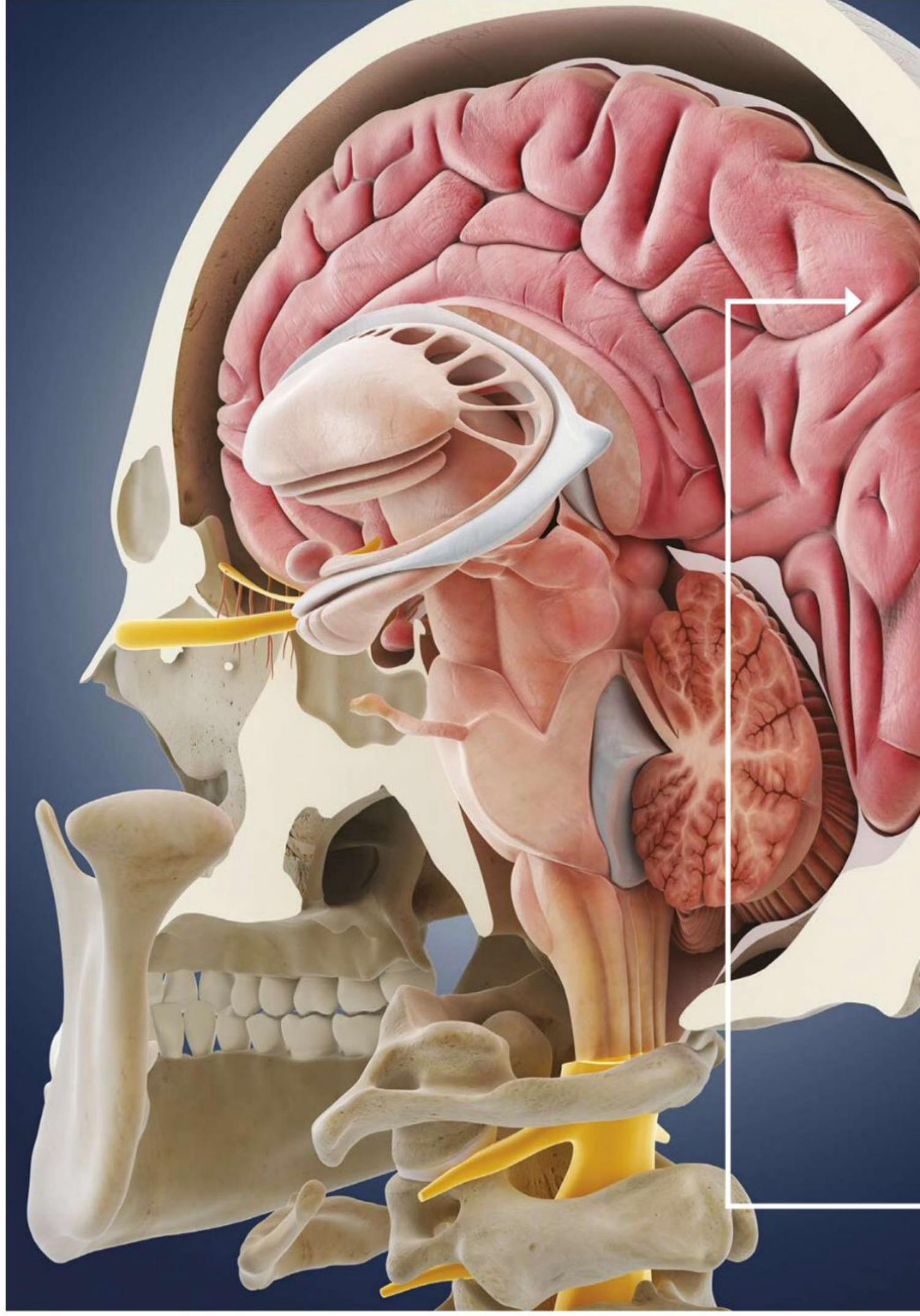
**If it's true that there is really no such thing as free will, what are the implications for our day-to-day lives, and our society?**

"What do you mean I don't have free will?" Many of us will tend to recoil at the very idea, because such a suggestion threatens many of the assumptions and institutions that our societies are founded on.

Religions that involve divine judgment make little sense if we don't actually have conscious control over our thoughts and actions. And what about ideas of moral responsibility? If we know we don't have free will, does that lead to a world where we can behave as we want, because we cannot be held responsible for whatever we do?

Psychology researchers at Oregon and Minnesota found that the more people doubted free will, the less they favoured punishments that make offenders suffer for their crimes – suggesting that a world that knew it had no free will might be more compassionate. They wanted rehabilitative punishments instead, focusing on discouraging further crime. However the researchers, Azim Shariff and Kathleen Vohs, also found that people who are convinced that we do not have free will are more likely to cheat, lie and harm others during experiments.

According to Helen Beebee, Professor of Philosophy at Manchester University, many philosophers believe that it is precisely because free will does not exist that we have to build social institutions and laws to stop us killing each other. "They see this as a pale imitation of moral responsibility," she says. "However, I'd see it as real moral responsibility."



> Magicians and mind-readers have long known that free will is an illusion. In fact, we've been using that knowledge to our advantage for centuries. Any good performer can create the perfect illusion of free choice and yet secretly manipulate events so that the choice is anything other than free. It's fascinating to me that neuroscientists are only now discovering the science behind why this is possible. Choices only feel free because of a psychological principle called cognitive dissonance. Good performers use this to give an audience the feeling that they've made decisions for themselves, but in some tricks these choices are largely irrelevant as the performer has already decided on the outcome or knows what choices are likely to be made. An audience will swear they've exercised free will, and that's what makes this principle so perfect for us.

PHOTO: SCIENCE PHOTO LIBRARY, ISTOCK, UNIVERSITY OF MANCHESTER

**Marc Paul, psychological magician**

www.marcpaul.com

looked similar to the patterns of Libet's readiness potential. He argued that what looked like a pre-conscious decision-making process might indicate a readiness to make a conscious decision, rather than the decision itself. In an experiment, he showed that participants who had built up the most neural noise were quickest in making 'spontaneous' choices.

"Schurger is interesting," says Haggard. "You could say that his theory is compatible with free will because this crossing of the threshold is the decision to act, but I think he's rightly cautious about whether the process is conscious."

Indeed, it is the big question of consciousness that needs to be addressed, because questions of free will are irrelevant without understanding it better. "I do think we have a conscious experience of what we are about to do," Haggard continues, "but it's for others to decide whether that is free will. It's this stream of experience that our research is concentrating on. We need to know if there's a difference between conscious actions – making a cup of tea, say – and those you can do unconsciously like walking. That will help us understand how consciousness affects our control of our actions."

Neuroscientists are looking at two areas of the brain that seem to give us a sense of control over what we're doing. The posterior parietal cortex at the back of the brain seems to have a role in planning and monitoring our actions. And the fronto-median cortex, where the two hemispheres meet, is active before movement. When doctors stimulate this area with electricity, patients have reported feeling the urge to move their arm. "That sounds a little bit like will," says Haggard.

## THE BROADER PICTURE

Philosophers, too, are accommodating advancing neuroscience into their enduring debates about free will. The fact is, says Helen Beebee, Professor of Philosophy at Manchester University, that what

Users move the glass (or plate, in this case) on a ouija board without realising it

Philosophy professor Helen Beebee says that it is possible to act freely and that we do not feel as if we are in a zombie-like state

The brain's posterior parietal cortex seems to have a role in planning and monitoring our actions

> Do we have free will? Yes, I believe we still do. It doesn't matter that we live in a deterministic universe in which the future is, in principle, fixed. That future is only knowable if we were able to view the whole of space and time from the outside. But for us and our consciousnesses, embedded within space-time, that future is never knowable. It is that very unpredictability that gives us an open future. The choices we make are, to us, real choices, and because of the butterfly effect, tiny changes brought about by our different decisions can lead to very different outcomes and different futures. So, thanks to chaos theory, our future is never knowable to us. You might prefer to say that the future is preordained and that our free will is just an illusion, but our actions still determine which of the infinite number of possible futures gets played out.

neuroscientists are saying hasn't come as a particular surprise to many.

"There's a great philosophical tradition, one which I am part of, which says that even if everything we do has a cause that can fully explain that it is going to happen, it's still perfectly possible to act freely. Before Libet, most of us thought there were prior causes anyway – we just didn't know what they were."

Beebee believes that a rounded look at human experience reveals that neuroscience is only part of the picture. "Say, for example, you looked at the last million years on a purely molecular level: you wouldn't see evolutionary processes, or animal behaviour. You'd have your story of how one thing led to another in terms of physics and chemistry, but you'd have missed out on some other very important stuff. If you look at the brain as a neurological machine, of course you're not going to find free will there, because it's not the level of description at which free will crops up."

**Jim Al-Khalili, physicist**

Writing in 2013

bit.ly/1aNFooC

"Why do we require determinism to be false to have control over our lives? None of us feel we have a gun to our head, are being coerced into making our cup of tea or are in the grip of some hypnotic, zombie-like state."

The real lesson from recent research on human consciousness and decision-making is that neuroscientists and philosophers alike know that we are not robots, emptily fulfilling pre-ordained roles. We know that to accommodate the infinitely rich experience of being human, the brain has infinitely complex processes, and that current research is only scratching the surface of the simplest of these. Deciding whether to push a button is one thing; deciding whether to marry someone is another thing entirely. The case against free will is definitely not proven. ■

SIMON CROMPTON is a science journalist, and a former health editor for both *The Times* and *The Daily Telegraph*

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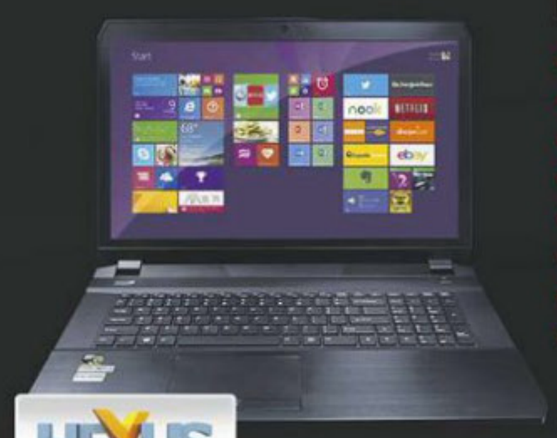


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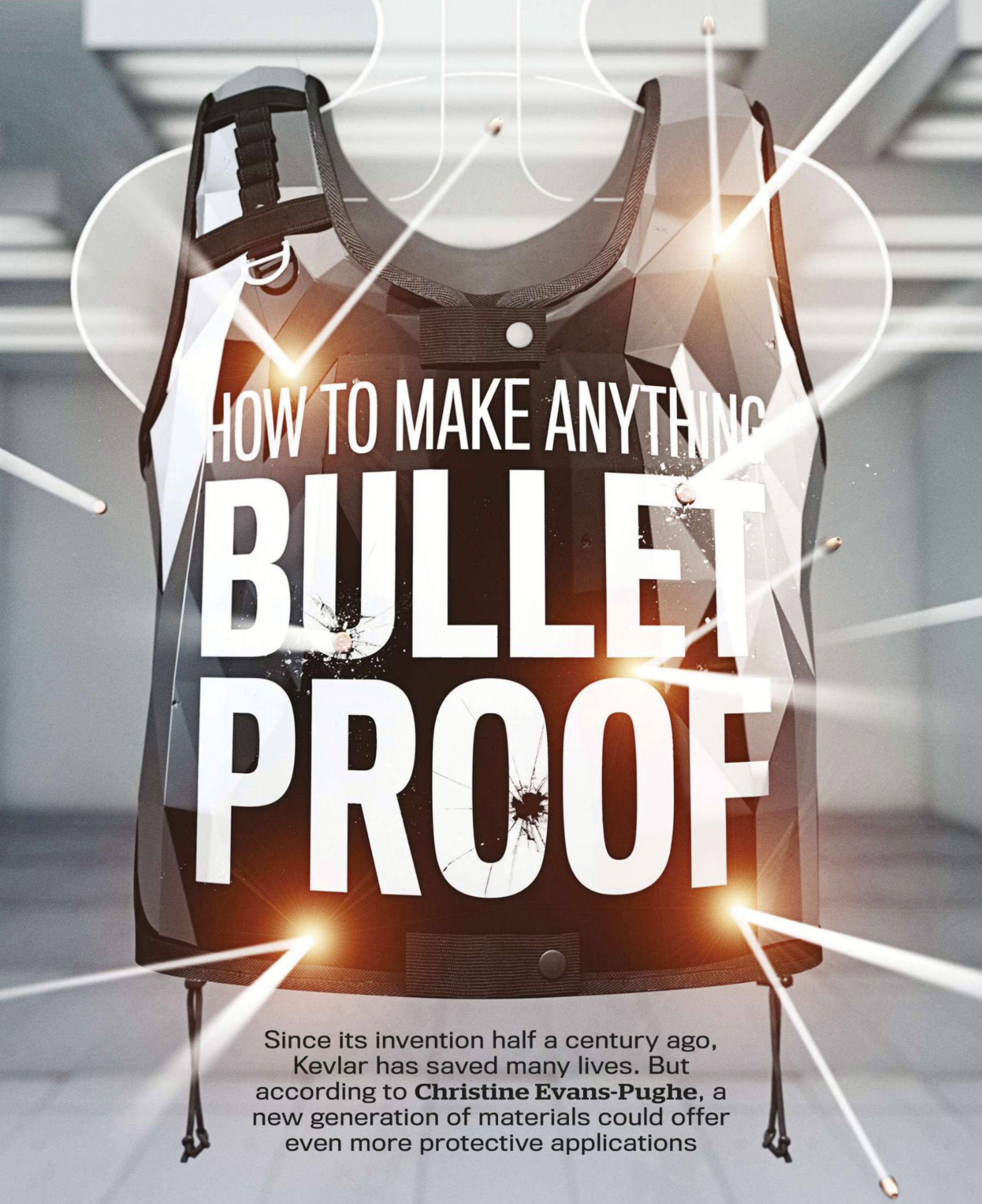


# HOW TO MAKE ANYTHING BULLET PROOF

Since its invention half a century ago, Kevlar has saved many lives. But according to **Christine Evans-Pughe**, a new generation of materials could offer even more protective applications

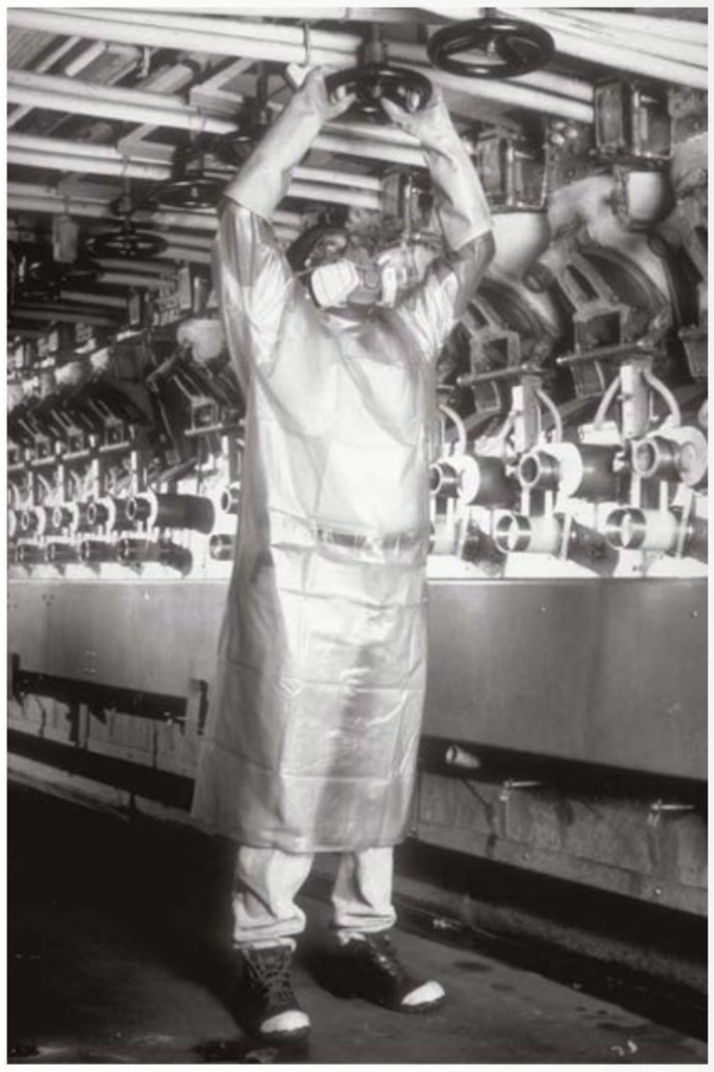
FIFTY YEARS AGO, a chemist working at DuPont in the US created a plastic that was light, flexible and seriously strong. In fact, Stephanie Kwolek had invented a substance that was five times stronger than steel of the same weight, making it tough enough to stop bullets and deflect blows from knives. Poly-paraphenylene terephthalamide, or Kevlar as it is more commonly known, has since been used in everything from bulletproof vests to soldiers' helmets. It's even used for protective shielding on the International Space Station. But half a century since its creation, can Kevlar keep up with advances in science and engineering to retain its crown as the go-to protective substance? Or will a new generation of materials allow us to make anything bulletproof?

Kevlar is a polymer. Polymers are substances made from a large number of repeating units – monomers – that are joined together. In Kevlar, these monomers are arranged in ring-like structures similar to those seen in benzene. It is this structure that is key to the material's properties.

## BULLETS AND BENZENE

"Kevlar was revolutionary because the chemical structure of the polymer chains forces them to align in one direction," explains Asa Barber, Professor of Advanced Materials Engineering at the University of Portsmouth. "If you think of a tangle of rope fibres as similar to randomly arranged polymer chains, these are easy to pull apart. But once you arrange the rope fibres side-by-side, the structure has great strength. That's how Kevlar works. The bulky benzene groups are also part of the deal. It's like having a series of big knots hanging off the sides of a piece of string – the string cannot be flexible because they stop it from bending. These 'side groups' also force the main chain to be ordered in one direction."

But for a material to be resistant to bullets, it also needs to be able to absorb energy over a large volume in order to spread out the impact of the force. Kevlar is a stiff, low-density

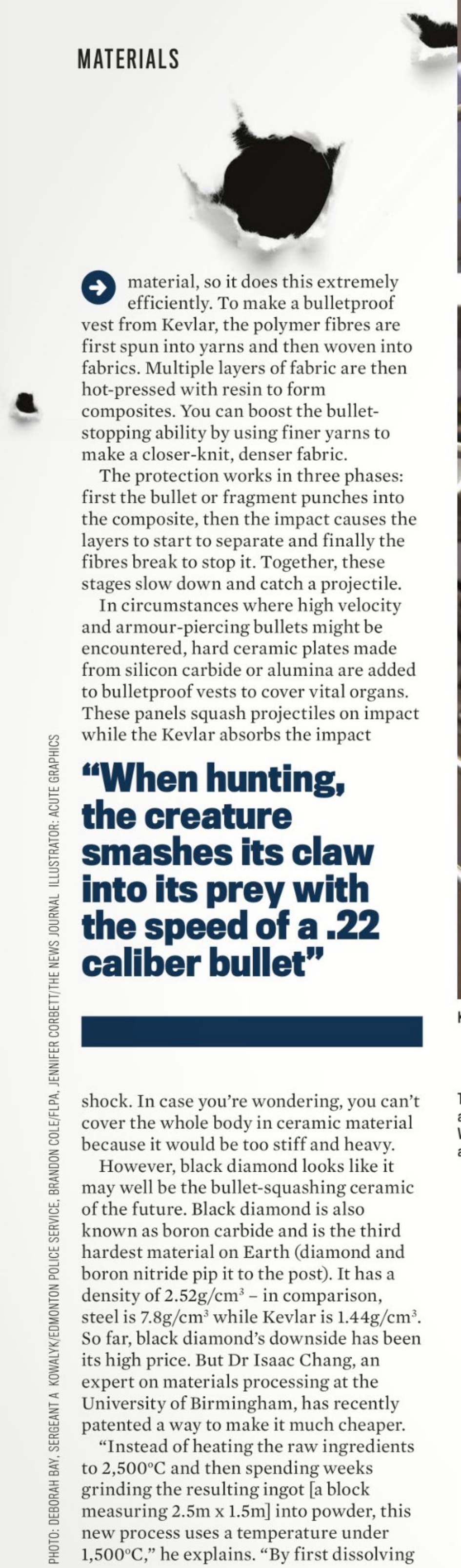


A DuPont worker adjusts the valve on a Kevlar spinning machine

KEVLAR IS FIVE TIMES STRONGER THAN STEEL OF THE SAME WEIGHT

Kevlar is lightweight, yet it can still protect soldiers from bullets, grenades and fires

PHOTO: DUPONT, GETTY ILLUSTRATOR: MAGIC TORCH



material, so it does this extremely efficiently. To make a bulletproof vest from Kevlar, the polymer fibres are first spun into yarns and then woven into fabrics. Multiple layers of fabric are then hot-pressed with resin to form composites. You can boost the bullet-stopping ability by using finer yarns to make a closer-knit, denser fabric.

The protection works in three phases: first the bullet or fragment punches into the composite, then the impact causes the layers to start to separate and finally the fibres break to stop it. Together, these stages slow down and catch a projectile.

In circumstances where high velocity and armour-piercing bullets might be encountered, hard ceramic plates made from silicon carbide or alumina are added to bulletproof vests to cover vital organs. These panels squash projectiles on impact while the Kevlar absorbs the impact

**"When hunting, the creature smashes its claw into its prey with the speed of a .22 caliber bullet"**

Kevlar thread can be woven into fabric to make light and strong body armour

shock. In case you're wondering, you can't cover the whole body in ceramic material because it would be too stiff and heavy.

However, black diamond looks like it may well be the bullet-squashing ceramic of the future. Black diamond is also known as boron carbide and is the third hardest material on Earth (diamond and boron nitride pip it to the post). It has a density of 2.52g/cm$^3$ – in comparison, steel is 7.8g/cm$^3$ while Kevlar is 1.44g/cm$^3$. So far, black diamond's downside has been its high price. But Dr Isaac Chang, an expert on materials processing at the University of Birmingham, has recently patented a way to make it much cheaper.

"Instead of heating the raw ingredients to 2,500°C and then spending weeks grinding the resulting ingot [a block measuring 2.5m x 1.5m] into powder, this new process uses a temperature under 1,500°C," he explains. "By first dissolving

To make a tougher vest, layers of Kevlar fabric and resin are hot pressed to form composites. When struck by a bullet, these layers separate and the fibres break, which slows the bullet

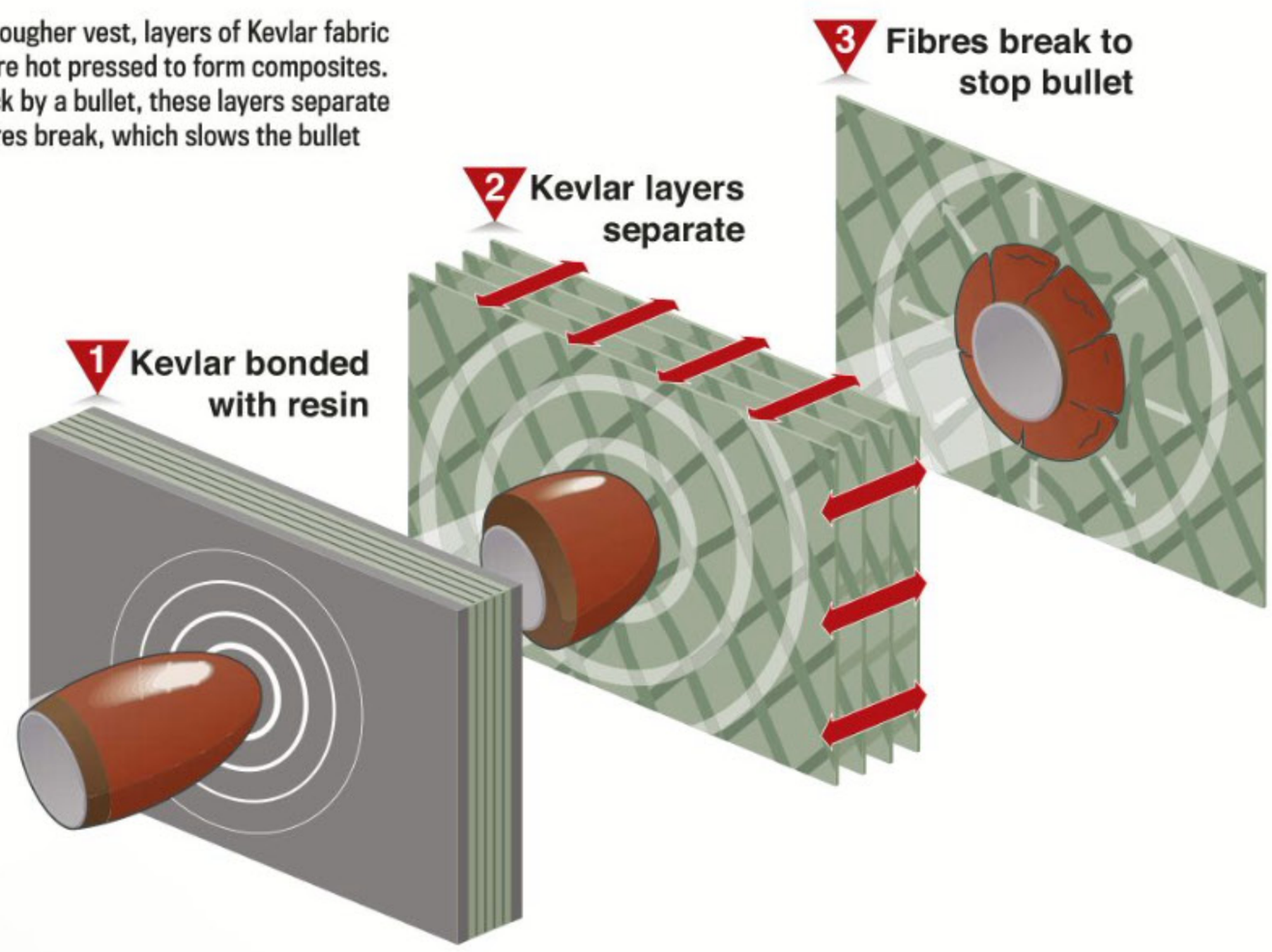
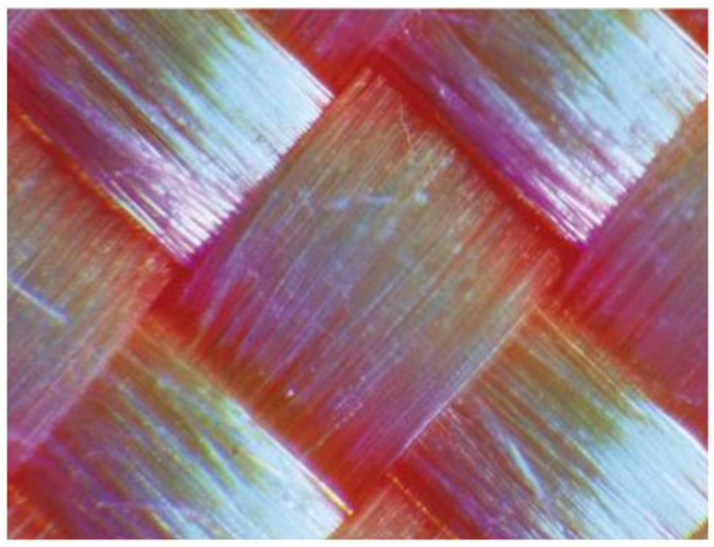
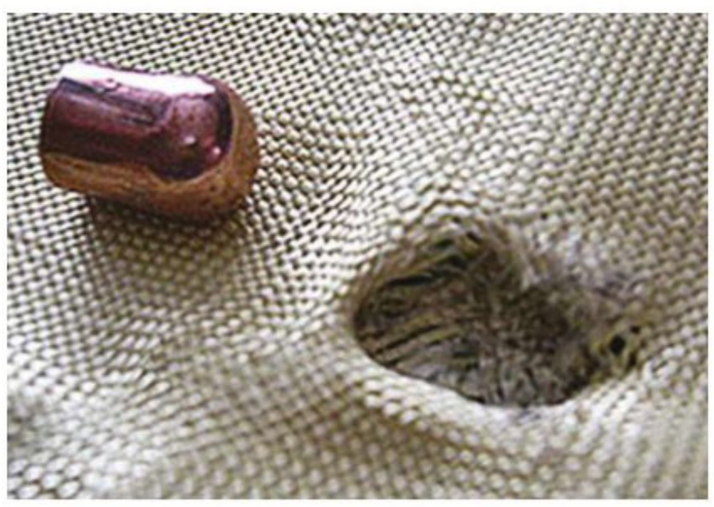



PHOTO: DEBORAH BAY, SERGEANT A KOWALYK/EDMONTON POLICE SERVICE, BRANDON COLE/FLPA, JENNIFER CORBETT/THE NEWS JOURNAL ILLUSTRATOR: ACUTE GRAPHICS



Kevlar fibres woven into fabric

Hagfish slime is being researched as a Kevlar successor



Imagine what this bullet could have done...

## THE BIRTH OF KEVLAR

One chemist's discovery is used for body armour, motorcycling clothing and even oven gloves

Stephanie Kwolek's invention keeps soldiers safe, but also protects keen cooks from burns

US CHEMIST Stephanie Kwolek developed Kevlar in 1965 while working as a research scientist for DuPont. Kwolek specialised in low-temperature polymerisation, which is a process used to make plastics by linking together molecules known as monomers. During the early 1960s she was given the task of looking for a lightweight but durable fibre that could be used in the manufacture of tyres. Many of the materials she created were too unstable to remain for more than a few seconds. But one combination caught her eye when it turned into a cloudy fluid. This was in contrast to the clear, treacle-like form of most of the previously discovered polymers. When spun into a fibre, the material proved to be very strong. She realised at once that she had discovered something special. In 1971, her creation reached the market under the name Kevlar.

the ingredients into a special solution, we get a precursor material that when heated results in a ready-to-use powder."

He's currently working with the US Army Research Laboratory (ARL) and the UK's Defence Science and Technology Laboratory (DSTL) on developing and testing this material for ballistic use.

### FIERCE CREATURES

Designs inspired by the natural world are also looking like key players in the future of armour-plating. Prof Barber's group recently published work on goethite, which is an incredibly strong material found in the tiny teeth of limpets. Limpets rasp their strong teeth over rock surfaces to remove the algae on which they feed. The fibres of goethite are just the right size to make up a resilient, hardwearing structure, and could potentially be copied for use in high-performance engineering applications.

Another natural structure capable of resisting ballistic type impacts is the hammer-like claw of the peacock mantis shrimp. When hunting, the creature smashes its claw into its prey with the speed of a .22 caliber (diameter in inches) bullet. The crustacean's claw is made from an incredibly hard material and can withstand similar pressures to silicon carbide. However, it has the advantage that it can be formed at room temperature (or sea temperature...) rather than requiring the high temperatures of a furnace. The hammer has an impact region made of precisely aligned hydroxyapatite crystals. Behind this is an area of spiralling layers that act as shock absorbers. Each layer sits at a slightly different angle from the layer below and this helical structure prevents cracks from spreading. Last year, researchers at the University of California, Riverside, the University of Southern California and Purdue University received a $7.5m grant from the US Department of Defense to develop this work further.

A SINGLE HAGFISH CONTAINS HUNDREDS OF KILOMETRES OF SLIME THREAD

A number of research teams have also proposed novel successors to Kevlar. These substances are based on spider silk, graphene, nanocellulose and even the gloopy slime produced by a sea

# AMMO IN ACTION

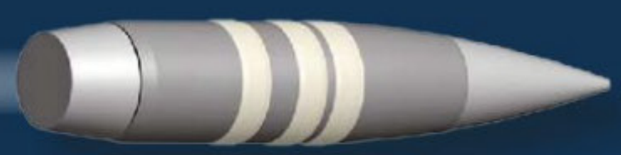
Some of the high-tech weaponry that Kevlar and other bulletproof materials are up against

### HOLLOW-POINT BULLETS

These have a cavity on the front that makes them expand when they strike an object, creating more damage than a round-nosed bullet. This fragmentation also decelerates the bullet to reduce the penetration depth. While hollow-point bullets are banned for military use, they are widely used by police and law enforcement agencies in Europe and the US as a way of instantly stopping hostile subjects.

### XM25

This 25mm grenade is designed to explode into fragments. It is aimed close to, rather than at, the target and a timed fuse tells it when to explode based on the calculations of a small computer located inside the grenade.



### EXACTO

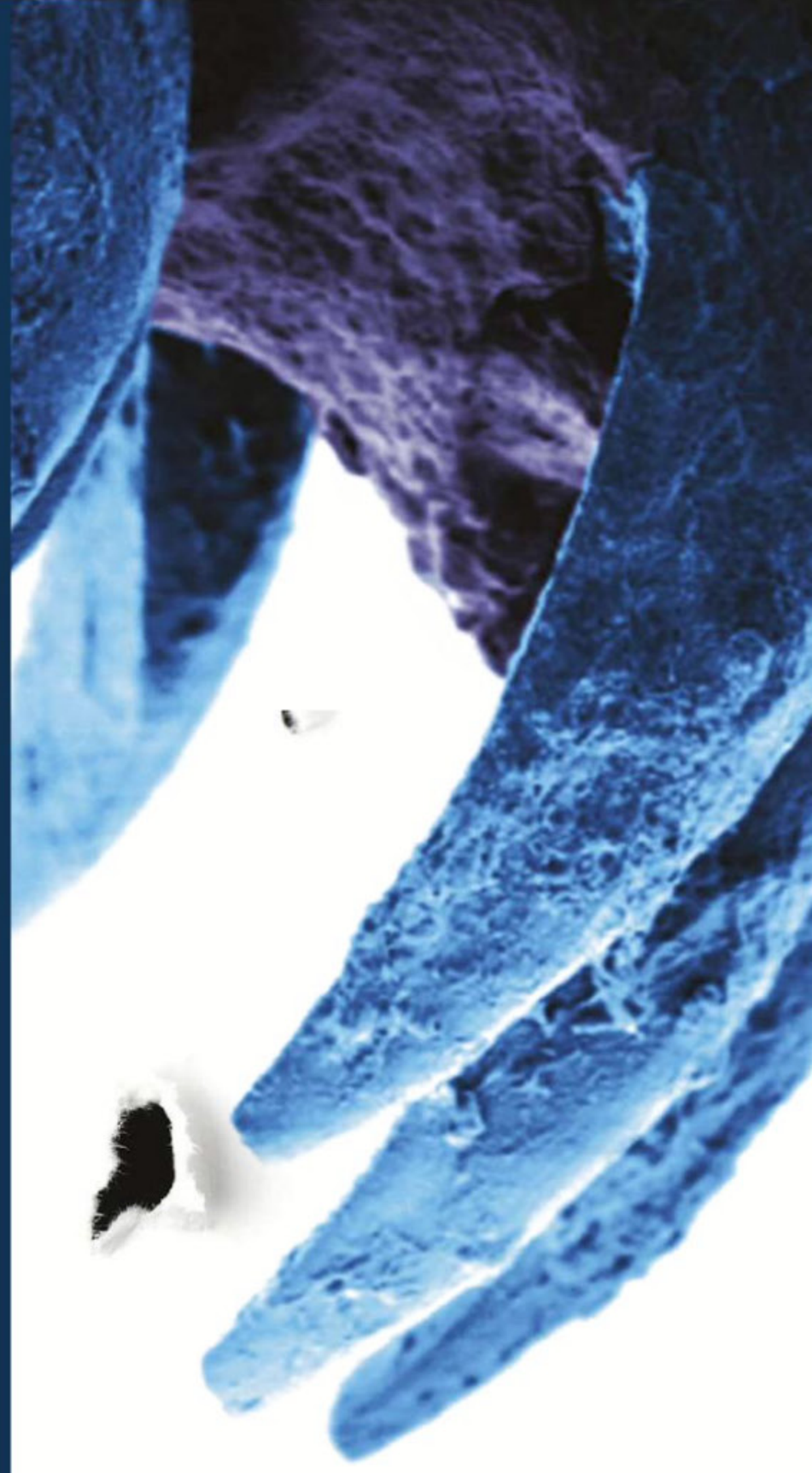
DARPA has developed this device for snipers. It uses a real-time guidance system to change its path and home in on a target. Inside the .50 caliber round is an 8-bit computer, which steers the device by moving small fins attached to its body.

### ARMOUR-PIERCING BULLET

These are generally created for rifles and pistols. They have a pointy penetrator that's usually made from tungsten, tungsten carbide or steel. The high-density material is designed to keep its shape to carry the maximum quantity of energy deep into the target.

### DEPLETED URANIUM BULLETS

These are pyrophoric, which means that they ignite spontaneously in air. They are self-sharpening on impact, resulting in intense heat and energy focused on a minimal area of the target's armour.



**"The project involves building computer models of all kinds of ballistic materials down to an atomic scale"**

creature called a hagfish. Nevertheless, it is ultra high molecular weight polyethylene (UHMWPE) that is gaining the most attention. UHMWPE is similar to the polymer used in plastic bags. But whereas the polymers in bags are arranged in a higgledy piggledy fashion, the fibres in UHMWPE are spun from a gel to stretch and align the strands. Made in this way, the material has a strength-to-weight ratio 8 to 15 times higher than steel, although one disadvantage is that it starts to break down at temperatures over 130°C.

UHMWPE could be made even stronger if the lengths and ends of these aligned polyethylene molecules (the fundamental building blocks of the fibres) were 'tidier', explains Lorenzo Iannucci, Royal Academy of Engineering Chair in multi-scale armour design and Professor in Advanced Aerospace Structural Design at Imperial College. "They currently look like curly spaghetti, which weakens the structure. Everyone is looking to gain better control of the mass production process to improve this. If this was possible, we could raise the strength of the fibres two-fold," he says.

Iannucci's laboratory has facilities to fire projectiles with speeds up to 1,400m/s, more than four times the speed of sound, using a gas gun. High-speed cameras take photographs at one million frames per second to show the progress of fragments and the damage they cause to a

**US MILITARY HELMETS CONTAINS 19 LAYERS OF KEVLAR**

Limpet teeth have to be strong to allow them to scrape rocks while feeding

sample – even as far as seeing the evolution of damage and individual shockwaves.

Iannucci is one of a number of British scientists working with the DSTL and ARL to design new protective materials for perceived future threats as far ahead as 2040. Dubbed MEDE (Materials in Extreme Dynamic Environments), the project involves building computer models of all kinds of ballistic materials – polymers, metals, and ceramics – right down to an atomic scale.

## DRESS TO IMPRESS

"We want to be able to simulate the performance of an entire ballistic vest based on models that came from information at an atomic level," explains ARL's Dr John Beatty, who is in charge of the MEDE project. In contrast, commonly used computer models of ballistic performance are currently based mainly on experimental data. This data comes from firing bullets at various materials rather than knowledge of how atoms behave.

Dr Isaac Chang has patented a cheaper way to make boron carbide

Beatty's researchers have recently made a breakthrough in developing fast and accurate equations for how individual atoms in polymers interact. This makes it feasible to simulate millions of polymer atoms interacting at once on a computer. Previously, it was only possible to look at roughly a thousand atoms in this way.

"These new models seem very accurate when we compare them with quantum mechanical calculations as well as with experimental data," says Beatty.

The US Army Research Laboratory's own polymer processing plant will be starting up this year. In 10 years, Beatty expects to have developed the fundamental science for designing most classes of protective materials. But what of the threats Beatty and his colleagues are expecting to be combatting in 2040? They're classified. ■

**CHRISTINE EVANS-PUGHE** is a science and technology journalist who has written for *The Guardian* and *The Economist*

PHOTO: DARPA, US ARMY, GETTY, UNIVERSITY OF PORTSMOUTH, UNIVERSITY OF BIRMINGHAM

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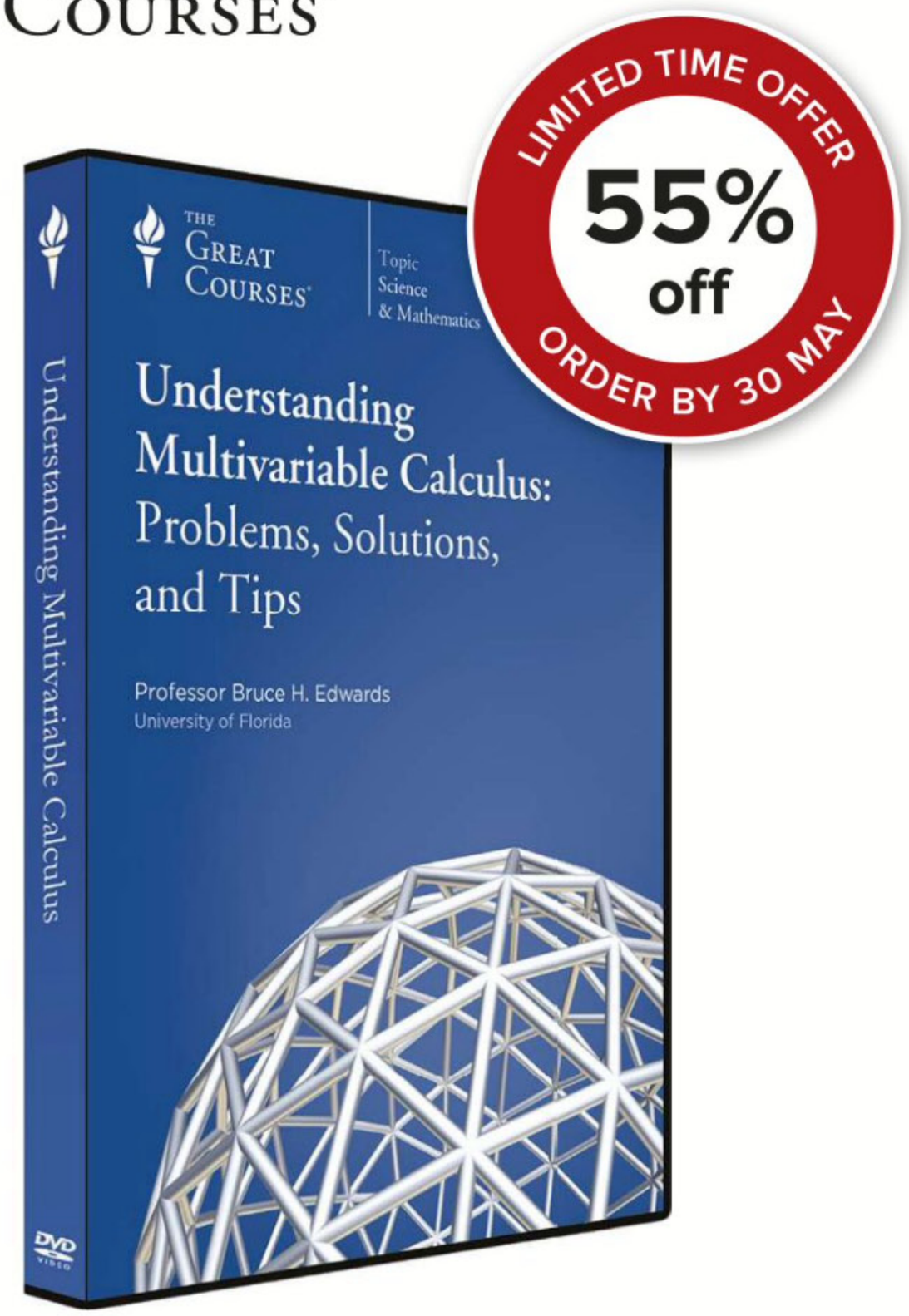


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18. Applications of Lagrange Multipliers
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20. Double Integrals and Volume
21. Double Integrals in Polar Coordinates
22. Centers of Mass for Variable Density
23. Surface Area of a Solid
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25. Triple Integrals in Cylindrical Coordinates
26. Triple Integrals in Spherical Coordinates
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28. Curl, Divergence, Line Integrals
29. More Line Integrals and Work by a Force Field
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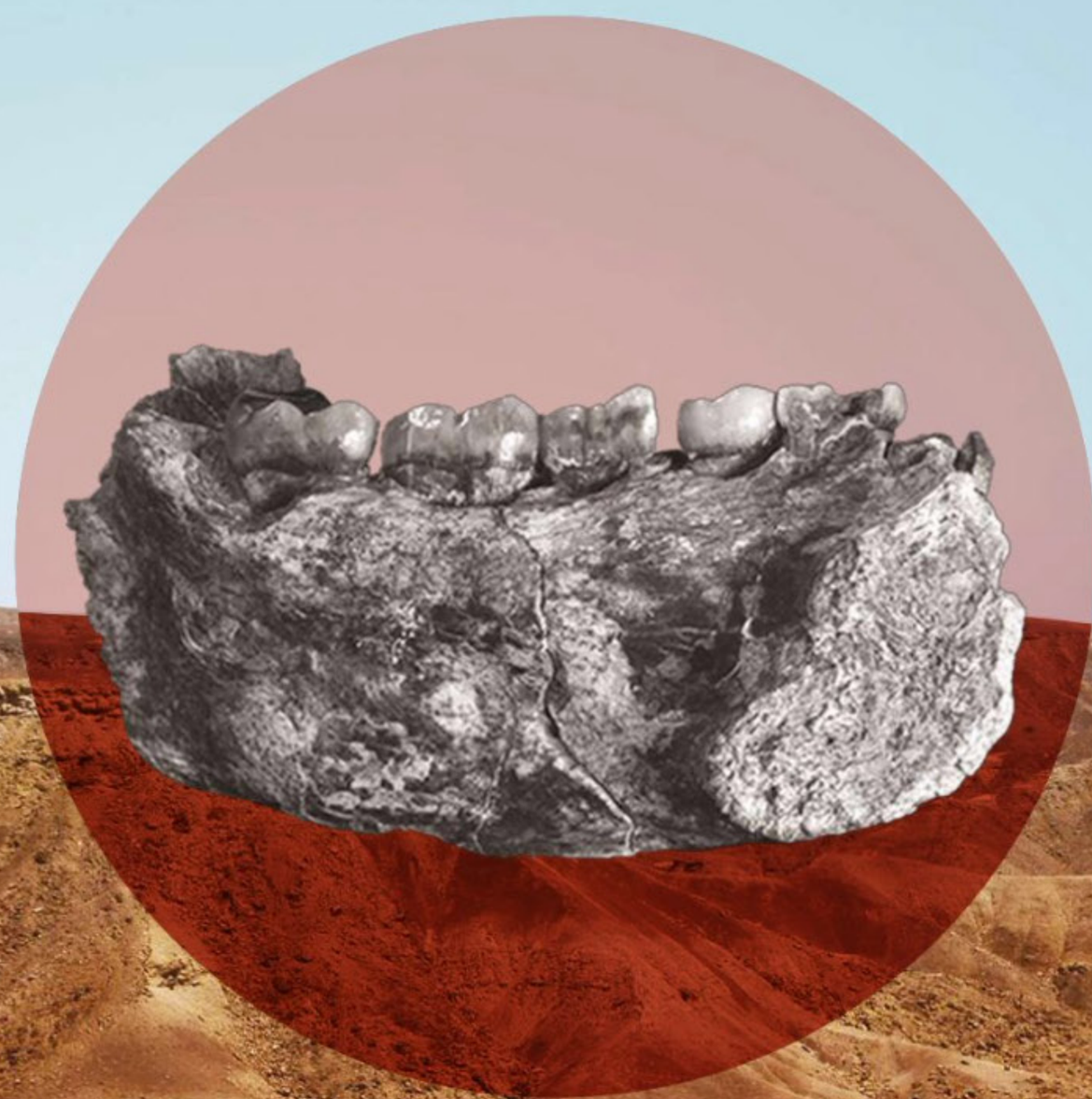
# UNCOVERING THE BIRTH OF MODERN HUMANS

A fossil found in Ethiopia could push the emergence of the *Homo* genus back by half a million years. **Prof Chris Stringer** digs into our history



ONE MORNING IN January 2013, Chalachew Seyoum, a graduate student in anthropology at Arizona State University, made an astonishing chance discovery. He was walking up a plateau during a field trip to the Ledi-Geraru research area in Ethiopia's Afar region when he noticed a jawbone poking out of the sediment. Something about it caught his eye so he went over to uncover it, and knew he'd spotted something fantastic. His enthusiasm was justified: in March 2015, researchers studying the fossil announced in the journal *Science* that the bone is around 2.8 million years old.

PHOTO: ARIZONA STATE UNIVERSITY X2

To the untrained eye, the jawbone doesn't look like anything special: it's a few centimetres long and has five teeth jutting out of it. However, it appears to combine primitive and more evolved features. At the front, its chin region is thick and receding. This is similar to the earlier and possibly ancestral species *Australopithecus afarensis* that lived 2.9 to 3.9 million years ago (the most famous example of which is the 'Lucy' skeleton found in Ethiopia in 1974). However, further towards the back the jaw becomes more human, in the shape of its premolar and molar teeth and in its reduced thickness. This suggests it is a form of *Homo*, and that this creature was changing its diet and behaviour in ways that made it more like those of later humans.

## A TIME OF TRANSITION

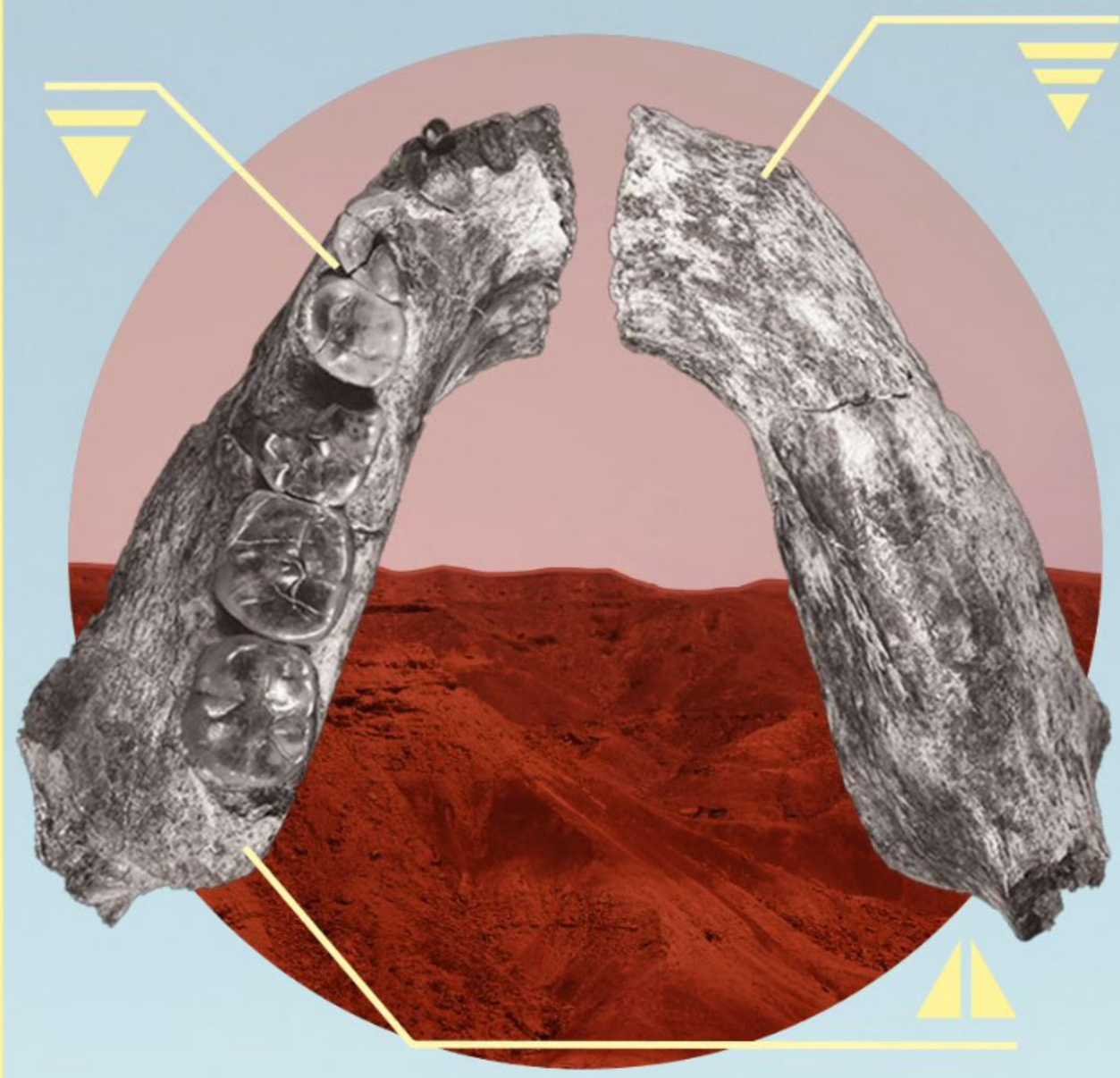
Associated evidence indicates the new find comes from a drier, more open environment than was typical for Lucy's species, so perhaps these earliest known humans were moving into more open country. William Kimbel, Director of Arizona State University's Institute of Human Origins, thinks the find helps narrow the evolutionary gap between *Australopithecus* and early *Homo*. "It's an excellent case of a transitional fossil in a critical time period in human evolution," he says.

But how certain are we that this fragmentary jawbone represents a human, and where might the fossil fit in the bigger picture of our origins? Human skeletons are characterised by small jaws and teeth, and large brains and long legs. This corresponds with our behaviour of toolmaking and meat-eating. The Ledi jaw may look human in the parts preserved, but, thanks to the absence of a more complete skeleton, we cannot determine its brain size and leg length. We can only guess as to whether it was making tools or eating meat.

We have to move on another million years after the Ledi jaw before we can be confident that all those features were in place, with the species *Homo erectus*, known from East Africa and from Dmanisi in Georgia. Puzzlingly, living alongside *Homo erectus* in Africa there were two other species of human, *Homo habilis* and *Homo rudolfensis*, known from less complete fossil remains. Although it is less clear how like modern humans these other human species were in body shape, new studies suggest that both had relatively small teeth and jaws, and variably-sized brains.

"Sophisticated statistical analyses reveal differences in the shape of the jaw between these early human species that are sometimes as large as the differences between humans and chimpanzees," reports researcher Dr Philipp Gunz from the Max Planck Institute for Evolutionary

## KEY FEATURES



**MOLARS AND PREMOLARS** are similar in shape to those found in a modern human.

**THICK SLOPING CHIN** similar to *A. africanus*, an extinct hominid thought to be an ancestor or close relative of the genus *Homo*.

**SLIMMER REAR JAW** suggests the bone belonged to an early form of the genus *Homo*.

Prof Brian Villmoare, co-author of the paper published in *Science*, studies the Ledi jawbone

PHOTO: ARIZONA STATE UNIVERSITY, ALAMY, X2, WIKI COMMONS, GETTY, W JUNGERS, AARON MAYES/UNLV PHOTO SERVICES

# TIMELINE OF ANCIENT REMAINS

**1.8** million years old

### OLDUVAI HOMINID 7
A lower jaw, skull and hand bones from *Homo habilis* were found in Olduvai Gorge, Tanzania in 1960

### KNM-WT 15000
A skull and partial skeleton of 'Turkana Boy', a *Homo erectus*, were found in Nariokotome, Kenya in 1984

**1.5** million years old

**850,000** years old

### ATD 6-5
A lower jaw from a type of *Homo* antecessor was found in Gran Dolina, Spain in 1994

### TRINIL 2
A skull cap from a type of *Homo erectus* was discovered in Trinil, Java in 1891

**700,000** years old

**600,000** years old

### MAUER 1
A lower jaw from a type of *Homo heidelbergensis* was found near Heidelberg, Germany in 1907

### BROKEN HILL 1
A type of *Homo rhodesiensis* was found in Zambia in 1921. Some believe it is the same species as *H. heidelbergensis*

**300,000** years old

**45,000** years old

### FELDHOFER 1
A skull cap and partial skeleton of a type of *Homo neanderthalensis* was found in Neander Valley, Germany in 1856

### LB 1
A skull and partial skeleton from a type of *Homo floresiensis* was found in Liang Bua Caves, Indonesia in 2003

**30,000** years old

Anthropology in Leipzig, Germany. So how do these different forms of early human relate to each other, and how did they evolve?

## A SINGLE ANCESTOR?

This brings us to a crunch question, the answer to which could undermine the claim that all of these different species were truly human. Is the diversity we see in East Africa 1.8 million years ago the result of evolution from a single ancestral form of *Homo*, such as the Ledi jaw, or could these different *Homo* species have evolved in parallel from separate, Australopithecine-like ancestors?

**"COULD THESE *HOMO* SPECIES HAVE EVOLVED IN PARALLEL?"**

It's important to note at this point that Lucy's species was not alone in East Africa 3.5 million years ago. There was also another pre-human form called *Kenyanthropus platyops*. *Kenyanthropus* had distinctively high cheekbones, like the famous '1470' skull from Kenya – the type specimen of *Homo rudolfensis*. So some experts think that *Kenyanthropus* could represent a potential ancestor for *Homo rudolfensis*, while *Australopithecus afarensis* and the Ledi jaw might trace a lineage leading to *Homo habilis*.

So where did *Homo erectus* come from? There is a 2.3 million-year-old upper jaw from Ethiopia – AL666-1 – which looks most like *Homo erectus*, and could indicate a third ancient line of evolution to *Homo*. Tracing that line back in time to about three million years ago could reveal the true origins of the genus *Homo*, and might sideline the other claimed early human lineages. If, around three million years ago, several different kinds of Australopithecines started to spend more time on the ground, walking upright for longer and longer distances and taking up regular toolmaking and meat-eating, could this have driven the evolution of human-like features, in parallel, in different parts of Africa from distinct ancestors? Perhaps another fortuitous find will bring us a step closer to the answer. ■

PROF CHRIS STRINGER is Research Leader in Human Origins at the Natural History Museum, London

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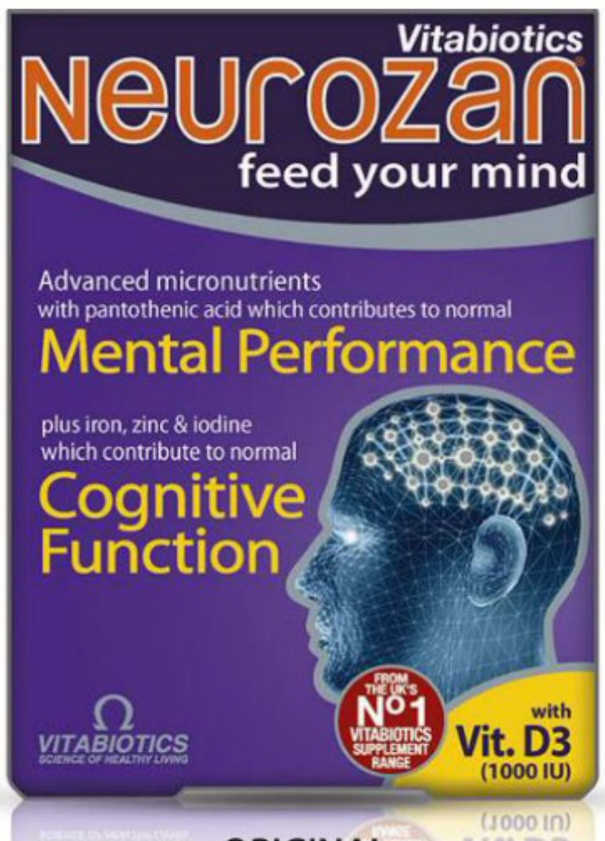


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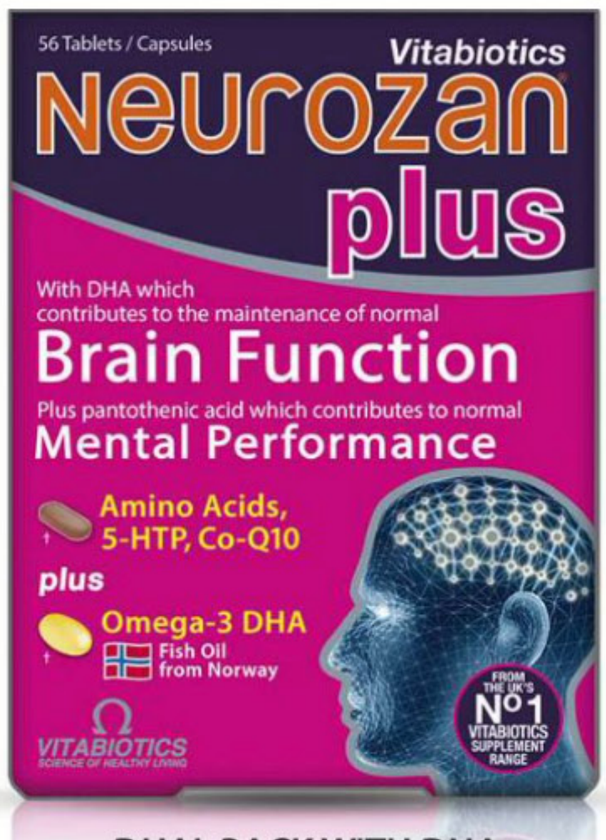


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# TRUTH WILL OUT

In a new book, a former CIA officer reveals how to get anyone to tell you the truth. **Jo Carlowe** uncovers the tricks of the trade...

SOCIAL PSYCHOLOGIST Jerald Jellison famously claimed that humans are lied to 200 times a day. Little wonder, then, that reams have been written on how to spot a liar. But what do you do if you think someone has told you a fib? How do you convince them to tell you the truth when it may be in their best interest to lie? Well, former CIA officer Philip Houston, co-author of *Get The Truth*, believes he knows how.

In his 25-year career with the CIA, working as both an investigator and a polygraph examiner, he has eked confessions from some of the most entrenched liars, including terrorists and spies. And he says the techniques he uses in real-life counterterrorism and criminal investigations are applicable to all of us in our daily lives. There are methods that we can use in real-life situations to get a partner to admit to an infidelity, or a child to confess to a misdemeanour.

Surprisingly, the way to the truth has its roots not in relationship psychology, but in the science of persuasion. We obtain the truth by getting people to use short-term thinking. A shopping channel presenter, for example, will never say, "pick up your chequebook" because that will get viewers

thinking about their finances (or lack of them). Instead, they will say, "pick up the phone". Likewise, agents in pursuit of the truth will do everything in their power to stop you thinking about the long-term consequences of your actions. And both salespeople and investigators use a 'sales pitch' to get you to switch focus away from your own goals and onto theirs.

## SELL THE TRUTH

In the case of the criminal investigator, the 'sales pitch' is actually the interrogation. This differs from the initial interview, which is a dialogue in which the investigator asks questions and the suspect responds. By contrast, the interrogation is a monologue in which the investigator does most of the talking. It is akin to the marketer's sales pitch, but instead of a product, the investigator is selling the idea that telling the truth is the only way forward.

"The interview is often not effective because each question is another opportunity to lie. With every lie the person tells, they become more psychologically entrenched [committed] in maintaining the lie," Houston explains.

To overcome this, the interrogator can switch to a monologue to lead the person into short-term thinking, causing them to become temporarily more focused on the rationale provided in the monologue than the long-term consequences.

"If a person is truly thinking clearly and logically, they should never confess – confession is a losing proposition for them," admits Houston. "When we are training law enforcement officers, we often joke that in the interrogation, they have to become an 8ft x 10ft [2.4m x 3m] condominium salesman. That is extremely difficult real estate to sell, but the concept of short-term thinking is so psychologically powerful that it makes their monologue effective and successful."

The methods are universal and can be used to elicit the truth from anyone – not just hardened criminals. And it turns out that the truth is not so hard to reach, because humans actually like to unburden themselves. Indeed, a Canadian neuroimaging study from 2014 revealed that our cortical reward system is more active when telling the truth than when

Beating up suspects and instilling fear is not an effective way to achieve a truthful confession

**"The more you question someone who is lying, the more psychologically committed to their lie they become"**

Philip Houston, former CIA officer and co-author of *Get The Truth*

Know someone is lying? You might not need to dust off the old polygraph machine to get a confession

PHOTO: ISTOCK, GETTY

## WHAT MAKES SOMEONE MORE LIKELY TO LIE?

### THEIR SOCIAL CLASS

US scientists have found that the upper classes lie more in negotiations and cheat to win money more than the lower classes. When asked about values, the upper class participants had more favourable attitudes towards greed, which may go some way to explain the correlation between social nobility and ethical ignobility.

### THEY ARE PRESSURED FOR TIME

Psychologists asked participants to roll a die and to report the result to determine their pay. Those given a short amount of time to report the outcome were more likely to lie. Experts suggest that when given more time, individuals are unable to inwardly justify lying and so they tell the truth.

### THEY WERE RAISED BY LIARS

Children lied to by adults are also more likely to lie. In one study, children were told there were sweets in another room. When the kids discovered there weren't any sweets, they were more likely to cheat and lie in a subsequent task than children who were not lied to at the outset.

### IT'S THE AFTERNOON

We are more likely to lie in the afternoon than the morning. Studies show that we are 20 to 50 per cent more likely to be dishonest in the afternoon, by lying and cheating more in various tasks. Experts put this down to 'psychological depletion' – as the day wears on we become cognitively weaker.

### THEY WANT PEOPLE TO LIKE THEM

Studies show that 60 per cent of people lie at least once during a short conversation with someone new and on average tell two to three lies. Women are more likely to lie to make the other person feel good, while men are more likely to lie to make themselves look better.

During his 25-year CIA career, Philip Houston extracted confessions from seasoned spies and terrorists

lying. In other words, we get more satisfaction from being honest.

"We tap the very same principle in every interrogation scenario we encounter, whether the aim is to get a terrorist to disclose the details of a bomb plot, a serial killer to confess to a murder or a child to admit they didn't do their homework," says Houston. The key to success is to transfer to the monologue the moment you are confident that you are not being told what you need to know.

"Remember, the more you question someone who is lying, the more psychologically committed to their lie they become," warns Houston.

### GOOD COP

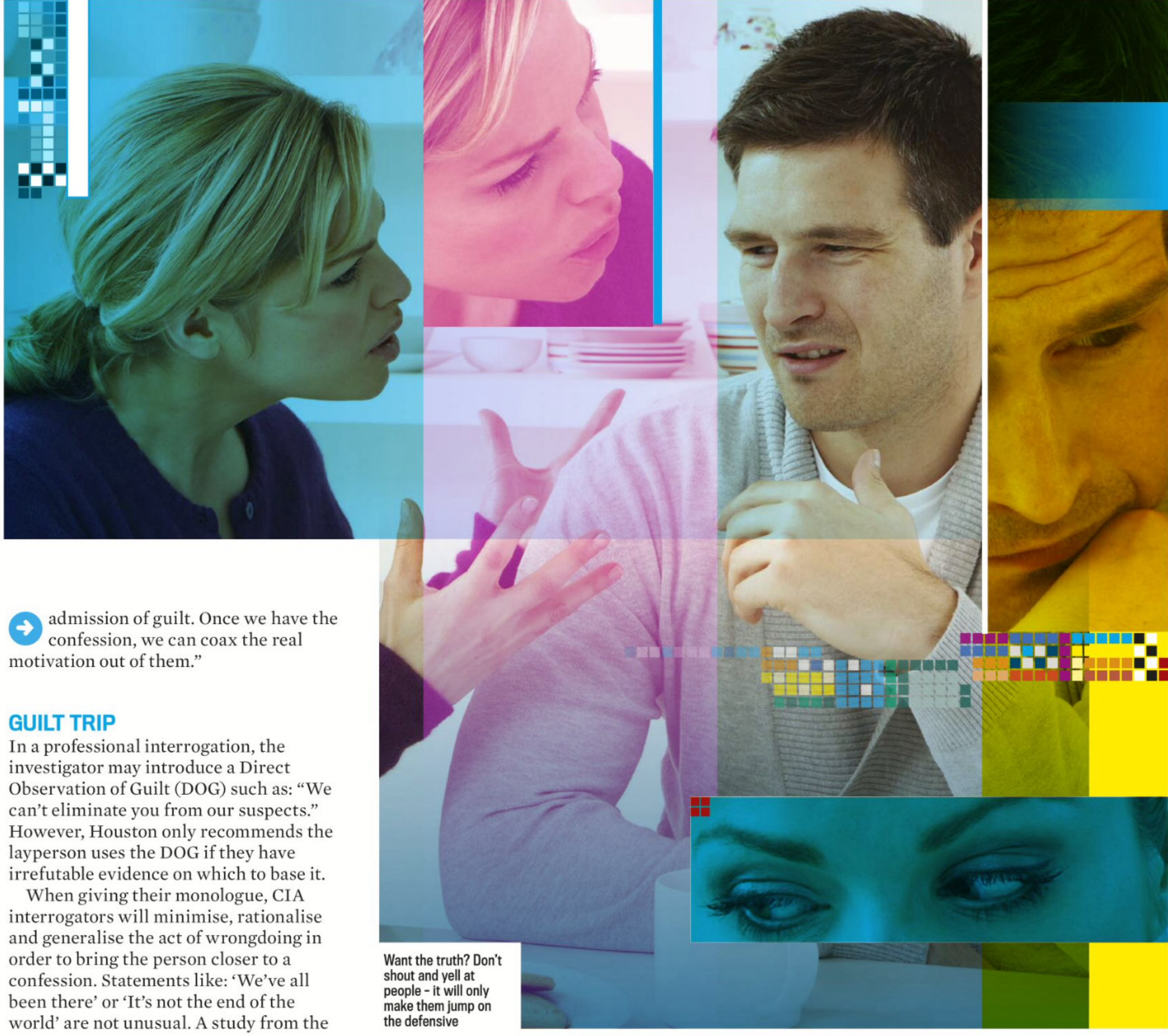
So how do you switch from a friendly dialogue into the more serious monologue? Houston recommends you make what's known as a 'transition statement' that is a Direct Observation of Concern (DOC), an example being: "Something is clearly on your mind."

"The DOC is critical. It sends the simple message in a non-adversarial tone that everything the person has done to try to get away with the act of wrongdoing has failed. It psychologically orientates the person's thinking to the realisation that they need a new game plan, and the interrogator is perfectly positioned to provide that game plan via their monologue." In essence it says: 'You have failed so don't think your way any more – think my way'.

In the 'interrogation phase' it is more effective to use statements rather than questions. "If you ask a question, it signals that you still don't know if they're guilty, so they still have a chance to convince you they're not," says Houston.

Statements suggest that the truth is a given. As more facts come into play, you can make your proclamations stronger. 'I know the who, I know the what, now I need to understand the why', is an especially useful statement.

"This particular approach is very effective because it causes the person to ask themselves 'why is the *why* so important?' The answer is often a realisation that the 'why' could influence the severity of the consequences," says Houston. "As a result, the person often initially fabricates or fudges on the 'why'. That's okay, because virtually any explanation of 'why' equals an



admission of guilt. Once we have the confession, we can coax the real motivation out of them."

## GUILT TRIP

In a professional interrogation, the investigator may introduce a Direct Observation of Guilt (DOG) such as: "We can't eliminate you from our suspects." However, Houston only recommends the layperson uses the DOG if they have irrefutable evidence on which to base it.

When giving their monologue, CIA interrogators will minimise, rationalise and generalise the act of wrongdoing in order to bring the person closer to a confession. Statements like: 'We've all been there' or 'It's not the end of the world' are not unusual. A study from the University of Montreal's School of Criminology found that methods such as minimisation are effective at getting suspects to open up. Houston believes these techniques are permissible but must be tailored to suit the seriousness of the situation and likely outcome.

Want the truth? Don't shout and yell at people – it will only make them jump on the defensive

**"Lessening of fear by relying on the monologue and short-term thinking is more powerful and effective than instilling or increasing the fear"**

Philip Houston, former CIA officer and co-author of *Get The Truth*

"I would encourage parents to avoid using minimisation to the degree that they leave their child feeling they have been hoodwinked. They also don't want to leave their child with the impression that this is how normal life is handled. This approach is reserved when there is significant deception and the truth is critical to resolution," he says.

Unlike Houston, few of us will be faced with situations in which getting to the truth is critical to national security, but there will be plenty of other times when these methods can come in handy. Some useful transition statements to elicit the truth in your personal life include the following:

**1.** You suspect your partner of cheating on you. 'Everyone makes mistakes, we're all human, we all make mistakes. What determines the future is not the mistake but how one handles it.'

**2.** You suspect your child of hiding something from you. 'Before you say anything, you need to understand that I need the whole story here. Anything less isn't going to work.'

**3.** You feel a colleague has been deceptive. 'I understand how things happen,

PHOTO: ISTOCK X4

## 5 STEPS TO GET ANYONE TO TELL YOU THE TRUTH

### 1 KEEP THEM IN SHORT-TERM THINKING

You need the person not to dwell on the consequences of their actions, otherwise they'll worry about job loss, divorce etc. To achieve this, minimise the seriousness of the situation with statements such as: 'It's not the end of the world' or 'It's a fixable problem'.

### 2 SOCIALISE THE SITUATION

Make the person feel that there are others in the same boat, so they don't feel isolated. This can be done with a monologue that includes statements such as: 'It's nothing I haven't dealt with before' or 'In our world, this is the sort of thing that happens all the time'.

### 3 FOCUS THEM ON TELLING THE TRUTH RATHER THAN ON THE ACTION ITSELF

The person needs to be convinced that the only way out of their current predicament is to be completely truthful to you. Here is an example of a useful statement: 'This is a fixable problem. To fix it, we need to get everything onto the table. That's the only way'.

### 4 MAKE A DIRECT OBSERVATION OF CONCERN

Ask questions such as: 'Something is clearly on your mind' or 'Help me understand what I am missing'. With more facts, make the transition to a direct observation of guilt: 'I know the what and the who, but I need to know the why'. Or stronger still: 'Based on the facts, it is clear you did it'.

### 5 SLOW YOUR SPEECH, TALK SOFTLY AND BE POLITE

If you rant, the person will focus on your behaviour rather than their own and become resistant. Choose your words carefully. For example, 'you took' rather than 'you stole', otherwise you'll conjure fears of job loss or prison and the person will quickly become defensive.

however, it would be really helpful for me to have real and candid feedback regarding this situation.'

In all cases, the statement has to be delivered in a respectful and low-key manner. Houston says that we should 'SEL' ourselves if taking this approach. That means **S**low your rate of speech, **E**ngage by orientating your body and your focus on the person (but not in a challenging way) and **L**ower your voice by speaking softly.

In short, what you are doing is compelling the other person to move from wanting to deceive you to feeling compelled to tell you the truth. And it is all done without threats or violence.

In recent years, the CIA has been accused of using much more brutal methods in its interrogations, particularly with al-Qaeda suspects following the September 11 attacks.

'Good cop' CIA techniques can help you extract the truth from anyone... no matter how young

### TORTURE TRUTHS

Torture is prohibited under the Geneva Conventions and in international human rights laws. But perhaps the greatest argument against torture is its ineffectiveness. In December of last year, The Senate Intelligence Committee concluded that the CIA's 'enhanced interrogation techniques' produced either no intelligence or 'fabricated information' that resulted in faulty intelligence.

"The lessening of fear by relying on the monologue and short-term thinking is more powerful and effective than instilling or increasing the fear," agrees Houston.

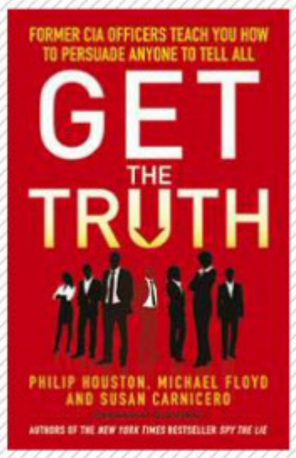
Indeed, the notion that good cop is better than bad cop is supported by science. A study by Michel St-Yves and Nadine Deslauriers-Varin from the University of Montreal's School of Criminology found suspects were more likely to confess if they had a good rapport with their interrogator. According to the researchers, getting criminals to admit their guilt is 'an art form' that relies on finesse rather than coercion.

Getting physical might elicit a confession of sorts, but it won't bring you the truth. Convincing a person through charm and guile will. ■

JO CARLOWE is a science journalist who writes for *The Times* and *The BMJ*

**Find out more**

***Get The Truth***
by Philip Houston, Michael Floyd and Susan Carnicero, Icon Books, £12.99



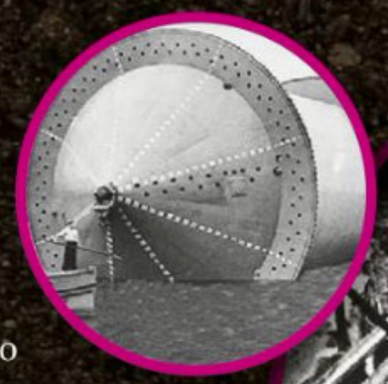
To listen to *The Truth And Nothing But The Truth*, visit **www.bbc.co.uk/programmes/b01sj1sy**

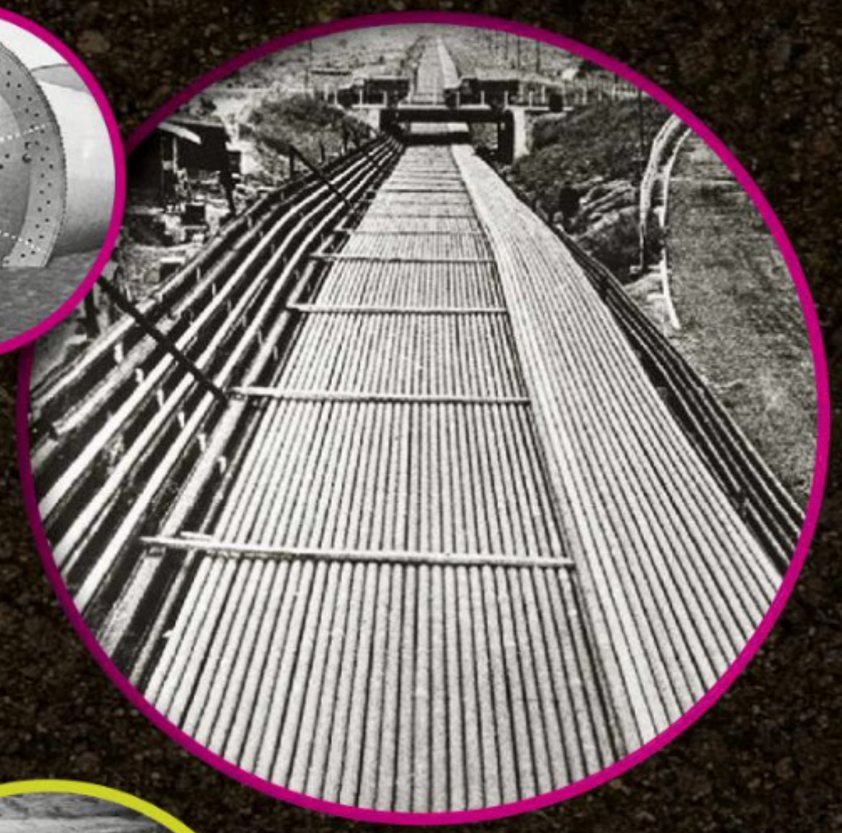
## 4

### Underground urban farm

**Location:** London
**Depth:** 33m

In an old air-raid shelter beneath the Northern Line, two Londoners are growing herbs and veg hydroponically – a method that requires no soil, with a mineral-rich solution, recycled water and low-energy LED grow lights providing the key ingredients for photosynthesis. After 18 months of testing, the duo plan to start supplying local businesses later this year. With stable temperatures and no need to deal with pests or the British weather, underground urban farms could help to reduce farm-to-plate food miles.





## 5

### Operation PLUTO pipelines

**Location:** English Channel
**Depth:** Up to 80m below sea level

During WWII, Allied troops in Europe needed a constant supply of fuel. Cue Operation PLUTO. This top-secret project removed the risk of tankers being hit by bad weather or German subs by bridging the English Channel with 7.5cm-wide steel pipelines laid on the sea floor. In total there were 18 PLUTO pipelines, supplying up to 4,000 tonnes of fuel a day from pumping stations dotted along the English coast, disguised as houses and ice cream shops.

## 6

### Art treasure trove

**Location:** Blaenau Ffestiniog, Wales
**Depth:** 150m

The film *The Monuments Men* is based on the true stories of how priceless artefacts were stashed away during WWII. In the UK, the National Gallery hid its valuable paintings in a disused slate mine in Blaenau Ffestiniog, Wales. Being stored deep underground had its benefits: as humidity and temperature varied less than above ground, art historians were able to study how the collection fared in more stable conditions.

## 7

### Mines under the sea

**Location:** Land's End, Cornwall
**Depth:** Up to 640m below sea level

As the Industrial Revolution brought mechanised tools, miners dug deeper than ever before. Just off Land's End, three tin mines created a labyrinth of tunnels extending under the Atlantic Ocean, where miners toiled in 30°C heat at depths from 12m to 550m below the seabed. Since the falling price of tin closed the mines in 1990 they have flooded, but there's talk of draining them.

JHENI OSMAN is a science writer, author and presenter. Her books include: *The World's Great Wonders*

BBC TWO
Don't miss Britain *Beneath Our Feet* coming soon to BBC Two

PHOTO: ALAMY X6, GETTY X4, ZERO CARBON FOOD X2, GEEVOR TIN MINE

# BRITAIN BENEATH OUR FEET

An upcoming BBC programme goes on a subterranean mission to reveal a world of secret bunkers and hidden railways

## 1 Mail rail

**Location:** London
**Depth:** 21m

Deep below the streets of London lies a forgotten railway. It's not part of the Tube, but a whole separate subterranean rail system, stretching 10.5km from Paddington to Whitechapel. The Post Office Railway opened in 1927 to speed up delivery between sorting houses, as the roads had become clogged with traffic. In its heyday, driverless electric trains transported 12 million items a day along the 2ft (610mm) narrow-gauge track. It closed in 20013, but a 1km section is due to open to the public in 2020.

## 2 German underground military hospital

**Location:** Guernsey, Channel Islands
**Depth:** 30m approx

Slave workers captured by German forces during WWII were set to work hacking away at solid rock to create this 7,000m² underground hospital and ammunition store, complete with its own subterranean reservoir. The largest construction in the Channel Islands, the only evidence of its existence above ground is some square holes which were used as escape shafts. Now open to the public, it's an eerie site to visit.

## 3 Burlington Bunker

**Location:** Corsham, Wiltshire
**Depth:** 30m

As the Cold War heated up, the government needed somewhere to evacuate 4,000 ministers and civil servants in the event of a nuclear attack. Completed in 1961, the 35-acre bunker – really more of a subterranean village – comprised offices, workshops, living quarters, kitchens, a laundry, an infirmary, a telephone exchange and store rooms. Battery-powered buggies were used to navigate its 16km of tunnels. Decommissioned in 1991 and declassified in 2004, it remains closed to the public.

# MICROBES ON THE MOVE

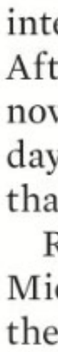
A new study paints a surprising picture of the microbes found around the home. **Tom Ireland** discovers that each family has their own personal zoo of bacteria...

HUMAN BEINGS ARE increasingly seen by scientists as walking microbial ecosystems. Our bodies contain up to 10 times as many bacterial cells as human ones, and we each deposit a unique blend of bacterial cells everywhere we go.

Microbiologists are only just beginning to understand how the trillions of organisms that live in and on our bodies affect our digestion, immune response and behaviour. And an emerging area of study is looking at how bacteria we deposit around us interact with the buildings we inhabit. After all, some studies suggest people now spend between 22 and 23 hours a day indoors – and nearly 70 per cent of that time is spent in our homes.

Researchers from the Home Microbiome Study recently assessed the microbial communities associated with seven families and their homes over six weeks, including three families that moved house. They found that we quickly spread our own 'microbial signature' throughout the places we live. By sequencing the DNA of bacteria in the home, the researchers were able to create a picture of the genetic diversity of microbes in each environment – its 'microbiome' – and compare how genetically similar bacteria were to those found elsewhere.

The bacterial flora of each household was so unique that researchers were able to accurately match individuals to their dwellings – even when their 'home' was in fact a hotel room they'd only recently moved into. Not only did all the houses contain very different bacteria from each other, the study also showed that when families moved, their microbial signature



ILLUSTRATOR: ROBIN BOYDEN

quickly re-established itself in the new location.

Simon Lax, a co-author of the study from the Department of Ecology and Evolution at The University of Chicago, says the reason our bacteria dominate the places we live is simply because there are few other routes by which bacteria enter those buildings. "Almost all of the bacteria in the home can be traced back to the inhabitants. If you have humans constantly coming into a home, then they are the most common source of bacteria," he says.

What's more, obsessive cleaners might want to rethink their strategy: the study suggests that the more people potter around the house cleaning, the more bacteria they deposit. The best thing they could do to reduce the amount of microbes in their homes, Lax says, is not be there. "When you think of what people's homes are made from, they are mostly relatively new materials that bacteria haven't evolved to live and thrive on. These homes would normally have quite a low bacterial biomass until someone comes in," he says.

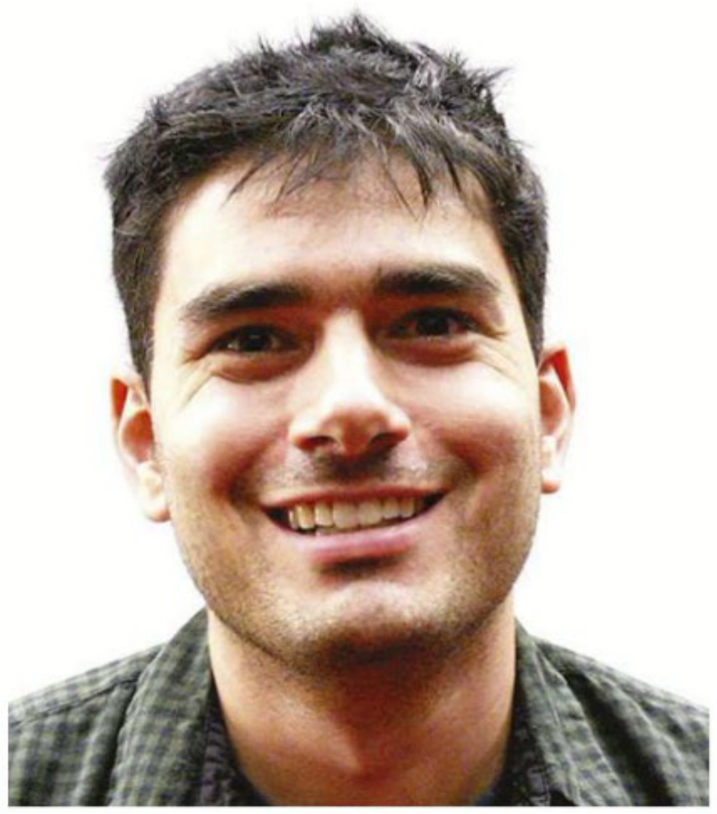
The idea of stepping into someone else's house, knowing it's teeming with the microbes of its inhabitants, may be unsettling to some. The way we constantly share microbes with people is something

**"Obsessive cleaners might want to rethink their strategy: the study suggests that the more people potter around cleaning, the more bacteria they deposit"**

few people think about, but anyone spending a long time in a room full of people is likely to come out with a microbial flora more like the crowd's than their own. However, it might also be strangely comforting to know that the bacteria in any room you inhabit is likely to be 99 per cent 'yours' within 24 hours of you moving in. "The colonisation of a room is almost instant," says Lax. "Then a few days after a family leave, their bacterial signature diminishes again."

As part of the study, researchers took thousands of samples from inhabitants' noses, hands, and feet, and from various places in their homes: the kitchen floor, worktop and light switch, the bedroom floor, bathroom doorknob and front door.

We may like to think certain places in our houses are cleaner than others, but the



According to Simon Lax at The University of Chicago, we can only reduce the microbes in our home by not being there

PHOTO: BIOLOGY & BUILT ENVIRONMENT CENTER/UNIVERSITY OF OREGON/CAMERON SLAYDEN/COSMOCYTE ILLUSTRATOR: ROBIN BOYDEN

team actually found that different places within family homes were more alike microbially than the same locations in different houses. In other words, the bacteria on your kitchen table are more similar to the ones in your bathroom than the ones on your neighbour's kitchen table.

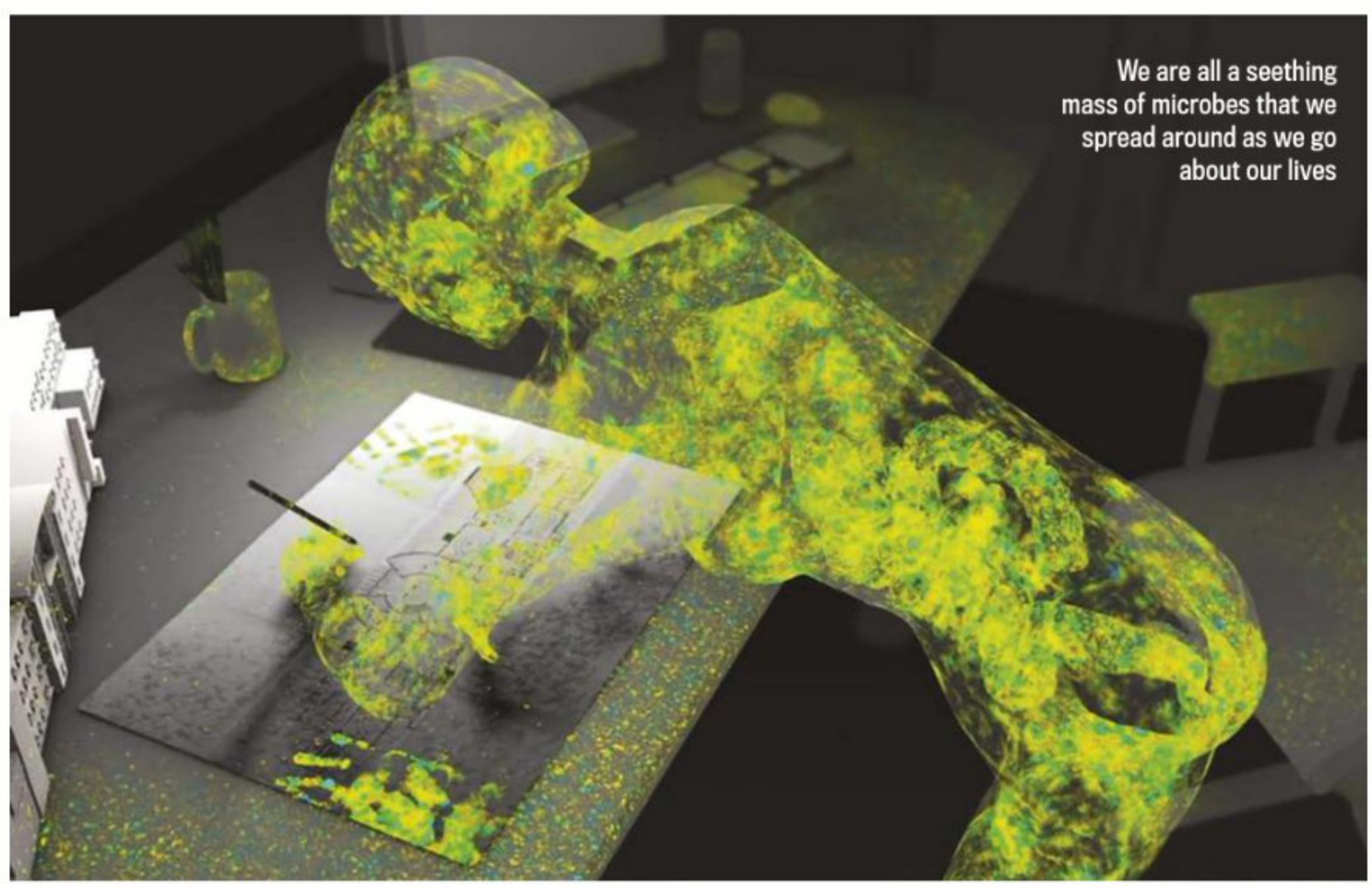
## IT'S A FAMILY AFFAIR

Who we live with and what we do also plays a key role in determining which bacteria take up residence in our homes. The study found that people sharing a home are more microbially similar to each other than those not sharing a home. The hands of young couples and couples with children were especially similar, thanks to regular physical contact. But there's one area of the body where we are each more individual: the nose.

"The nose is fairly stable environment that may be more unique to each person," says Lax. "But for places like the hand, it really comes down to what you've been in contact with, what you do for a living, who you've met, whether you live in the country or in the city. It's more of a lifestyle thing than anything genetic."

Although the bacteria found on people and their homes were always highly correlated, houses were not necessarily closely matched with the bacteria of their pet. The presence of a pet does, however, hugely expand the diversity of bacteria found in a home. Samples from homes with pets contained more proteobacteria, a class of microbe that contains many well-known pathogens including *Salmonella* and *E. coli*. While that may sound like a bad thing, the more we understand microbial diversity the more we find that it helps us in more ways than it harms us. Exposure to varied bacteria at a young age is important for the development of a healthy immune system, for instance.

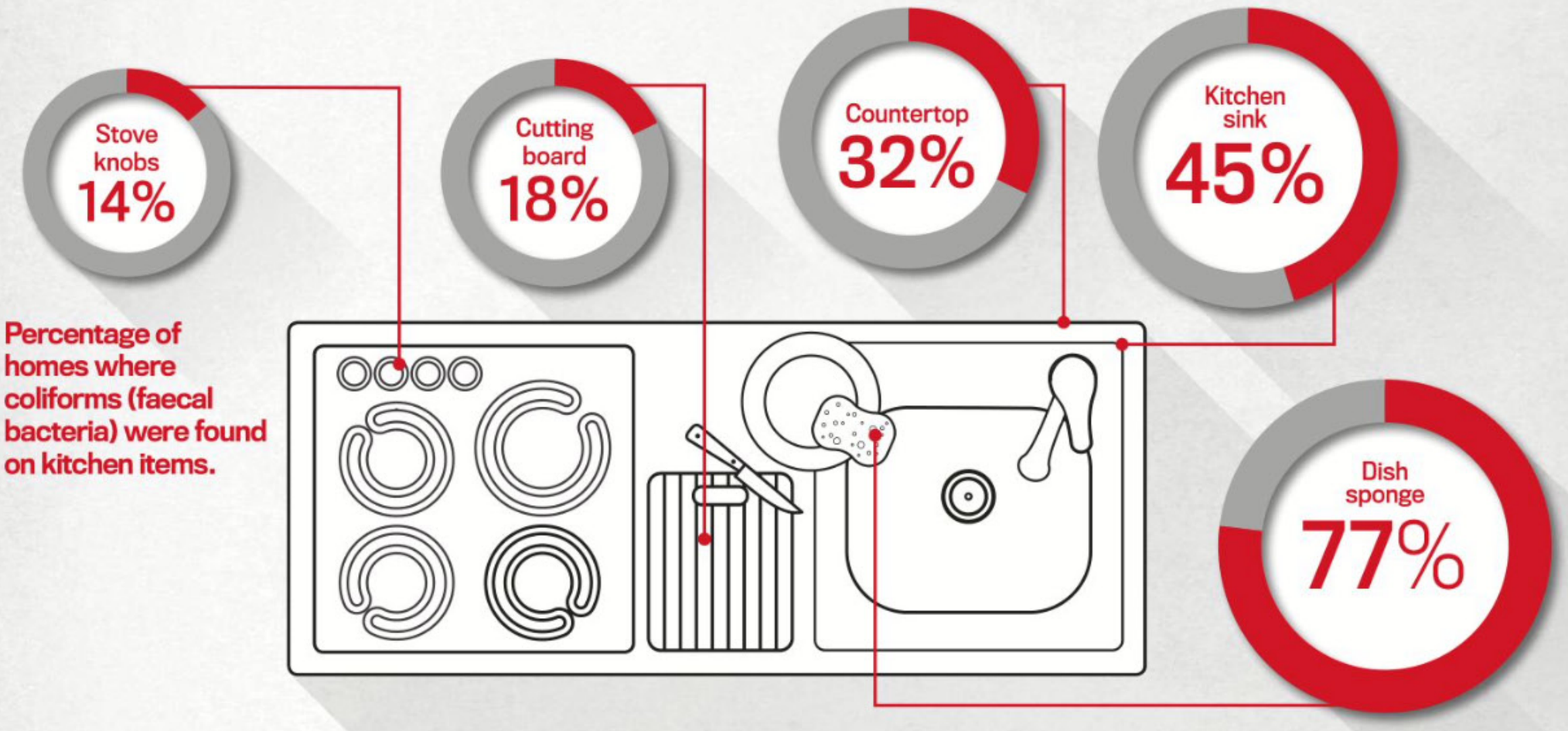
"It's not really a case of one house being more unhygienic than the other," says Lax. "But what we know *isn't* good for



We are all a seething mass of microbes that we spread around as we go about our lives

# MICROBIAL HOTSPOTS IN OUR HOMES

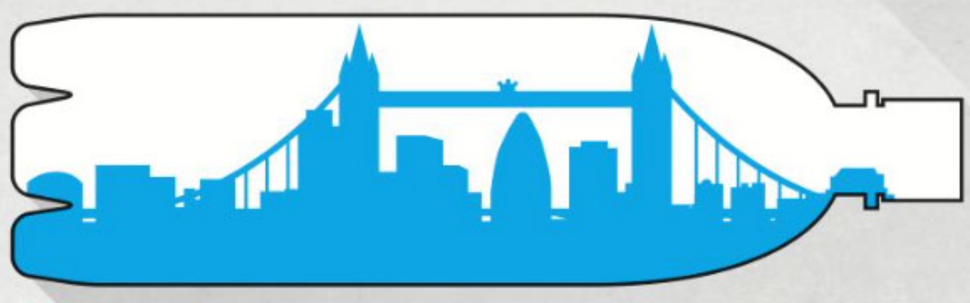
Our perception of hygiene often bears little relation to the reality of what microbes live where. Here's a rundown of some of the most colonised areas




**Percentage of homes where coliforms (faecal bacteria) were found on kitchen items.**

**10x**

more bacteria is in the human digestive tract than there are cells in the human body.



**1.5ml** of human saliva has 150 million bacteria – equivalent to the amount found in one litre of Thames water.

An iPad typically houses 30 times more *Staphylococcus aureus*, the bacteria that can cause MRSA, than a toilet seat.

One sneeze can increase the amount of *Staphylococcus aureus* in the air by five times.

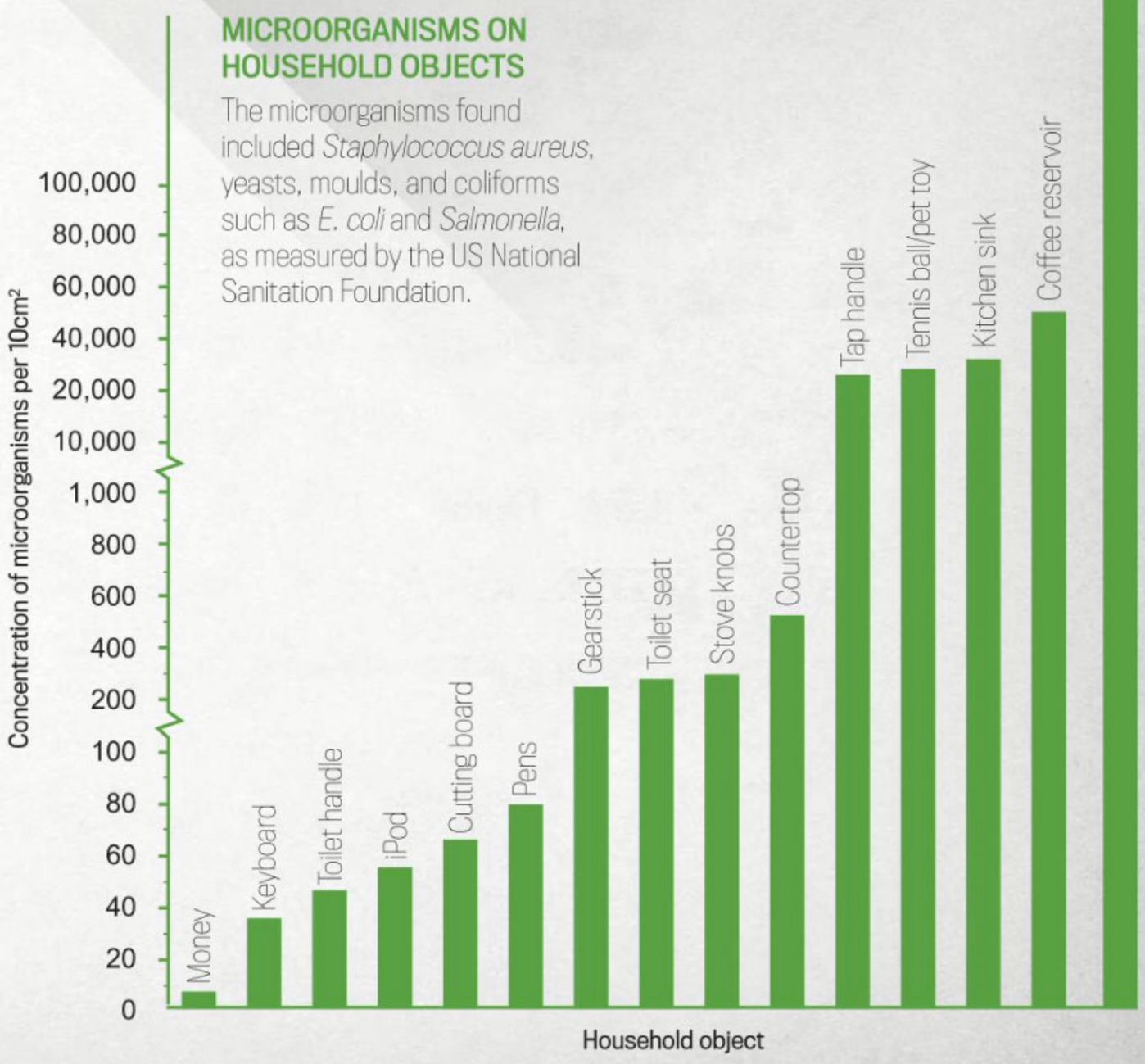
**1,000,000,000,000**

bacteria are harboured on human skin, which is **10 per cent the total number of cells that make up the human body.**

ILLUSTRATOR: ROBIN BOYDEN

## MICROORGANISMS ON HOUSEHOLD OBJECTS

The microorganisms found included *Staphylococcus aureus*, yeasts, moulds, and coliforms such as *E. coli* and *Salmonella*, as measured by the US National Sanitation Foundation.



## "What we know *isn't* good for babies is only experiencing the microbiome of their own environment and their parents"

Simon Lax, Department of Ecology and Evolution, University of Chicago

babies and young children is only experiencing the microbiome of their own environment and the bacteria of their parents," he says. It's a bewildering concept – not only that we are covered head to toe in this strange microbial mixture, but that it might actually be a vital part of a growing family's health.

The Home Microbiome Project is the first study to try to see families, their microbes and their homes as complex interacting ecosystems. Research has traditionally focused on where and for how long bacteria survive in the home, and also how to eradicate them. This new approach may contribute towards a fuller understanding of what a healthy home is – for example, what levels of bacteria can help develop a healthy immune system and what levels may constitute a health hazard.

The team's next aim is to scale up its investigation and survey the microbiome of hospitals. "We are now taking this approach and applying it to environments where the health implications are much higher," says Lax. "We've seen hospitals with identical layouts and identical cleaning methods, so it can only be the different people that affect the bacterial samples found there. And in a hospital environment, there really are such a thing as good and bad microbiomes."

### A NEW UNDERSTANDING

As our understanding shifts from a fear of all bacteria to an understanding of their role in ecosystems, our approach to tackling infection is likely to change. Attempts to simply wipe bacteria away seem increasingly futile. Indeed, some bioscience companies believe sprays containing 'good bacteria' may be a more effective way of preventing dangerous human pathogens from taking hold in certain places.

More projects measuring the impact of microbes in the built environment are planned. Some even involve architects, who hope that future buildings can be built to encourage a healthy microbiome, or species that absorb pollutants from the air.

For Lax, the results of his study have opened his eyes to the unseen microbial mark humans make wherever they go. "I'm not grossed out by it, but it definitely makes you think. Am I leaving my signature behind when I visit this house? Am I changing what bacteria live here?".

In time, perhaps we will all come to see our house's bacteria not as dirty intruders, but welcome guests – perhaps even tiny members of our extended family. On the sofa tonight, sit back and relax in the knowledge that it's just you, your family, and a trillion bacteria that seem to enjoy your company in particular.

It's true what they say – there really is no place like home. ■

**TOM IRELAND is managing editor of *The Biologist*, the Society of Biology magazine**

**Find out more**

Listen to *A Natural History Of Me!* on the human microbiome at **bbc.co.uk/programmes/b01rvpkb**

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Sarah Lonsdale – Sunday Telegraph

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Justin Harper – Daily Mail

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Mr. T. G. General Manager, The Days Inn Hotel, Hyde Park

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K. Sawbridge, Ops Director, Alfa Leisureplex Holiday Group

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# Q&A

# YOUR QUESTIONS ANSWERED

## BY OUR EXPERT PANEL

**SUSAN BLACKMORE**
Susan is a visiting psychology professor at the University of Plymouth. Her books include *The Meme Machine*

**DR ALASTAIR GUNN**
Alastair is a radio astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester

**ROBERT MATTHEWS**
After studying physics at Oxford, Robert became a science writer. He's a Visiting Reader in Science at Aston University

**GARETH MITCHELL**
Starting out as a broadcast engineer, Gareth now writes and presents *Click* on the BBC World Service

**LUIS VILLAZON**
Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*

**EMAIL YOUR QUESTIONS TO questions@sciencefocus.com**
or post to *Focus* Q&A, Tower House, Fairfax Street, Bristol, BS1 3BN

**Q** LUCY MILLIGAN, PETERBOROUGH

## Where is the biggest shipyard in the world?

**A** THAT ACCOLADE GOES to the Hyundai Heavy Industries shipbuilding facility (pictured) in the South Korean city of Ulsan. Built in the 1970s, the yard covers an area of 7.2 square kilometres. Its 10 dry docks turn out on average 80 vessels per year, comprising about 16 per cent of the global shipbuilding market. The massive Ulsan yard is incredibly versatile too, producing oil tankers, military vessels, container ships and car ferries. **GM**

This huge propeller is for a supertanker built at Hyundai Heavy Industries

PHOTO: STEPHAN GLADIEU/FIGAROPHOTO/CAMERA PRESS

**In Numbers**

# 750

is thought to be the max. number of mature European sturgeon in the wild. In the worst case scenario, the figure may be as low as 20

Q JOHN SIMPSON, BURGESS HILL

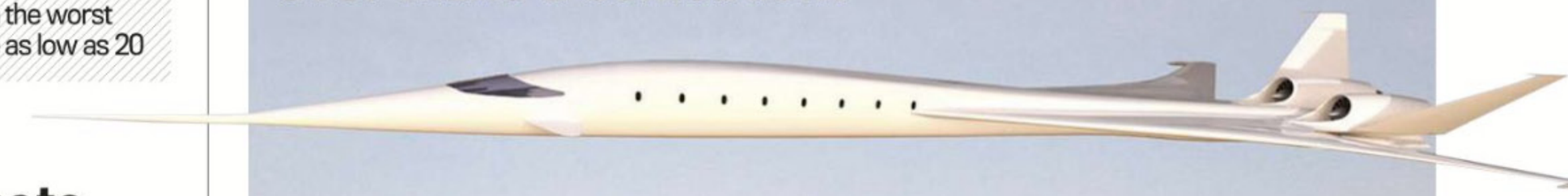
## Why aren't planets overcome by the Sun's gravitational pull?

A THE PLANETS DON'T crash into the Sun because they are moving too fast. Gravity pulls the planets towards the Sun, but the planets are also moving around the Sun. The sideways motion balances the force of attraction so that the planets don't move appreciably in the Sun's direction. In effect, the planets are constantly falling towards the Sun but always miss! Without the Sun's gravity to pull it 'down', the Earth would career off into space. Or, putting it another way, if the Earth stopped moving it would crash into the Sun. You can create a similar effect by swinging a large spring with a weight attached to one end. If you swing it fast enough, the spring won't stretch, unless it goes faster. But if it slows down, the spring will pull the weight in. **AG**

Thanks, Sun!

Q SERENA SMITH, ST ALBANS

## Will supersonic flights ever make a comeback?



The SonicStar will hold no more than 20 passengers. You can guarantee one will be a screaming baby

A WITHIN AT LEAST the next generation, the answer has to be 'very unlikely'. To understand why, one hardly needs to look further than the Airbus A380. The trend in aviation is to increase efficiency of aircraft, not speed. It's partly an equation of bigger planes, and thus less energy per passenger per kilometre. But the massive A380 also gains economies with its light carbon fibre frame, advanced avionics and engines with large air intakes that burn fuel more efficiently than smaller turbofans. Yet firms such as the UK's HyperMach believe they can achieve hypersonic speeds at subsonic efficiencies by cruising at twice the altitude of conventional aircraft where the air is thinner. Hypersonic is faster than supersonic, and is generally defined as Mach 5 and above.

HyperMach plans to fly a prototype of its SonicStar plane in 2023. But even then, it will not quite be the beginning of fast air travel for the masses. The first planes would be executive jets, which would open up two-hour Atlantic crossings – but only to the mega rich. **GM**

Q TOM BELL, SALFORD

## Is there a way to walk across slippery surfaces without falling?

A RECENT RESEARCH AT the Salk Institute for Biological Sciences in California found that we balance on slippery or narrow surfaces using clusters of RORa neurones in the spinal cord. These 'mini brains' process the huge amount of sensory information coming from your skin, muscles, inner ear and eyes and make hundreds of tiny corrections per second. It's a bit like the ABS in your car constantly watching for a skid and pumping the brakes before it happens. You can also reduce your chances of a fall by copying penguins. When you walk normally, your centre of gravity is only directly above the weight-bearing foot for a small part of each stride. If you waddle from side to side instead, your centre of gravity always stays above one foot or the other. This reduces the sideways forces and makes it much less likely that your foot will suddenly slip out from under you. **LV**

Walk like a penguin to avoid slippery mishaps

PHOTO: HYPERMACH, GETTY X2, ISTOCK X2

**WINNER!** Alex Round wins *Expanding Universe: Photographs From The Hubble Space Telescope* (Taschen, £44.99)

## QUESTION OF THE MONTH

There's a serious glitch in The Matrix

Q **ALEX ROUND,** LONDON

# Can déjà vu be explained?

A THE PHENOMENON OF déjà vu is a sudden and intensely convincing feeling that you've been somewhere before, or that it has happened before. Many people jump to the conclusion that they dreamt the scene and now it's coming true. But there are no documented cases of people, in this state, predicting what's going to happen next. And many attempts to prove precognitive dreams have failed. An old theory is that déjà vu happens when one part of the brain senses something fractionally before another part, wrongly setting off the feeling of familiarity. Another blames excessive or unusual temporal lobe activity. The temporal lobes handle many memory functions and are responsible for the sense of familiarity. Temporal lobe epileptics often report déjà vu. People with highly variable temporal lobe activity tend to be creative, believe in the paranormal and have lucid dreams, spiritual and out-of-body experiences as well as déjà vu. Next time you get this feeling, blame your temporal lobes. **SB**

Q **HILARY GEE,** CUMBRIA

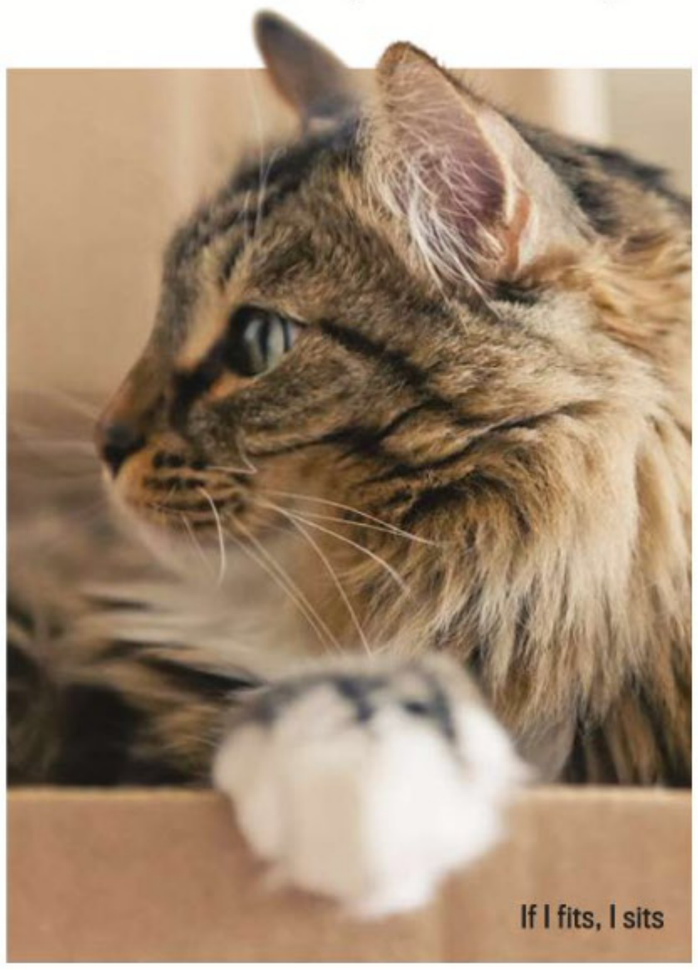
# Why does turning a device off and on often solve issues?

A MANY DEVICES RUN some kind of computer code. The software often runs in a loop, executing commands repeatedly while the device awaits input. For instance, your screen constantly refreshes until you press a button. Sometimes, the code slips into a non-functional permanent loop that only breaks when you reset everything by switching the device off and on. **GM**

Q **SARAH JONES,** LUTTERWORTH

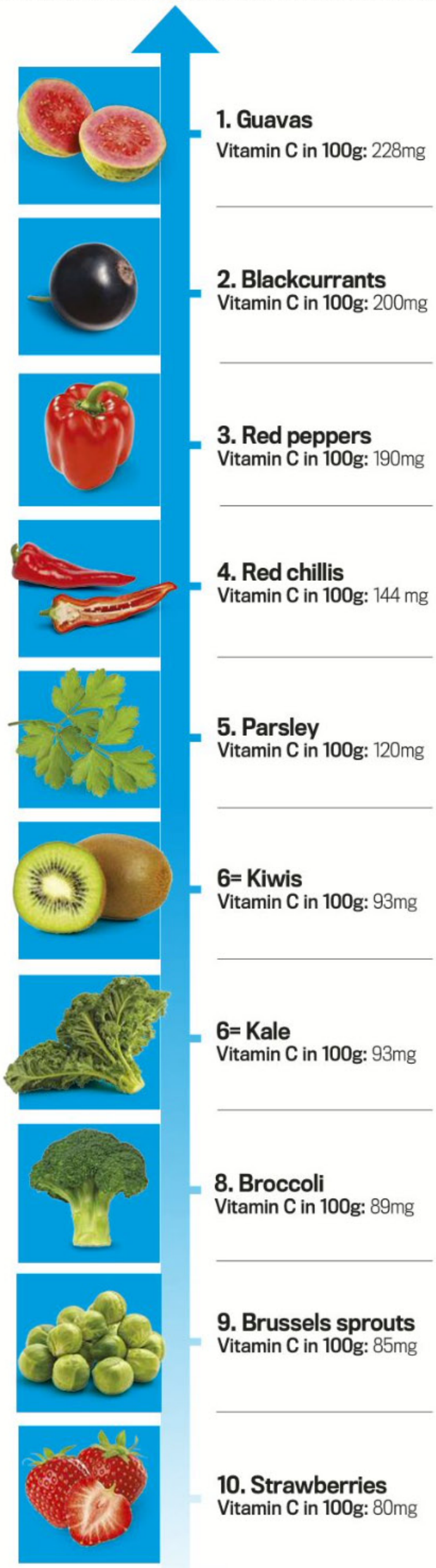
# Why do cats like boxes?

A WOLVES, EAGLES, JACKALS, foxes and snakes prey on wild relatives of the cat. Cats hide in bushes or burrows during the day to escape their predators and to go to sleep. This behaviour lingers in domestic cats. A study at the University of Utrecht in the Netherlands found that cats in animal shelters were much less stressed by their new surroundings if they had a box to hide in. Even when cats aren't stressed, a box feels more secure, cosy and comforting. **LV**



If I fits, I sits

# TOP 10
## MOST VITAMIN C-RICH FOODS



**1. Guavas**
**Vitamin C in 100g:** 228mg

**2. Blackcurrants**
**Vitamin C in 100g:** 200mg

**3. Red peppers**
**Vitamin C in 100g:** 190mg

**4. Red chillis**
**Vitamin C in 100g:** 144 mg

**5. Parsley**
**Vitamin C in 100g:** 120mg

**6= Kiwis**
**Vitamin C in 100g:** 93mg

**6= Kale**
**Vitamin C in 100g:** 93mg

**8. Broccoli**
**Vitamin C in 100g:** 89mg

**9. Brussels sprouts**
**Vitamin C in 100g:** 85mg

**10. Strawberries**
**Vitamin C in 100g:** 80mg

PHOTO: ISTOCK X12, GETTY, SCIENCE PHOTO LIBRARY

**Q** AMIRHASSAN MONTAZER, IRAN

## Why does the Moon appear larger than normal on the horizon?

**A** IT HAS BEEN known since ancient times (at least as far back as Aristotle in the 4th Century BC) that the Moon can appear to be larger than normal when close to the horizon. At the same time, however, it can be shown that the Moon is in fact no different in size than when it is at the zenith. This dichotomy is known as the 'Moon illusion'. Ptolemy and others have tried to attribute the phenomenon to the refraction due to the atmosphere, but this is in fact erroneous. Although there is no definitive explanation, it is generally accepted that it is merely an effect of perception. When the Moon is close to the horizon, other objects such as buildings and trees are included in the eye's field of view. Most authorities suggest that this makes the Moon appear larger than when it's surrounded by an expanse of empty sky. **AG**

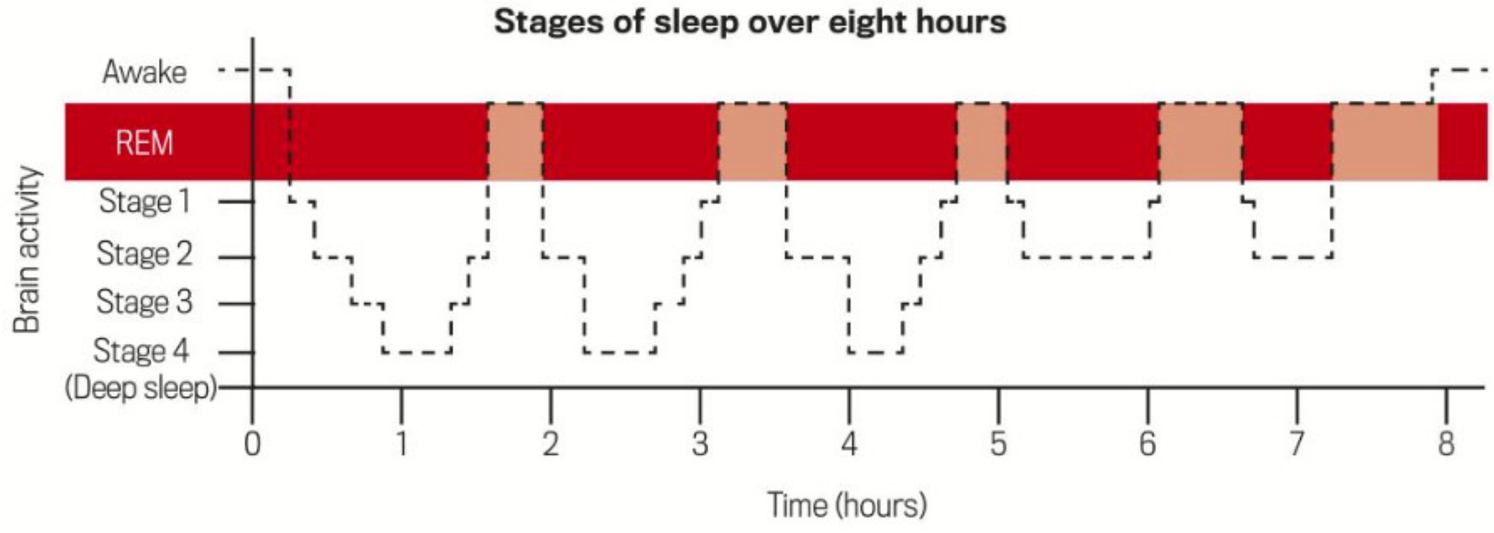
Party time for werewolves

**Q** ANGELA MUNRO, LAUSANNE, SWITZERLAND

## Why do we toss and turn when we sleep?

**A** A TYPICAL NIGHT'S sleep consists of REM and non-REM sleep. REM stands for Rapid Eye Movement and is named after the way your eyes dart around under your eyelids. REM sleep is when you dream. To prevent you acting out your dreams, nerve impulses from your motor cortex are intercepted in the spinal cord and blocked. So you'll never thrash about during a dream, no matter how vivid it is. Instead, most of the tossing and turning actually happens in the brief moments after REM sleep when you wake up. This only lasts a few seconds and we usually don't remember having woken, so it feels like we are tossing and turning in our sleep. You can have four or five REM/non-REM cycles every night and the wakeful interludes give you a chance to change position or adjust the covers. **LV**

**Stages of sleep over eight hours**



**Q** **CASPAR PETCH,** BY EMAIL

# What do dogs hear when we talk to them?

**A** THERE'S GOOD EVIDENCE that dogs can recognise many of the subtleties of human speech. A 2014 study at the University of Sussex found that dogs use the right side of their brain for processing the emotional content of speech, such as tone of voice, and the left side for verbal commands. Dogs can tell when a recognised command word is given, even when said with an unfamiliar accent. And they can tell the difference between correct commands, such as "Come on, then," compared to one with jumbled syllables, "Thumb on, Ken!" **LV**

Ate the Sunday roast? Me? Never!

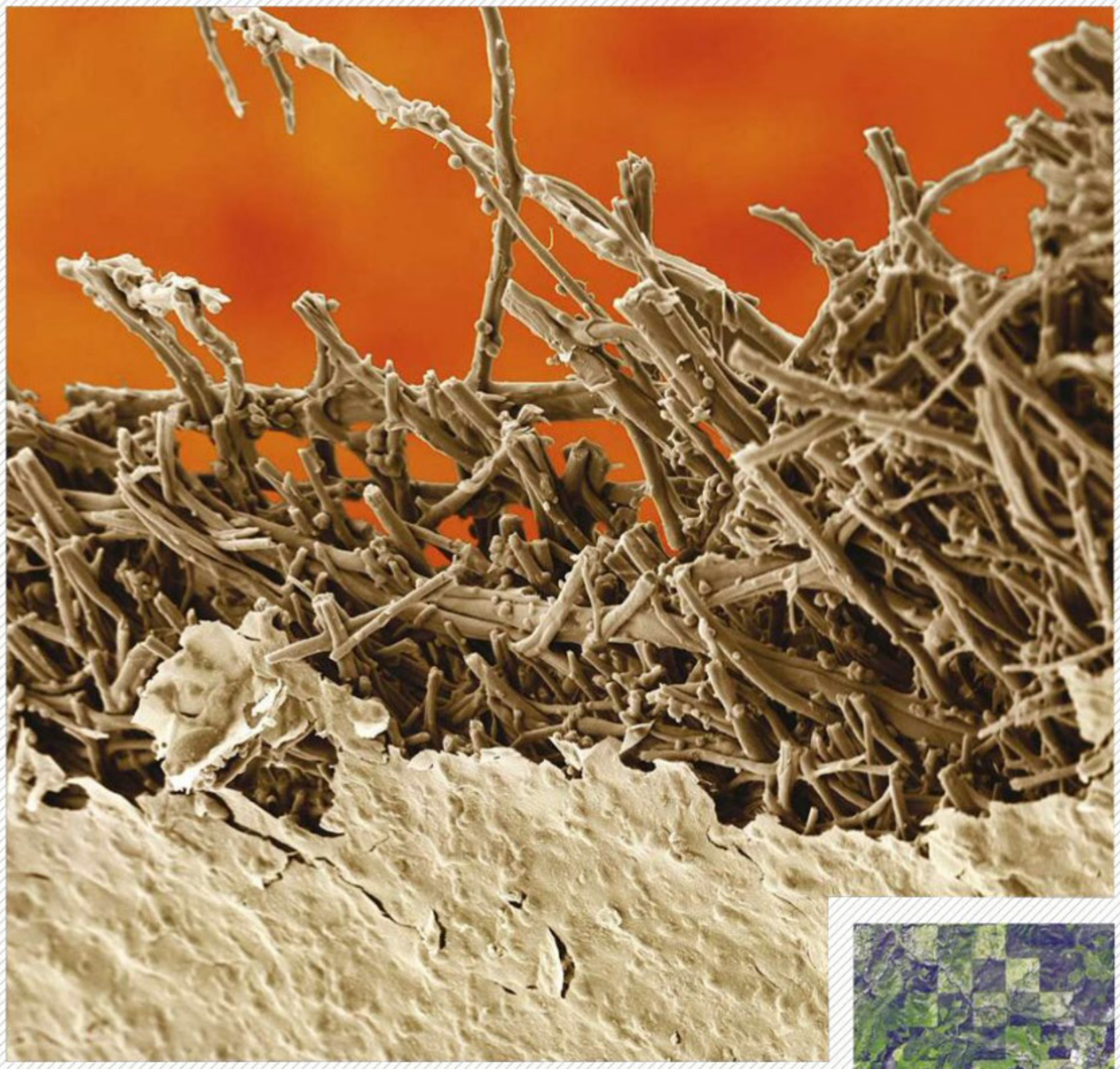
**Q** **KIERAN MUIR,** BY EMAIL

# If I throw a ball up vertically in a moving train, will it move away from me?

**A** NO – IT WILL land just as if you were standing still. That's because the ball started off in your hand, so was also travelling forward with the speed of the train. Once airborne, it doesn't lose that forward speed, so it keeps up with you and lands in your hand. **RM**

Play catch on the train

## WHAT IS THIS?



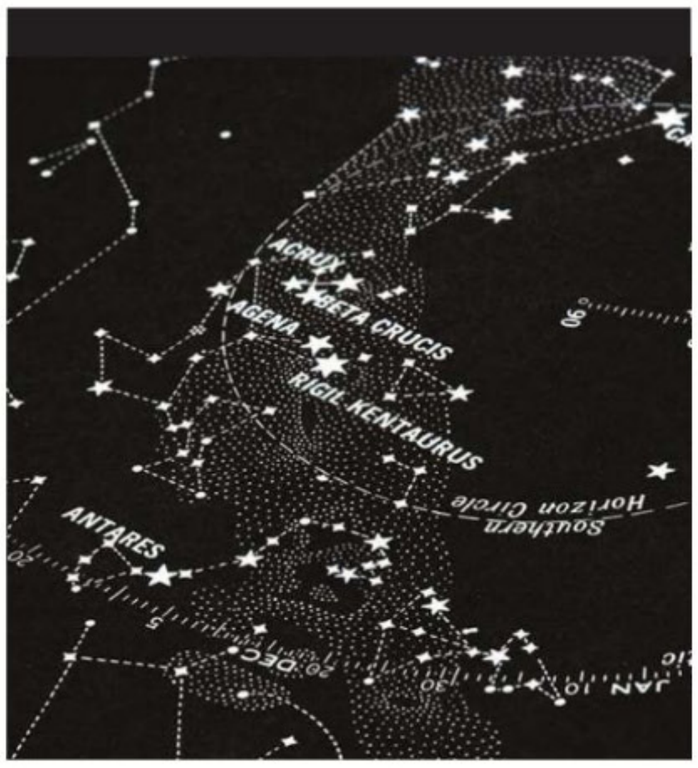
**KNOW THE ANSWER?**
Submit your guess now at
**sciencefocus.com/qanda/what**

**LAST MONTH'S PICTURE**
Dave Taylor correctly guessed the pattern of logging activity

**Q** **CHARLIE O'BRIEN,** LEEDS

# What are constellations?

**A** CONSTELLATIONS ARE MERELY patterns of stars that were originally associated with mythological or astrological figures. Many of them probably date back to the Sumerians. Usually, the only connection between the stars in a constellation is that they appear in the same part of the sky. They may, in fact, be located at very different distances. In modern astronomy, the constellations are defined not by the actual pattern of stars, but by a particular area of the sky with defined borders. **AG**




In reality, there are no scorpions and prancing goats in the sky

Q CLAIRE THOMAS, HEREFORD

# Does excessive screen time damage a child's brain?

A SERIOUS SCREEN ADDICTS suffer sensory overload, lack of sleep, and loss of attentional control. Their brains show shrinkage of parts of the cortex, including the frontal lobes. These are important for planning, organising and controlling impulses. This is especially worrying in young people because the frontal lobes grow slowly and keep developing until their mid-20s. There are also changes in the brain's white matter, with long-range connections between neurones being interrupted. The arousal produced by exciting games affects the reward systems and alters levels of dopamine in the brain, which can have long-term effects on attention span. Relying so much on vision and movement may mean that other sensory areas are neglected, and children may lose out on building social skills and relationships. However, some screen-based activities develop new thinking skills, improve problem solving, enhance memory, and help hand-eye coordination, reaction speeds and multitasking. All of these can improve the growing brain. **SB**

Dad is just stroppy because Jimmy is better than him at *Minecraft*...

**In Numbers**

**316,600**

people over 100 years old live around the world. By 2050, this figure could increase to more than three million

Q TERRY BANKS, POOLE

# Why do people lie?

A TO GAIN FAME, riches, approval and attention; to refrain from hurting others or causing conflict; or to avoid admitting mistakes or seeming weak – there are many reasons. Liars prefer the consequences of lying to facing up to the truth, but the consequences of telling fibs are rarely benign. Relationships can be ruined by even small lies, exaggerating can lower self-esteem, people who lie a lot become less trusting of others, and children are harmed by even little lies. It's hard to discover how often people lie, but one study of 2,000 British people found that men tell six lies a day, while women tell three. The most common lie was: "Nothing's wrong. I'm fine." **SB**

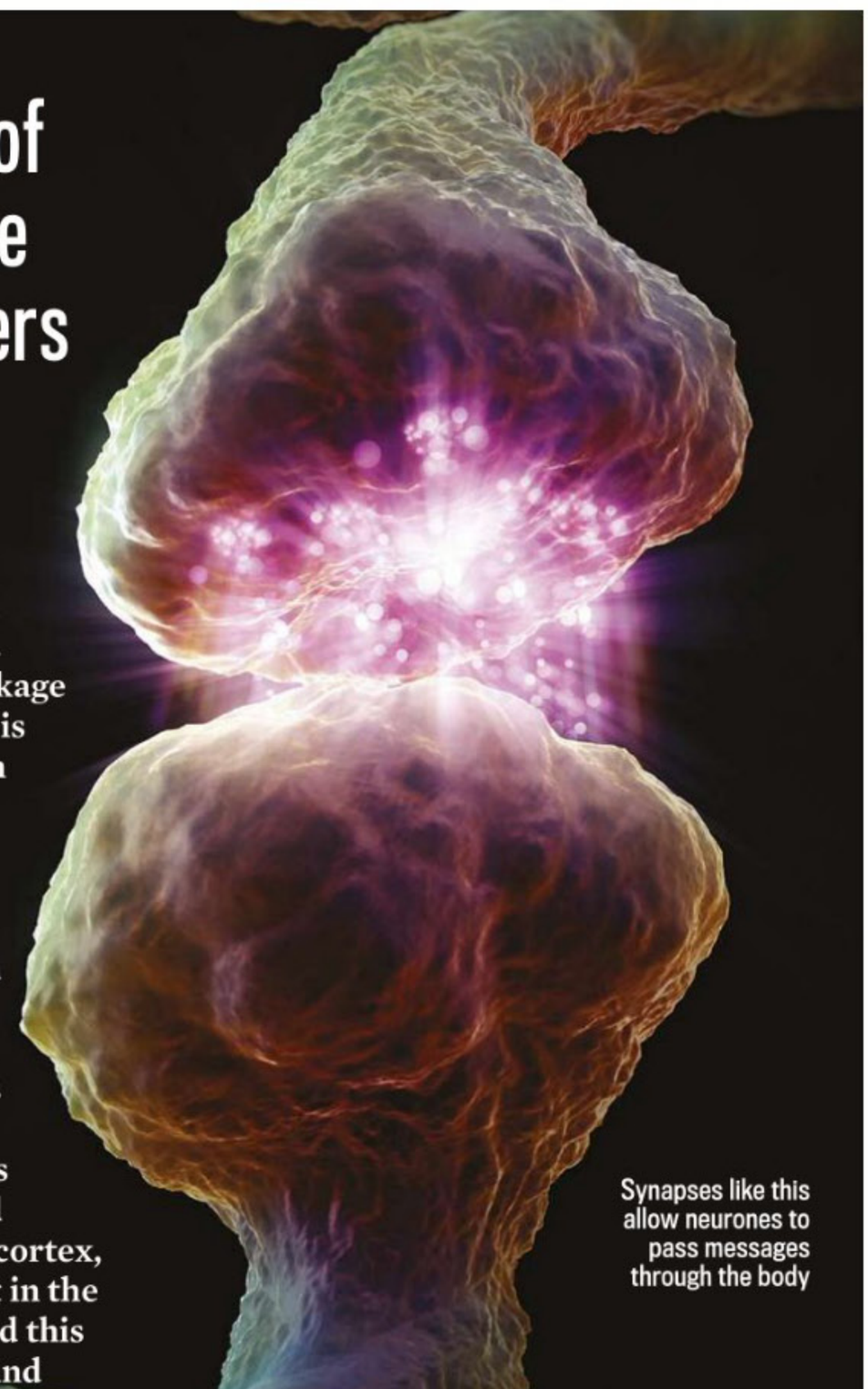
"I did not have sexual relations with that woman"

Q MYLES BROOKS, OXFORD

# Do some areas of the brain decline faster than others due to old age?

A **YES, ALTHOUGH THE pattern varies depending on people's health and lifestyle. Some decline is due to shrinkage and loss of cells, while some is down to chemical changes in neurotransmitters and synapses. The cortex is the thick, folded, outer layer of the brain and its grey matter begins thinning from our mid-20s onwards.**

**The brain's white matter, which consists of long axons transmitting information between neurones, increases until about the age of 40 and then slowly declines. In the cortex, age-related decline is fastest in the frontal and parietal lobes and this affects executive functions and memory systems. Language areas towards the front of the brain decline more quickly than those towards the back. Decline is also slower in the occipital lobe at the back of the brain, which is devoted to visual processing. This makes sense since the visual cortex is so important to our survival and it is constantly active when our eyes are open. SB**



Synapses like this allow neurones to pass messages through the body

PHOTO: ISTOCK X2, CORBIS, GETTY, FERMILAB, SCIENCE PHOTO LIBRARY

Q SALLY PIERCE, LONDON

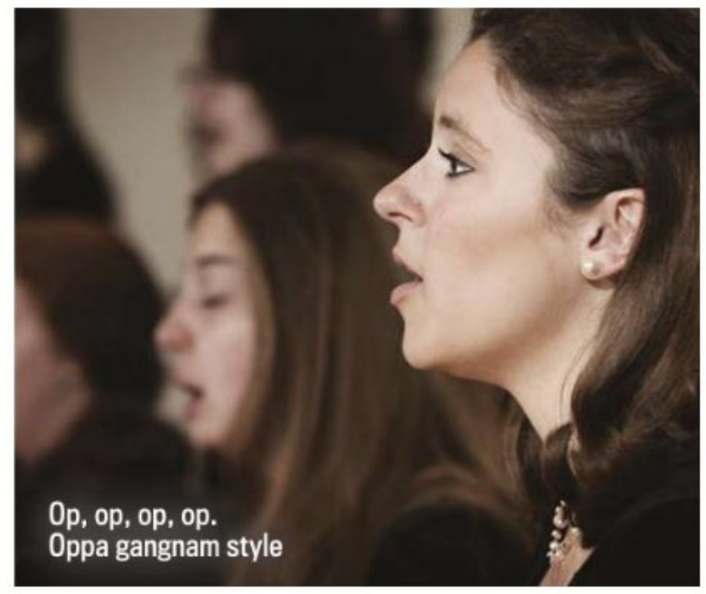
## How much salt does it take to poison an adult?

A THE MEDICAL LITERATURE lists an estimated lethal dose of between 0.75g and 3g per kilogramme of body weight. For a 75kg adult, that means a minimum of 56g of salt or about 10 teaspoons, taken all at once. But salt poisoning is about the concentration of salt in your blood, not the amount that you eat. Your body will remove excess salt through your kidneys and your sweat. If you have access to plenty of fresh water, you can cope with a much higher salt dose than if you are dehydrated. **LV**

Mmm... just about the right amount for our chips

Q JULIA FROST, WELSHPOOL

## What makes a person's voice unique?



Op, op, op, op. Oppa gangnam style

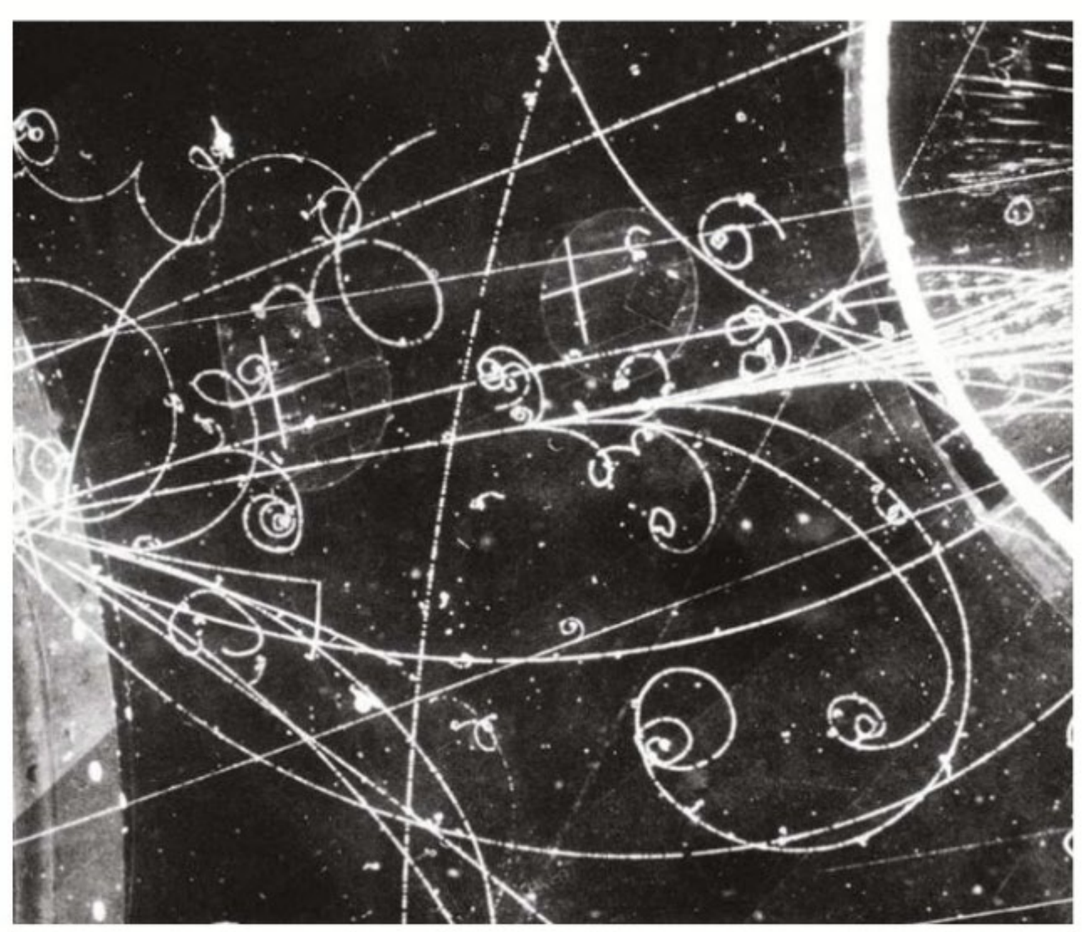
A LIKE A MUSICAL instrument, the sound of your voice is determined by the shape and size of its parts. The length of your vocal cords, the shape of your nose and the contours of your throat all contribute. The exact timing of the contractions of muscles in your mouth, tongue, larynx and diaphragm are different for everyone – even when they are saying the same words. These things are affected by the accents or cultures that surrounded us when we learned to speak. **LV**

Q SIMON PARSON, TOWCESTER

## Have particles ever been detected travelling faster than the speed of light?

A ACCORDING TO SPECIAL Relativity, no particle with mass can travel at the speed of light – around 300,000 kilometres per second – let alone faster. But in 2011, a European team of scientists claimed to have found evidence of particles breaking Einstein's speed limit. Known as neutrinos, these particles were timed as they travelled over 700km from their origin at the CERN laboratory in Geneva to a detector in Italy, and they seemed to arrive around 60 billionths of a second sooner than a beam of light travelling through empty space could manage. Unable to explain the anomaly, the scientists asked for help. It quickly emerged that their timing equipment was faulty, and the neutrinos had actually complied with Einstein's speed limit.

Physicist Robert Ehrlich of George Mason University in Virginia has argued that neutrinos may still be able to exploit a loophole in Einstein's theory, allowing them to travel faster than light. To do this, they have to possess so-called tachyonic mass, which is utterly unlike the conventional variety. According to Ehrlich, evidence that neutrinos are particles consisting of this stuff already exists in the results of lab experiments and in esoteric astronomical observations. Nonetheless, his interpretation remains controversial. **RM**



The paths of electrically-charged particles mapped in a bubble chamber

Q MARTIN WHITE, SHEFFIELD

# Do some facial expressions cause more wrinkles than others?

Those eyebrows could do with a serious trim, too

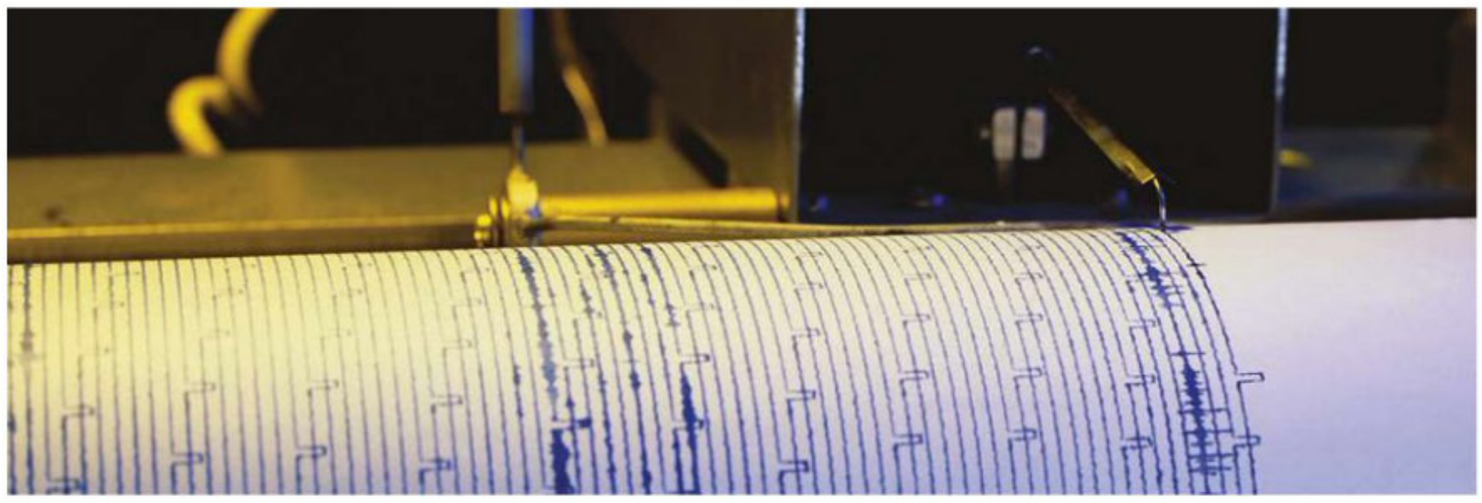
A WHEN YOU SMILE or frown, the creases in your skin begin as just temporary features. But as you get older, these same creases eventually become permanent wrinkles. Frowning mainly creases your brow, whereas a good smile will crease your eyes and mouth but not your forehead so much. The only expression that creases the entire face is the kind of horrified wince you make when you watch someone take a bad fall off a skateboard (try it!). This suggests that watching a lot of YouTube videos might just give you wrinkles! **LV**

Q ELLIE RICHARDS, DURHAM

# Is it possible to accurately predict earthquakes?

A SCIENTISTS ONCE BELIEVED they might one day find telltale signs of an impending earthquake sufficiently reliable to organise evacuations in plenty of time. Since the 1990s, however, the failure to identify any such useful 'precursors' has led to growing attention on two other strategies to minimise death and destruction.

The first strategy accepts that the time, location and size of an earthquake can never be predicted precisely, and focuses on identifying at-risk regions and making buildings and infrastructure more quake-resistant. The second exploits the ultimate 'precursor': the vibrations caused by the earthquake itself. So-called P-waves spread out from the site of the earthquake at over 18,000km/h – giving about a minute's warning of the impending arrival of the much more destructive seismic waves. This is enough time for the authorities to switch off utilities and give the alarm so that people can find shelter. Both of these strategies are now in use in Japan and Mexico. **RM**



These days, recordings of ground movement are often displayed on computers rather than on paper

Q ALAN THOMAS, FRANCE

# Is it possible to take too many vitamins?

Taking too many tablets will also make you rattle

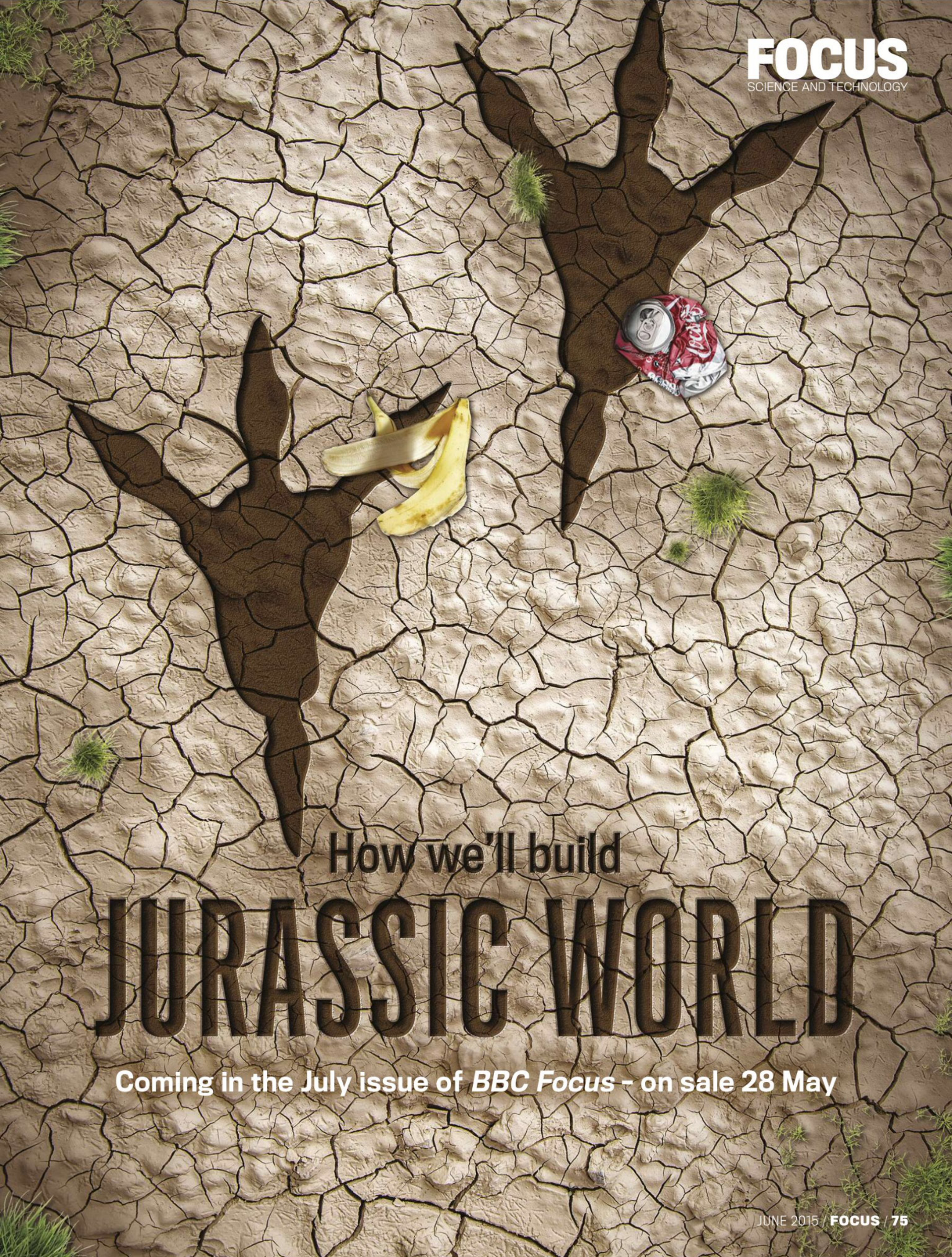
A MOST DEFINITELY. THE body normally regulates your levels of vitamins A, D and E, which you eat as part of a healthy diet. If you consume the vitamins in tablet form, you bypass this regulation mechanism and excess vitamins get stored in the liver, gradually building up over time. A daily dose of 2,500 micrograms of vitamin A for six months is enough to give you chronic vitamin A toxicity, with symptoms including blurred vision, hair loss and peeling skin. But you'd need to take more than 37 cod liver oil capsules a day to reach that quantity.

Taking vitamin supplements may even be bad for you – even at doses well below the toxic threshold. Probably the hardest one to overdo is vitamin C. The recommended daily intake for adults is 65 to 90mg (roughly one orange) but you can tolerate up to 2,000mg a day without any ill effects. At very high doses, vitamin C eventually causes diarrhoea, heartburn and kidney stones. **LV**

**NEXT MONTH Over 20 more of your questions answered**

For even more answers to the most puzzling questions, see the Q&A archive at **www.sciencefocus.com/qanda**

PHOTO: ISTOCK, GETTY, SCIENCE PHOTO LIBRARY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THE FUTURE OF GADGETS

# TECHHUB

EDITED BY **DANIEL BENNETT**

**THIS MONTH**


**APPLIANCES OF SCIENCE**
Solar car tyres, mobile juice on tap and more
p79

**ULTIMATE TEST**
We drive five of this year's most high-tech cars
p80

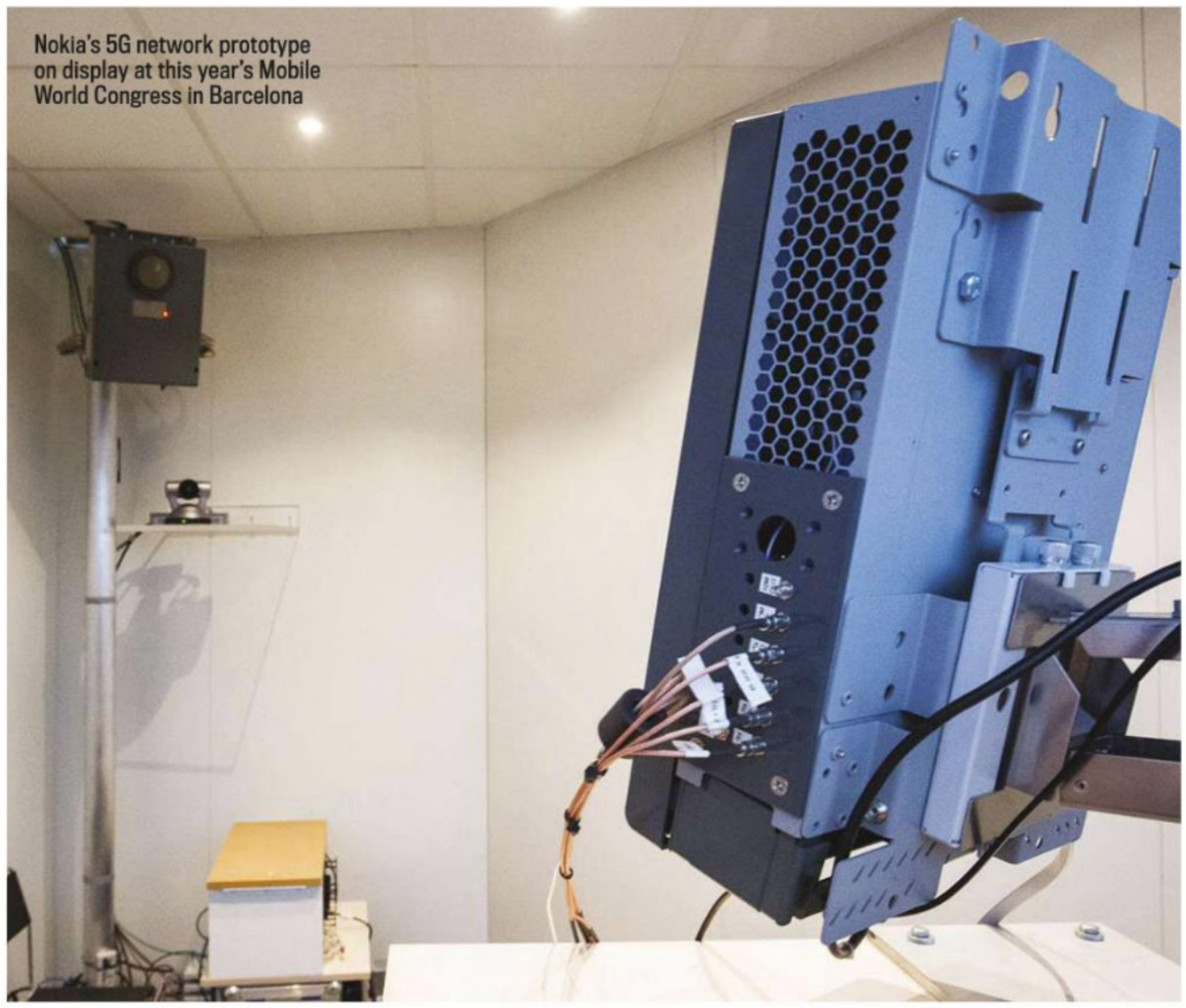
**ON THE HORIZON**

## 5G

The next-generation mobile phone network is coming

CHANCES ARE, if you've recently upgraded your phone, you'll have graduated from a 3G network to the faster, newer 4G technology. Films download in minutes, TV shows stream live and Facebook loads up in the blink of an eye. It's like using home broadband wherever you go, so we thought there'd be little need for another newer, faster technology, but we were wrong. The mobile network is about to explode.

Not literally, of course. But the number of nodes on our mobile network – that is, the number of connected devices – is about to expand rapidly. A few years ago, it was just our smartphones that needed data on the go, but now a whole new species of gadgets has evolved to feed on our data. There are already internet-connected cars, cameras and smartwatches that need their own SIM cards to function. Pile on advances like autonomous cars, intelligent traffic networks and homes stuffed with washing machines, fridges and cookers that can talk to your phone (collectively termed the



Nokia's 5G network prototype on display at this year's Mobile World Congress in Barcelona

Internet of Things) and you can see how our mobile networks might struggle in years to come. In fact, market analysts at Gartner predict that the number of networked devices will skyrocket from five billion in 2015 to 25 billion by 2020.

Fortunately, a solution might already be on its way. Several universities and companies are racing to build a new network standard by 2020 – just in time for the Tokyo Olympics – that will support the Internet of Things. One of the furthest ahead is Nokia, which is running real-world tests in Finland right now, reaching speeds of up to 10Gbps, 10 times faster than the fastest recorded 4G connections. To reach these figures, Nokia has had to reinvent how phone masts connect to our devices.

The solution lies in unused bandwidths. Currently, our mobile phones receive relatively large signals – low frequency radio waves, tens of centimetres long, that are less vulnerable to interference. But these frequencies are in high demand, so bandwidth is limited, and 4G already takes how much data we can squeeze into these waves to the limit.

But elsewhere in the radio spectrum there's plenty of room – so the people that build communications networks are starting to look elsewhere. In particular, they've begun testing higher-frequency waves. Until now these small 'millimetre' waves didn't work very well: they tended to lose more energy over long distances, and struggled to penetrate solid materials. And because they can be scattered by fog, rain and foliage, they require more power to send and receive data reliably.

That's where Nokia's technology comes in. It's tried to remedy millimetre waves' flaws in three ways. First, the network will set up several radio connections with your phone at once, so that data can be channelled back and forth through several streams simultaneously. Second, the antennae will use special arrays to focus and strengthen the beam sent to your phone. Finally, the network will use smaller 'cells', with smaller base stations that will disperse and reroute signals from mobile masts straight to your phone.

But this isn't the only solution. And if speed is the measure of success, then researchers at the University of Surrey's 5G Innovation Centre are way out in front. Its lab tests recorded speeds of up to 1 terabit per second (1Tbps), a speed 100 times faster than Nokia's test, though not much else is known yet about the technology involved.

Whichever method wins out, 5G is on its way. It can't come soon enough to cope with all the devices that will be online.

**DANIEL BENNETT** is the reviews editor at *BBC Focus Magazine*

## TECHOMETER

### WHAT'S HOT

### GRAPHENE

The 'miracle material' has yet to deliver many miracles to the general public, but they could be just around the corner. At the opening of the UK's National Graphene Institute in Manchester, the material's inventor showed off the world's first graphene product: a light bulb. It'll cut energy use by 10 per cent and last much longer than current energy-savers. Well, it's a start, isn't it?

### WHAT'S NOT

### ONLIVE

OnLive, a game streaming service we reviewed in issue 237, is closing down. You could connect to OnLive's servers via PC, tablet or its own console, and play blockbuster videogames on its computers while you controlled the action from your own screen. This meant that you didn't need expensive hardware to enjoy the latest games. Now, Sony has bought the company – along with 140 patents that will help improve its own streaming service.

### READER POLL

Are you excited about 5G?

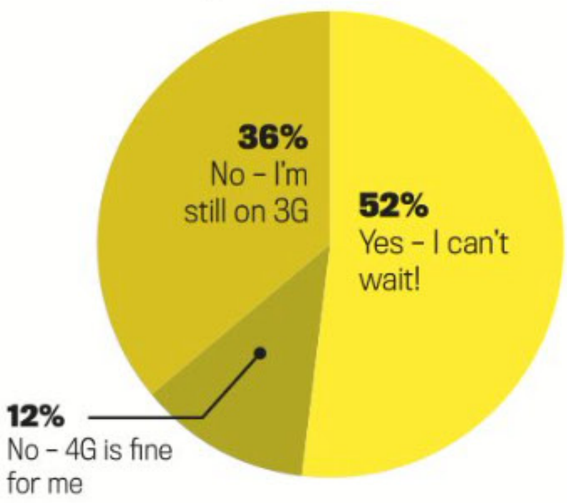
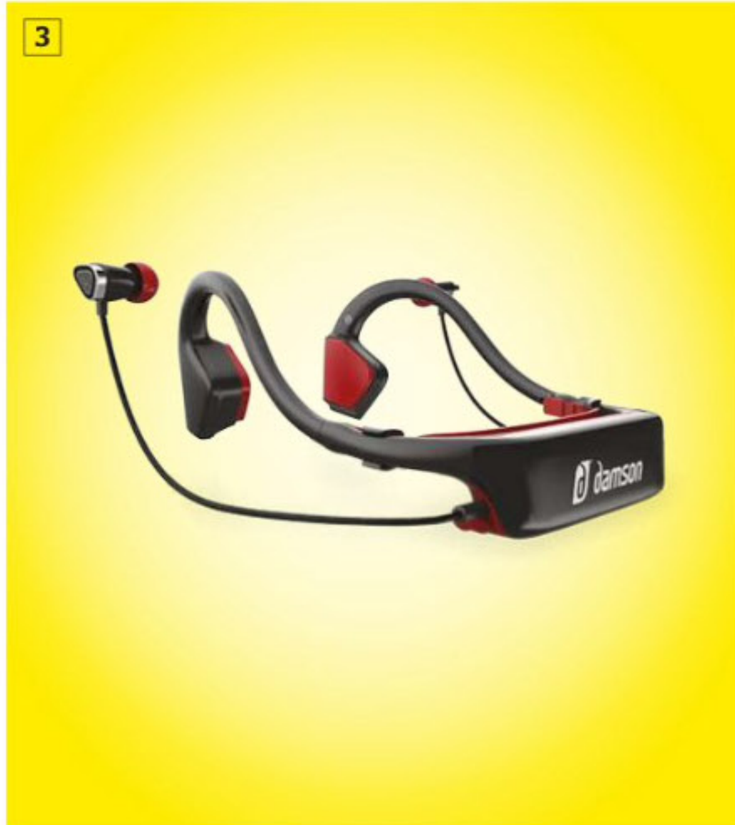
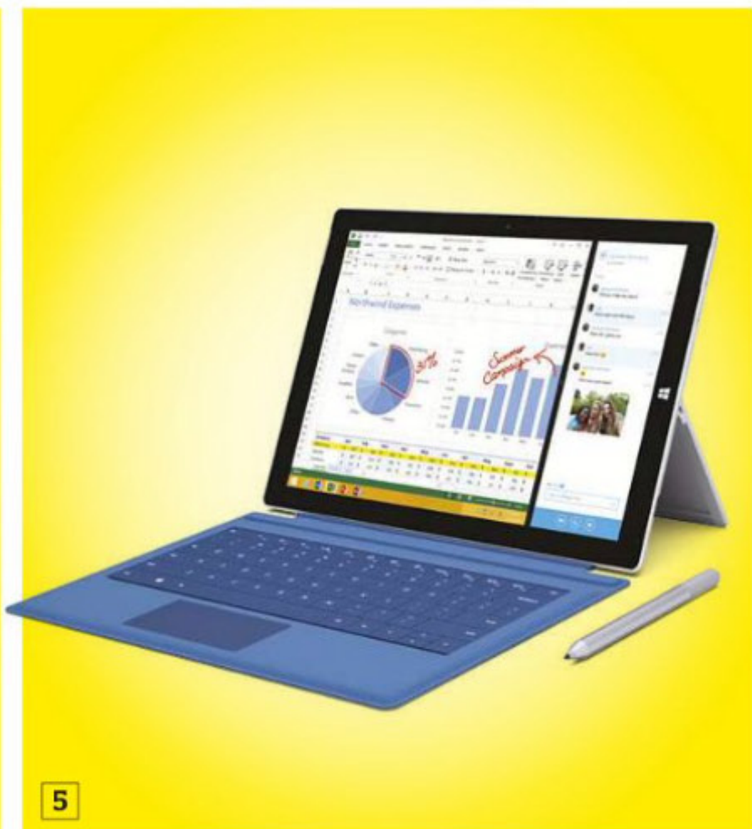



PHOTO: STEPHEN SHANKLAND/CNET, UNIVERSITY OF MANCHESTER





# APPLIANCES OF SCIENCE

## 1 YOU CAN STICK IT

Intel has squeezed an entire PC into this chocolate bar-sized device. To get Windows up and running, you slot the Compute Stick into your TV's HDMI slot, plug it in at the mains, then simply connect a mouse and keyboard via Bluetooth. With 32GB of storage and 2GB of RAM, it's powerful enough to handle most everyday tasks and even has a USB slot for plugging in any media. The best bit, though, is the price!

**Intel Compute Stick**
*$149 (£100), intel.co.uk*

## 2 TYRED OUT

As you munch through the miles on the motorway, there's tonnes of energy going to waste. The friction between your tyres and the tarmac generates a lot of heat, for example. So Goodyear's prototype tyre harvests this heat and converts it into electricity to charge a battery-powered car. Even stood still, black patches on the rubber will absorb sunlight and give you a few extra miles on the clock.

**Goodyear BH03**
*Price TBC, goodyear.com*

## 3 BEATS FOR BONEHEADS

Everyone knows how unsettling it is when you hear a recording of your own voice. That's because what we're actually used to hearing isn't our voice in the air, it's the sound waves travelling to our inner ear through our bones. These bone conduction 'headbones' deliver sound to your inner ear in much the same way, so that you can leave your ears unplugged and still be able to hear the outside world.

**Damson Audio Headbones**
*£99, damsonaudio.com*

## 4 FEELING BLUE

Solar power, fire power and man power can all be used to charge your phone – and now you can add water power to that list. The Blue Freedom is a personal hydroelectric power station made to charge your gadgets from flowing water. You just drop the turbine into the blue and secure the power station to the ground. One hour in the water will give your phone a whopping 10 hours of power.

**Blue Freedom**
*$319 (£213)*
*blue-freedom.net*

## 5 TABLET TRANSFORMER

It looks like a tablet, it works like a tablet, but what you're actually looking at is a fully-fledged PC. As well as doing all the things you'd expect a tablet to do, the Surface will work as your home computer, thanks to a new, more powerful processor that will run the majority of Windows software, where previous models often struggled. With the optional keyboard/touchpad dock, it'll be as deft as a laptop at more complex tasks, too.

**Microsoft Surface 3**
*£419.99, microsoft.com*

## 6 WAKEY-WAKEY!

Never sleep in again! The Wake smart alarm sits over your bed, and when it's time to get up the device's body heat sensors seek you out. Once it's got a lock-on, the alarm uses a parametric speaker to send ultrasound waves direct to your location – your partner won't feel a thing – and shines a focused light at your head. There's no snooze button: the alarm will only turn off when it sees you've left the bed.

**Wake smart alarm**
*$199 (£134)*
*luceralabs.com*

# SURVIVAL OF THE FITTEST

Cars are evolving. Today, they need to be cleaner, safer and smarter. **Daniel Bennett** tests the vehicles that are shaping motoring's future

PHOTO: ADAM GASSON

## THE CAR THAT... MAKES HYBRIDS DESIRABLE

# BMW i8

SAT IN THE car park of BMW's UK headquarters, where we picked it up, the i8 looks like it belongs in a different decade from the cars surrounding it. Unlike most concept cars, its futuristic features have made it to the factory floor – so it still has gull-wing doors that open upwards, it has wings at the rear that channel air over the body and it still has those blue paint details signifying the battery under the hood. The Philip K Dick aesthetics though, beautiful as they are, are the least exciting thing about it.

Underneath the i8's bonnet there's a 129bhp electric motor that powers the front wheels. Meanwhile in the back, right behind the cockpit is a 228bhp, impossibly small (1.5-litre) petrol engine sending power to the rear wheels. Somewhere in the back there's also a third tiny electric motor that helps recharge the lithium battery. Of course, all of this equipment is quite heavy, so BMW has made the doors and passenger cell out of a new composite material – carbon fibre reinforced plastic – which is 30 per cent lighter than aluminium. This cocktail means that the BMW can be frugal with your fuel when you want it to be (BMW says it can get up to 134mpg, though we averaged a laudable 40mpg). But flick the gear lever down into Sport mode, and this combination has another use: speed.

At the flick of a switch, the instrument cluster flashes red and the petrol engine snarls behind you. This in itself is not surprising, but what happens next is. The petrol motor throws all of its grunt into spinning the rear wheels, while the electric motor hauls you forward. All petrol engines will have an optimum power range, a spectrum in the rev counter where they run most efficiently. Outside of this range the power delivery drops off sharply, but in the i8 the electric engine simply fills in the gaps, hurling you forwards with almost brutal acceleration. There is nothing quite like it.

But even that's not what really won us over about the i8. Although this is a red-blooded sports car, its low $CO_2$ emissions (49g/km) mean it's exempt from road tax as well as London's Congestion Charge. It's also eligible for the government's plug-in car subsidy. So this car (insurance aside) won't kill your wallet after you've bought it. In fact, most of the time, since the UK's average journey length is under seven miles, you could in theory just potter around town and hardly spend a penny, using its 37km (23-mile) EV range. It's a money-saving combo that's proven so popular that owners can now sell the car for double the price they originally bought it for.

**BMW i8**
bmw.com
from £104,590

**Mercedes-Benz S 350**
mercedes.com
from £58,440

## THE CAR THAT... CAN DRIVE BETTER THAN YOU

# MERCEDES S-CLASS

A FEW HOURS into driving the S-Class, I was rendered immobile by London's pesky traffic. I'd thought the capital's roads might be quiet at 11pm; I was wrong. Still, it seemed like a good chance to poke and prod some of the S-Class's features. Twenty minutes later, I was enjoying an 'activating hot stone massage' from my seat, and I had 'ionized' the air, cleaning it of any contaminants. Bliss!

During the hour that I sat in traffic, it became clear that it was probably easier to list the features the car didn't have than the ones it did. For instance, while the cup holders will keep your drinks cool or warm, they won't cook a Pot Noodle. And while they have thought to fit a fridge in between the rear seats, there's no bar to store your 30-year-old single malt. How naïve. In all seriousness though, there are few vehicles on four wheels better equipped than the S-Class, and that's not just because of all the luxuries it offers.

Once the traffic dissolved, I got onto the A40 and flicked on the 'distronic' mode. The car's cameras took over the driving, guiding the vehicle between the white lines, blinking on the night vision on the dashboard whenever a pedestrian looked like they might cross the road. No one stepped out, fortunately, but the distraction meant I had begun to steer into the next lane. Just as the passenger side wheels grazed the white lines, the S-Class took over the controls, slowing the left wheels to pull me back into the lane before gently asking if I might need a rest. Maybe I did.

Nearer my destination in Amersham, I swapped the motorway for narrow country lanes, where I met a deer and its fawn idling in the road. Thanks to the enormous beam from the Merc's adaptive LEDs, their eyes gleamed at me in the dark. But the night vision had already flicked again to warn me of the hazard ahead.

By the end of my time with the Mercedes S-Class, I wasn't quite sure whether I had driven more miles or the car had. Either way, it's only a matter of time before I'm happy to hand over the controls for good.

PHOTO: NEWSPRESS X3

## THE CAR THAT... IMPROVES WITH AGE

# TESLA MODEL S

WHEN THE TESLA landed on UK shores last year, it blew us away. This pioneer proved that using batteries to power your car didn't have to mean sacrifice. The 355km (240-mile) range won't suit every driver, but it's plenty for most. Indeed, this time around we got to use Tesla's new supercharger network, and once we'd parked up and plugged in, it only took half an hour to top up. But in the time since our first drive, the car's power train has become its least interesting aspect.

The most amazing feat of the Tesla is how it has evolved over time. Normally a petrol or diesel car stays the same once it's left the showroom, but the Model S is different. The car is riddled with computers, and every part of the vehicle is connected to them. This means that Tesla's engineers are able to send upgrades through the air via the car's 3G connection. These updates download while the car's parked up at night, so when you get back into your Model S the next morning, it's got even better.

And these updates are more than superficial. For example, the last update added automatic emergency braking to the car – so that the Model S will stop if it detects you're about to slam into something. There was also a Valet Mode added in the last update that tames the Tesla's performance to make sure anyone else driving it behaves themselves. Best of all, some tweaking of the car's algorithms actually made the Model S faster, shaving 0.1 seconds off its 0-60mph time.

Even more exciting is what's to come. The next update promises to teach the car to drive itself on motorways, and come running when you 'summon' it from the garage. Both hint that the car is nearing the point where it'll soon be able to drive itself entirely – its creator, Elon Musk, just has to wait for the law to catch up with his technology. And it begs the question: why can't all our cars be upgradeable in this way?

The Model S is packed full of innovative tech

Tesla superchargers can juice up the car in half an hour

**Tesla Model S**
teslamotors.com
from £54,500

## THE CAR THAT... REMOVES DISTRACTIONS

# AUDI TT

**Audi TT**
audi.com
from £29,770

Keep your eyes forward with the virtual cockpit

FROM THE OUTSIDE this diminutive sports car looks like just that – a featherweight car that'll be as light on features as it is on the scales. But the TT's appearance belies what is an incredibly clever little machine.

The trouble with the cars we've mentioned so far is that, with all of their incredible features, they can be a little distracting. Doubly so, since most of these options are accessed via a central console that's lower than the windscreen you actually should be looking at. Audi has remedied this with what it's calling a 'virtual cockpit'.

What this means is that behind the steering wheel sits an LCD screen that's the motoring equivalent of an iPad. For example, when you hit the Sat-Nav button, the speedo and rev counter retreat to the sides, presenting a wonderful detailed map. You can flick through your media and all the car's different options and features, without ever fully diverting your attention from the road ahead. You never feel like you're dicing with death at 70mph just because you wanted to turn the air conditioning down.

It's also the small touches that make a big difference. For example, the dash is perfectly carved out to match the steering wheel, so no information is obscured by the wheel. The buttons are sparse but well placed, so you don't have to look away from the road to find them. For example, the car's temperature can be adjusted via the fans themselves. Another smart touch is the jogwheel which has a touch-sensitive surface so you can scrawl out addresses and contacts with your fingers. These might seem like small things, but as I drove across Bristol, I soon realised that this was the best designed interior I had ever driven in.

PHOTO: NEWSPRESS X3

# THE CAR THAT... COULD CLEAN UP OUR CITIES TOYOTA i-ROAD

AS INGENIOUS AS the previous cars were, they won't make a dent in one of motoring's biggest problems: congestion. Cars are choking the world's cities and the prognosis isn't pretty. A 2014 study by the Centre for Economics and Business Research calculated that British motorists spend four days a year sat in traffic, and that over the next 15 years congestion will cost the UK £300bn.

Toyota is trying to come up with a solution, and this is its latest attempt: the i-Road. Think of it as a motorised Boris bike with a 60km/h (37mph) top speed and a 48km (30-mile) range. The idea is you drive to the city, park up and swap your car for one of these battery-powered trikes. That might not sound great, but the i-Road makes a lot of sense.

Compared to the futuristic exterior, the interior is reassuringly familiar: there's a steering wheel, indicators and a dashboard. But that's where the similarities end. Steer left or right and the whole body gracefully leans over, like a speed skater shifting their weight into the corner. But unlike ice skaters, there's no risk of falling over. As the front suspension pushes one wheel downwards, gyroscopes and inertial sensors combine to determine just how far the car can tilt. The actual steering is done by the rear wheel, which means the back swings round when you want to make a tighter angle. It all sounds, well, slightly mad, but it took all of three minutes weaving through the streets of Grenoble (the only place in Europe you can drive one) for us to fall in love.

Imagine an entire city filled with cars like the i-Road. Traffic would all but disappear, smog would clear and the streets would be blissfully quiet. This is exactly what they're testing in Grenoble, where you can rent the car for €3 for 15 minutes and €1 for every quarter-hour after. Sadly the i-Road is still only a concept car right now, and as much as we'd love to see Bristol buzzing with little i-Roads, they're unlikely to reach here any time soon. But Toyota has said it's committed to the idea, so watch this space.

**Toyota i-Road**
Toyota.com
price TBC

DANIEL BENNETT is reviews editor of *Focus* magazine

# THE EXISTENCE OF BLACK HOLES

## BY BRIAN CLEGG

Fiction depicts black holes as yawning voids that lurk in deep space, gobbling up any planets in their path. The idea of 'dark stars' dates back to the 18th Century, but it was 1964 before hard evidence emerged

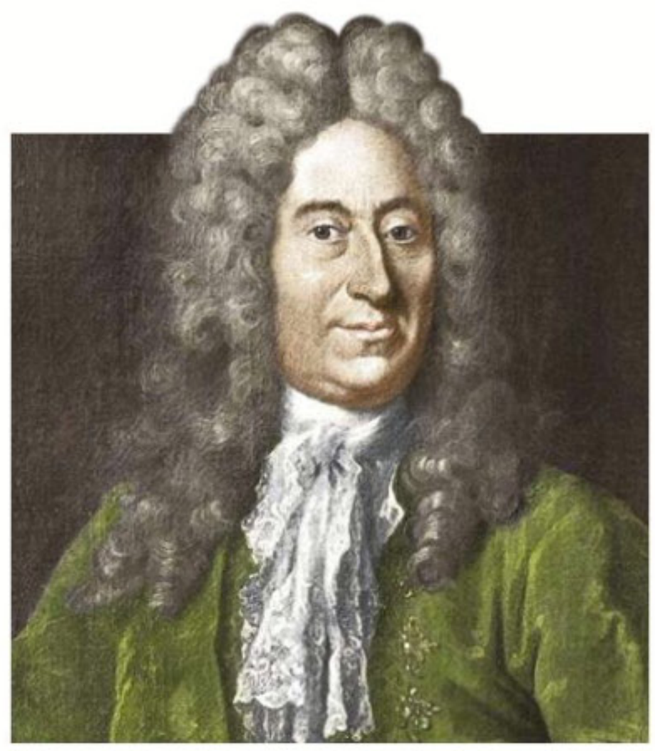
BLACK HOLES HAVE escaped from astrophysics into the everyday imagination. Yet the gaps in our knowledge of their nature and even, possibly, their existence are considerable.

Black holes were born from theory, not observation. We have known about conventional stars for as long as we've been able to look up at a clear night sky. But no one ever saw a black hole. Instead, they were predicted to exist at a time when there was no way of checking whether there was any such thing out there. And that prediction happened not once, but twice.

The first inspired thinking on the matter was back in the 18th Century. The man who dreamed up what he called 'dark stars' was John Michell, a Cambridge scientist who later became a clergyman. It was from his rectory that he came up with the concept, combining two key ideas of the latest science at the time.

One was escape velocity. Michell knew that when a bullet is shot straight up into the air, it has just two forces acting on it once it leaves the gun – air resistance and gravity. As it gets higher, both of these forces weaken. The air gets thinner and, as Newton had made clear, gravity's attraction drops off with the square of the distance between the centres of the bodies involved – in this case, the bullet and the Earth.

A typical bullet from the black powder guns of Michell's day could travel as fast as 300 metres per second. But despite this impressive velocity, the forces acting to slow it brought the bullet back down to Earth. Michell, though, knew that a bullet travelling about 37 times faster would be able to overcome the Earth's attraction and fly off into space. It would have achieved escape velocity. He combined this idea with a discovery from the 1670s, when Danish astronomer Ole Rømer realised that an apparent variation in the timing of Jupiter's moons was caused by the varying time that light took to reach us from the planet.



Ole Rømer calculated a speed for light, settling the dispute over whether it travelled instantly, or just very quickly

### LIGHT CONVERSATION

Ever since ancient times, there had been arguments over whether light travelled instantly, or just extremely quickly. Rømer found evidence for a measurable speed, as the changing relative positions of Jupiter and Earth in their orbits varied the time that light took to reach us. He calculated light's speed to be around 220,000km/s. In the following 100 years, this figure was measured more accurately so that Michell was working with something closer to our current 300,000km/s. But the specific value didn't matter – the point was that light had a speed.

Combining the two concepts of escape velocity and light having a

PHOTO: ALAMY, GETTY

Computer rendering of a supermassive black hole. Jets of matter are emitted at right angles to the accretion disc

## > IN A NUTSHELL

Studying black holes is particularly difficult as they cannot be seen directly. The work of eminent scientists like Albert Einstein, Kip Thorne and Stephen Hawking has helped increase our understanding, but many gaps in our knowledge still remain to this day.

finite speed, Michell wondered what would happen if a massive star had an escape velocity that was above the speed of light. The more mass in a body, the higher its escape velocity. Therefore, in principle, there could be a star so vast that even light would not escape from it. Such a 'dark star' would have to be immense. Even though the escape velocity from the surface of the Sun, for instance, is over 600km/s, it is still far lower than the speed of light.

Michell's theory was based on an incorrect assumption – that light was made up of normal particles that could be slowed down like any other projectile by the force of gravity. But the idea of these mysterious 'dark stars' faded into history.

Fast-forward to the 20th Century and Karl Schwarzschild revived the theories in the heat and horror of World War One. It was 1915 and the 41-year-old German physicist had volunteered to join up with the German army. Somehow, perhaps as a distraction from the devastation around him, he found time to think about Einstein's elegant equations and his brand new theory of General Relativity. Einstein's equations are too complex to provide a universal solution, but Schwarzschild solved them for the special case of a spherical body that was not spinning.

It emerged from the mathematics that if all the mass of that body was crammed into a sphere of a size now called the Schwarzschild radius, the distortion in space-time would be so great that light from the object would never escape. Anything closer than a sphere around the body of that radius would travel through a surface of no return, the black hole's event horizon.

The most obvious source of such a body would be a collapsing star. In normal operation, a star's nuclear reactions fluff it up against the pull of gravity. But once those reactions start

## THE KEY EXPERIMENT

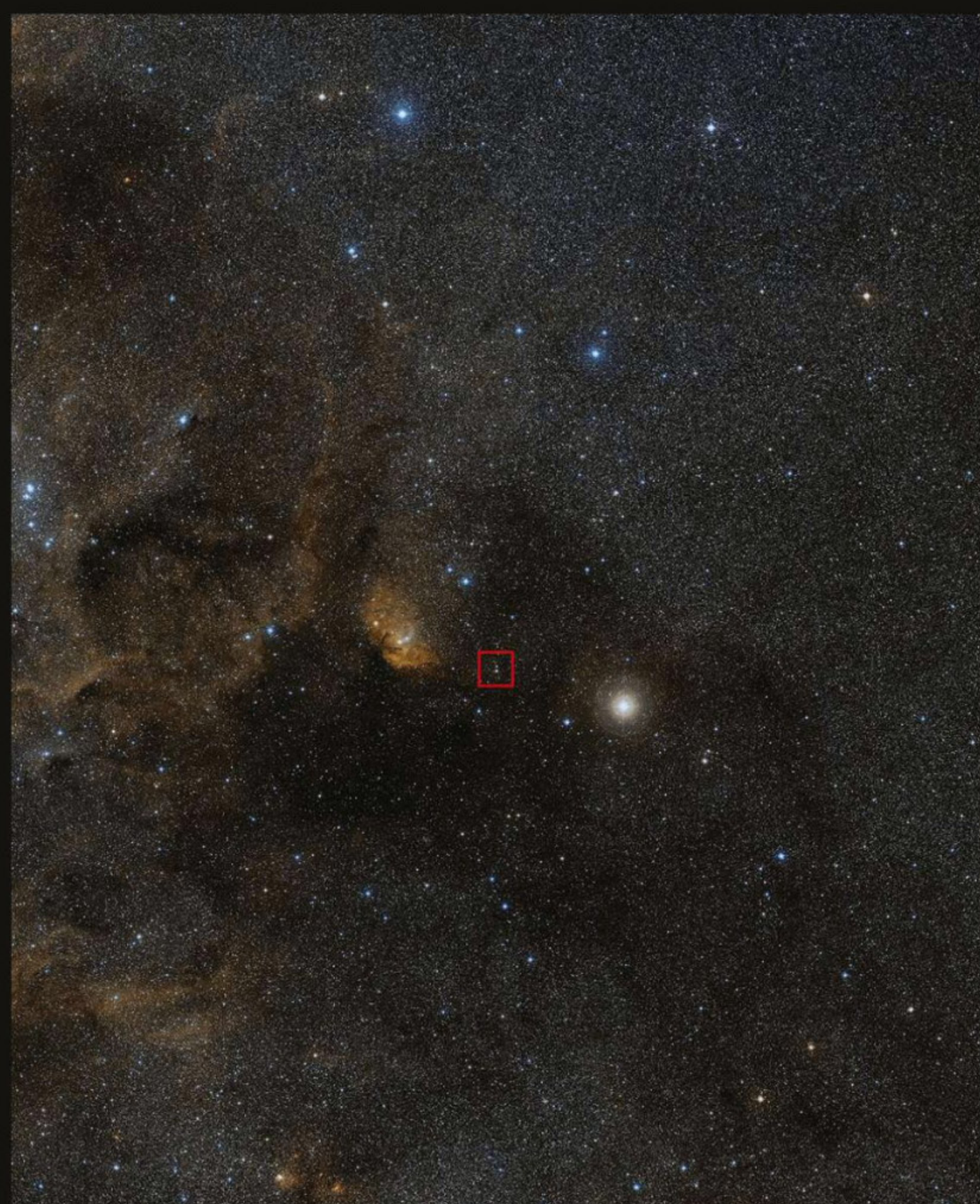
Black holes are tricky to study as even the closest one lies many light-years away, but scientists can identify candidates by observing their X-ray emissions

PERFORMING EXPERIMENTS ON black holes is a non-starter, as the nearest candidate so far detected is around 3,000 light-years away.

Confirmation of Cygnus X-1, the first significant candidate found, took a number of years as no single observation was capable of establishing such a remarkable find.

In 1964, a rocket launched from the White Sands Range in New Mexico discovered a strong X-ray source in the constellation of Cygnus. Also in 1964, two sub-orbital rockets mapped out X-ray sources, pinning down the location of Cygnus X-1.

In 1971, observations by the Uhuru X-ray satellite telescope showed that the Cygnus X-1 source underwent rapid oscillations, suggesting it was a compact object that was smaller than the Sun. That same year, radio telescope observations linked the X-ray source to the star HDE226868. This blue supergiant would not itself produce X-ray emissions, implying that it had a companion. Also in 1971, astronomers at the Royal Greenwich Observatory and Toronto's David Dunlap Observatory made further observations of HDE226868. They confirmed that it was in a binary with a massive but compact object. And in 1972, Charles Bolton at Toronto was the first to state definitively that this object was a black hole. This view was generally accepted by 1973.



Cygnus X-1 (location outlined in red). In this image, the blue supergiant companion star can be clearly seen to its right

PHOTO: ALAMY X2, GETTY X3, NASA

to fade, matter in the star can collapse. The expectation is that this collapse would be halted by a quantum effect called the Pauli exclusion principle, forming an intensely dense neutron star. If the star were massive enough, though, exceeding about three times the mass of the Sun, the exclusion principle should be overcome and the collapse would be unstoppable. In principle, the material in the black hole would continue to collapse all the way to a dimensionless point – a 'singularity' with infinite density and a force of gravity that headed off to infinity as it was approached. In reality, we don't know what would actually happen, because the singularity is an admission that our physics has broken down.

## DOWN THE HOLE

For a good time after Schwarzschild, black holes were purely theoretical. Or at least collapsed stars were, as they were yet to receive their more intriguing moniker. 'Black hole' is often ascribed to the American physicist John Wheeler, but its origins are shrouded in mystery. The term was first reported at an American Association for the Advancement of Science meeting in January 1964. It's not certain who used it, but Wheeler soon picked up the term and popularised it. It might seem that searching for black holes would be a waste of time. How do you see something that doesn't give off light? But as the physics of black holes developed, scientists realised that indirect routes were available.

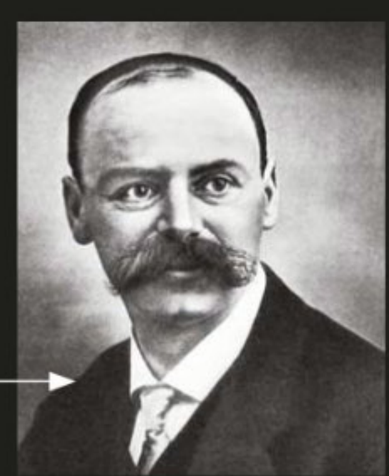
As astronomers can't see the hole itself, they need to look for its side effects. When matter is dragged into a spinning hole, and pretty well everything in the Universe does spin, it should produce an 'accretion disc', glowing brightly as a result of friction, and would also generate distinctive 'jets' from the poles. Then there are the gravitational effects. We might see nearby bodies influenced by the black hole. This is a venerable technique, and was used in the past to infer the existence of Neptune. Astronomers studied the way the orbits of the other planets were influenced by Neptune's gravitational pull.

Finally, there is 'Hawking radiation'. Stephen Hawking surprised himself as much as anyone else when in 1974 he realised that black holes

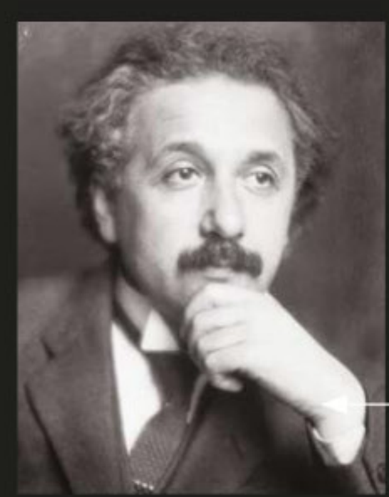
## CAST OF CHARACTERS

Five incredible physicists who have helped us with our understanding of black holes

**John Michell (1724-1793)**
Michell was born in Nottinghamshire and spent his academic life in Cambridge working on geology, gravity, magnetism and astronomy. After his marriage in 1764 he spent the rest of his life as a clergyman, most notably at Thornhill in Yorkshire. Here he continued with his scientific work from 1767 until his death.



**Karl Schwarzschild (1873-1916)**
Schwarzschild was a German physicist and astronomer who was born in Frankfurt. He worked as a professor for several years in Göttingen, then moved on in 1909 to become director of the town's observatory before heading up the Potsdam Astrophysical Observatory. He volunteered for the German army in 1914 and died of a skin disease in 1916.



**Albert Einstein (1879-1955)**
German-born Einstein is best known for his theories of Special Relativity and General Relativity, laying the foundations of quantum theory. He moved to the USA in 1933 to escape Nazi Germany and took up a position at the Institute of Advanced Study in Princeton.

**Kip Thorne (1940-)**
Thorne is an American astrophysicist whose studies of General Relativity have resulted in a wide range of predictions on black holes, wormholes and time travel. Thorne was consultant to the best cinematic representation of a black hole to date, the 2014 movie *Interstellar*.

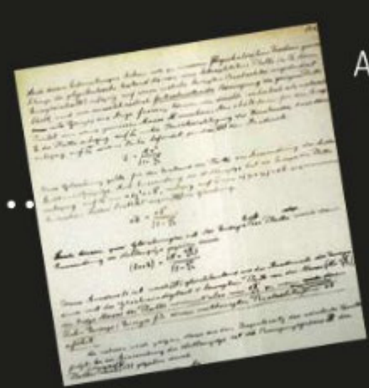
**Stephen Hawking (1942-)**
Cambridge-based Hawking is probably the most famous living physicist and has become iconic for his bestselling book *A Brief History Of Time* and for defying the onset of motor neurone disease to continue working into his 70s. His work has largely involved the General Theory of Relativity and cosmology.

## TIMELINE

Theories surrounding mysterious black holes have only been around since the 18th Century

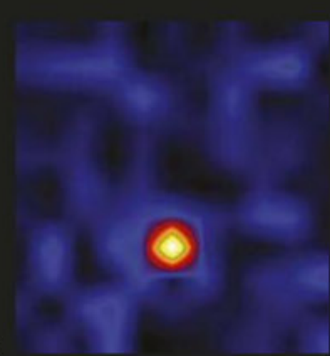
**1783** John Michell's 'dark stars' paper is read at the Royal Society. Michell hoped to deduce the mass of stars from their effect on light, and thought a massive enough star would be able to stop light entirely.

**1915** Albert Einstein publishes his field equations. This set of 10 equations at the heart of General Relativity describe gravity as a curvature of space and time.



**1916** Soon after Einstein publishes the theory of General Relativity, Karl Schwarzschild publishes his paper with the first non-trivial solution. This is applied to a non-rotating sphere, derived the previous year.

**1971** First candidate black hole is found. Cygnus X-1 is an X-ray source that was first detected in 1964 and is thought to be a binary star, where material from one star is accelerated into a black hole.



**1995** Star S2 (Source 2) is observed by the Max Planck Institute and UCLA. It orbits an apparent supermassive black hole, Sagittarius A*, at the heart of our Milky Way.

**2012** The best evidence to date of a star being ripped apart by a supermassive black hole is detected by the Pan-STARRS telescope on Hawaii and analysed by a Johns Hopkins University team.

PHOTO: GETTY, NASA X2, ROB RATKOWSKI, SCIENCE PHOTO LIBRARY, THE ROYAL SOCIETY

couldn't truly be black. The idea came from his understanding of quantum physics – the science governing very small things – and in particular the 'uncertainty principle'. This said that localised energy can fluctuate significantly over small periods of time, allowing pairs of quantum particles to emerge and then disappear again before they are observed. If this happens near a black hole's event horizon, one of these 'virtual' particles could be pulled in while the other flies off. These stray particles make up Hawking radiation. This is unlikely to be detectable at any great distance.

After Schwarzschild's solution, black holes seemed the natural end for the right kind of stars with masses at least three times that of the Sun. But this particular scale is not a limitation of the black hole itself, merely the formation mechanism. In principle, black holes could exist on any scale from the microscopic all the way through to millions of times the mass of the Sun. There are broadly four categories, two of which have probably been detected.

At the tiny, totally hypothetical end of the scale are micro black holes and quantum black holes. A micro black hole would form, for instance, if the Earth collapsed, forming an event horizon about 9mm across, though thankfully there is no known mechanism for this to occur. Quantum black holes are even smaller, from a scale of around 5,000 protons up. In principle, they could be produced in a particle accelerator and would almost immediately decay. Current accelerators don't have the energy to produce one unaided, but if the Universe has extra dimensions, this could reduce the energy threshold to something accessible.

The best evidence we have for conventional black holes, formed from the collapse of a dying star, is X-ray binaries. In these objects, material is accelerated from one normal star into an invisible star, giving off X-rays. This can happen with a neutron star, but if the 'eating' star has more than about three times the mass of the Sun, it should in theory be a black hole.

The first X-ray binary widely recognised as containing a black hole was Cygnus X-1. A powerful X-ray source was detected in 1964, and was identified as a black hole candidate in 1971. A blue supergiant star in the

## NEED TO KNOW

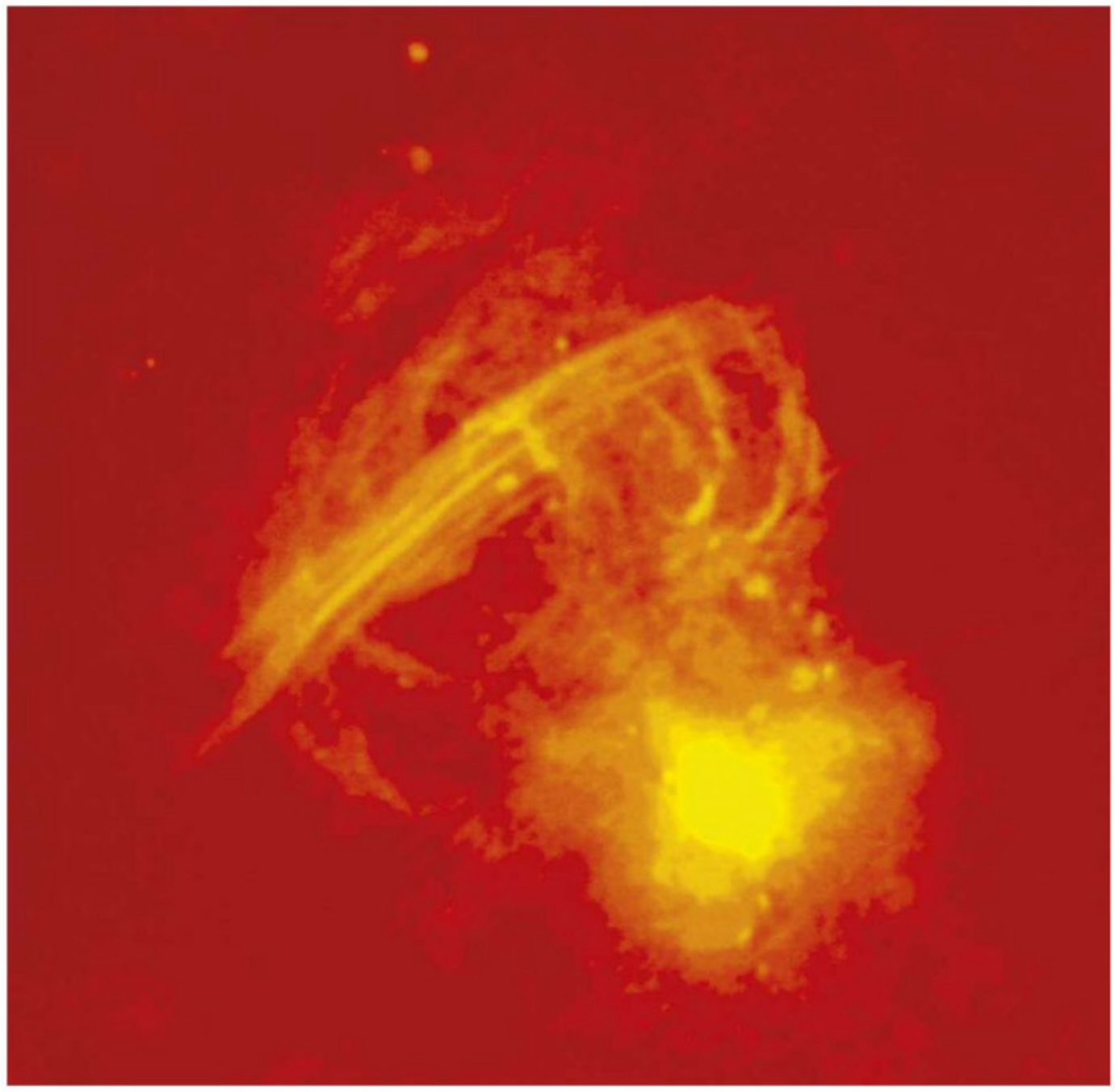
A handy list of the terminology surrounding black holes

**1 ACCRETION DISC**
Rotating matter is pulled into a disc shape by a star (part of the formation process of a solar system). In the case of black holes, nearby matter is accelerated intensely by gravity, giving off a bright glow.

**2 JET**
Streams of matter accelerated to nearly the speed of light are emitted at right angles to the accretion disc. The cause of these jets is uncertain, though they may be the result of a complex magnetic field.

**3 PAULI EXCLUSION PRINCIPLE**
This principle of quantum mechanics establishes that two fermions (a type of subatomic particle) cannot be in an identical quantum state. This results in 'exchange interaction', which is like a short-range force keeping fermions apart – except in extreme conditions like black hole formation.

**4 SINGULARITY**
In the case of astrophysics, a singularity is a mathematically predicted condition where space-time becomes so locally distorted by gravitation that the force of gravity tends to infinity and current theories of physics break down.



The Very Large Array telescope took this false-colour image of Sagittarius A, which lies at the centre of the Milky Way. A bright radio source, Sagittarius A*, is located in this region and is believed to be a supermassive black hole

binary was being stripped of material by the X-ray source, which appeared to have a mass in the region of 9 to 15 times that of the Sun. In 1975, Kip Thorne and Stephen Hawking made a bet as to whether this was, indeed, a black hole. Hawking, on the 'no' side, paid up in 1990 when better observational data was obtained.

## BACK TO BLACK

Since 1990, the identification of Cygnus X-1 has become less certain. This is because the companion star is very large, which makes it difficult to be sure of the mass of its 'compact object' companion. Many other candidates have been detected since, although evidence remains indirect and is based on theoretical assumptions about the maximum size of a neutron star that may not be borne out in practice.

Supermassive black holes are thought to exist at the heart of most galaxies, possibly forming from the collapse of a dense gas cloud in the galaxy's early life. Such black holes may play a significant role in galaxy formation, giving the galaxy a hub to coalesce around. Candidates have been detected at many galactic centres, thanks to unusually high electromagnetic emissions from these regions, and the odd motion of nearby stars.

A star called S2 orbits the centre of the Milky Way at about four times the radius of the orbit of Neptune. From S2's path, it seems likely that it's orbiting something with a mass of about 4.3 million times that of the Sun. The object matches the position of an intense radio source called Sagittarius A*, and there is currently no other explanation for this except a supermassive black hole. Elsewhere, stellar destruction gives a clue. Unusually bright light signatures in distant galaxies are thought to be stars being ripped apart by supermassive black holes.

All is not certain, though. A 2014 study suggested that black holes won't form at all. The authors suggest that as a star collapses, Hawking radiation during the collapse would reduce the mass of the star sufficiently that the black hole never reaches completion. There would be an ultra-dense body acting like a black hole, but without the singularity or the event horizon. The paper is not universally accepted, but illustrates how our understanding of black holes is primarily driven by theory. Whatever the reality, we can expect more surprises. ■

**BRIAN CLEGG** is author of many science books, including *Science For Life: A Manual For Better Living* and *Gravity: Why What Goes Up, Must Come Down*

**Find out more**

Listen to astronomer Dr Marek Kukula explain black holes and the Big Bang to *Today* presenter John Humphrys
http://bbc.in/1AvQXdm

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# TO DO LIST

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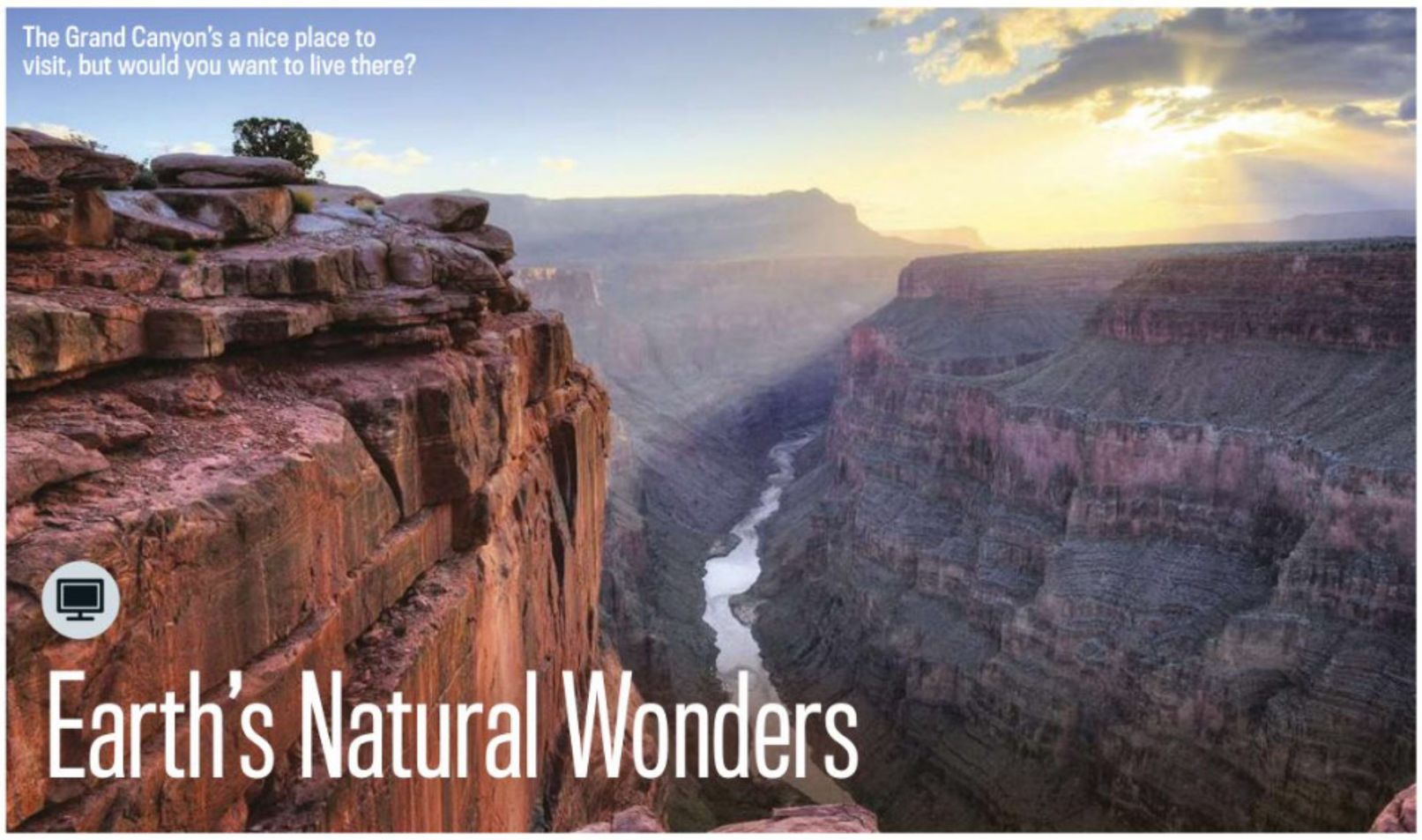
## PLAN YOUR MONTH AHEAD WITH OUR EXPERT GUIDE

### PICK OF THE MONTH



The Grand Canyon's a nice place to visit, but would you want to live there?

## Earth's Natural Wonders

FROM MOUNT EVEREST to the Grand Canyon, certain natural locations are recognised worldwide for their beauty and sheer scale. But it's one thing to admire stunning visual impact, quite another to imagine living there. That's where this series goes beyond the striking camerawork, to tell the stories of human lives happening in some of Earth's most extreme places.

To you, Everest may be a pub quiz fact or iconic image, but to icefall doctors like Temba, it's a hazardous workplace environment. On their expertise depends not only their own safety, but the lives of visiting climbers. You may think of Kilimanjaro only as a potential sponsored trekking destination, but if you lived in its shadow you'd probably be too busy keeping elephants away from your cattle-grazing to admire its majestic peak.

Many of the people living in these photogenic locations are far closer to nature than we are, watching from the comfort of our sofas. But before you get too misty-eyed with envy, brace yourself for the brutal struggle to survive and thrive that comes with the territory. Borneo's giant caves conceal treasure, in the form of bird's nests for bird's nest soup. But to bring back the valuable commodity, the locals must make a risky journey of almost 100 metres by bamboo ladder. And if you're sick of telling your kids they don't know how lucky they are, make sure they catch episode one, in which a group of nine-year-old boys endure an initiation ceremony in the Amazon jungle. They suffer the agonising stings of hundreds of fire ants.

From remote mangrove forests to the merciless Mongolian steppe, the locals see wildlife as far more than spectacular TV fodder. At best, it can help you feed your family, like the whale sharks that cooperate with deep-sea fisherman. At worst, its aim is to feed on you.

The locations alone read like a bucket list of awe-inspiring destinations. Add in the real-life drama and intriguing stories of little-known parts of the world, and we're set for a rewarding series.

**TIMANDRA HARKNESS**

BBC ONE

**Watch *Earth's Natural Wonders* on BBC One this spring. Check radiotimes.com for more details**

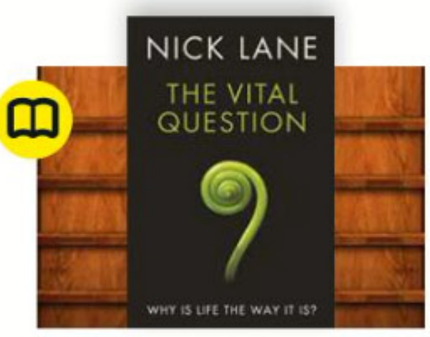
### DON'T MISS!

**China's Man Made Marvels**

A four-part series looking at China's role as a world leader in engineering p94

**Cheltenham Science Festival**

Guest speakers including Brian Cox and Alice Roberts discuss Mars, quantum computing, the multiverse and more p97




**The Vital Question**

This new book asks why complex life on Earth has evolved only once, and not many times over p98

PHOTO: ISTOCK

# WATCH

## TV & ONLINE

WITH TIMANDRA HARKNESS

13 MAY

### Danger Decoded

National Geographic, 8pm

Find out what happens to this chap

IT'S EASY TO see shocking footage online and think, "How could they not see THAT coming?" Now's your chance to try to spot the disaster before it happens, with a new series that uses real footage and statistical insights. When the action is paused, you have three computer-generated options to choose from. Can you predict the outcomes?

18 MAY

### Secrets Of The Earth

Eden, 8pm

Hurricane Isabel from the ISS

IMAGINE ALIENS STUDYING our planet in the same way we look at Jupiter, Venus, or more distant worlds. That's the approach this series takes to Earth. Scientists visualise its birth, then unveil the impact of gravity on our orbit around the Sun, of cosmic rays on clouds, and even the way invasive species reshape our biosphere.

22 MAY

### Churchill's Toyshop

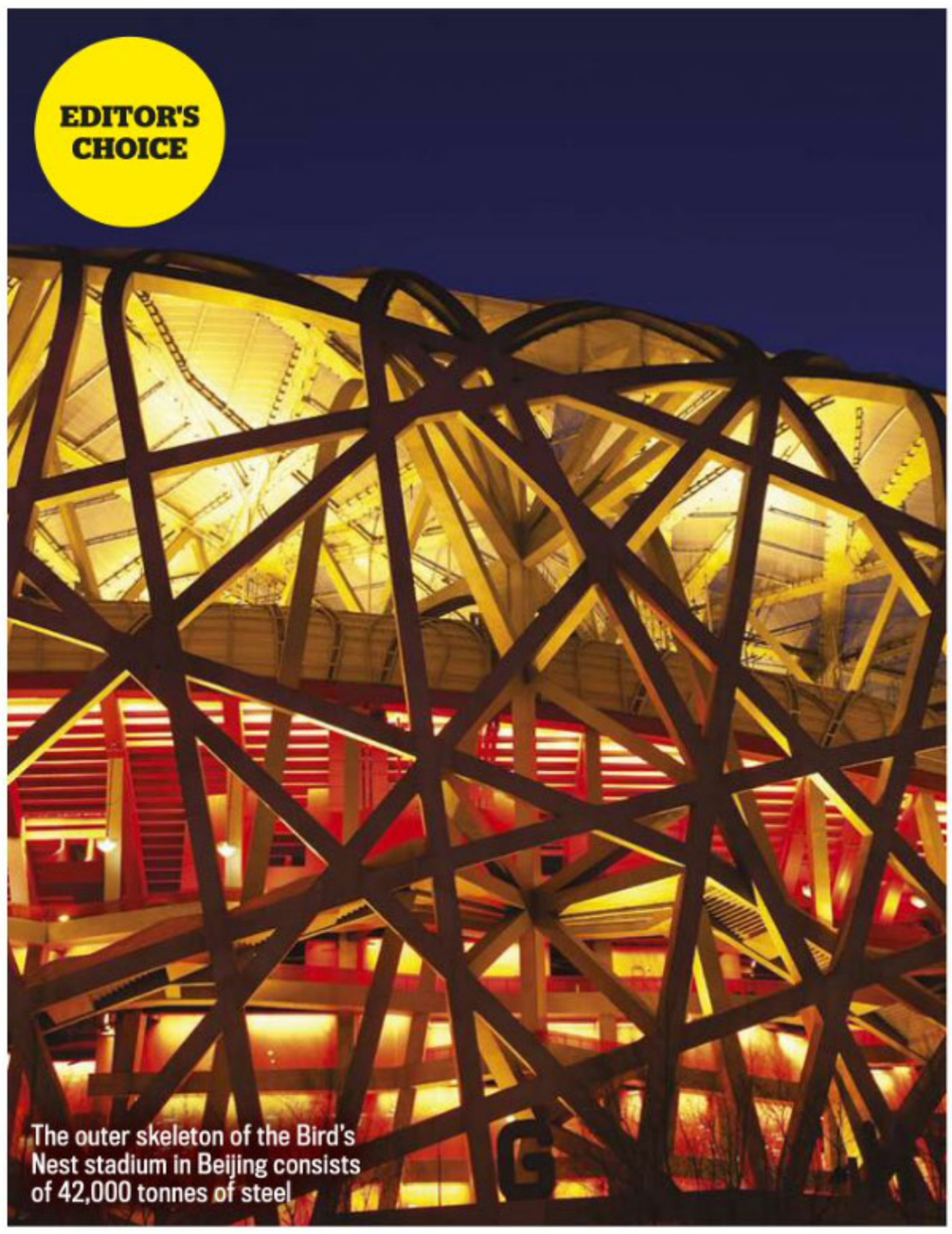
Discovery, 9pm

Stuart McRae with the sticky bomb, as recreated in this programme

DURING WORLD WAR II, Britain's technological arms race with the Nazis held the key to victory. This documentary uses interviews and archive footage to tell the story of Churchill's clandestine research institute. Modern experts use original blueprints to recreate some of the original inventions, lost for 70 years – sometimes with good reason.

**TIMANDRA HARKNESS is a stand-up comedian and a regular presenter on BBC Radio 4**

PHOTO: NATIONAL GEOGRAPHIC CHANNEL, ISTOCK, DISCOVERY NETWORKS, NASA




The outer skeleton of the Bird's Nest stadium in Beijing consists of 42,000 tonnes of steel

5 MAY

### China's Man Made Marvels

Quest, starts 5 May, 10pm

CHINA'S ECONOMIC PROGRESS has been impressive. By industrialising so fast, it has lifted millions from poverty.

Less often recognised, in spite of China's centuries-old role as engineering pioneer, is the advanced technology that propels the world's most populous country into the 21st Century. Don't be fooled by China's role as a manufacturing centre for other countries – it's long been an innovation nation.

Over 1,000 years ago, the Chinese were constructing giant statues of the Buddha, and using ingenious construction materials to build defensive walls that survive to this day. Today, the same ambition, technical skill and scientific creativity allow them to dazzle the world with very different structures. Airports, subways, the world's highest railway and the Bird's Nest stadium all showcase China's arrival as a leading world power.

This four-part series brings to life China's engineering marvels – ancient and modern – with location filming, CGI graphics and interviews. Discover the ambition of China's projects, but also the challenges that face the teams trying to bring them to fruition. With natural hazards and human fallibility to overcome, the economic and bureaucratic elements start to look trivial.

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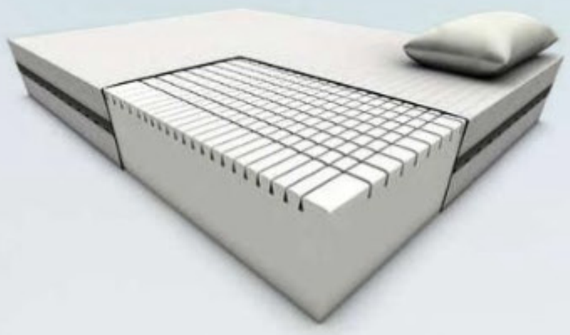

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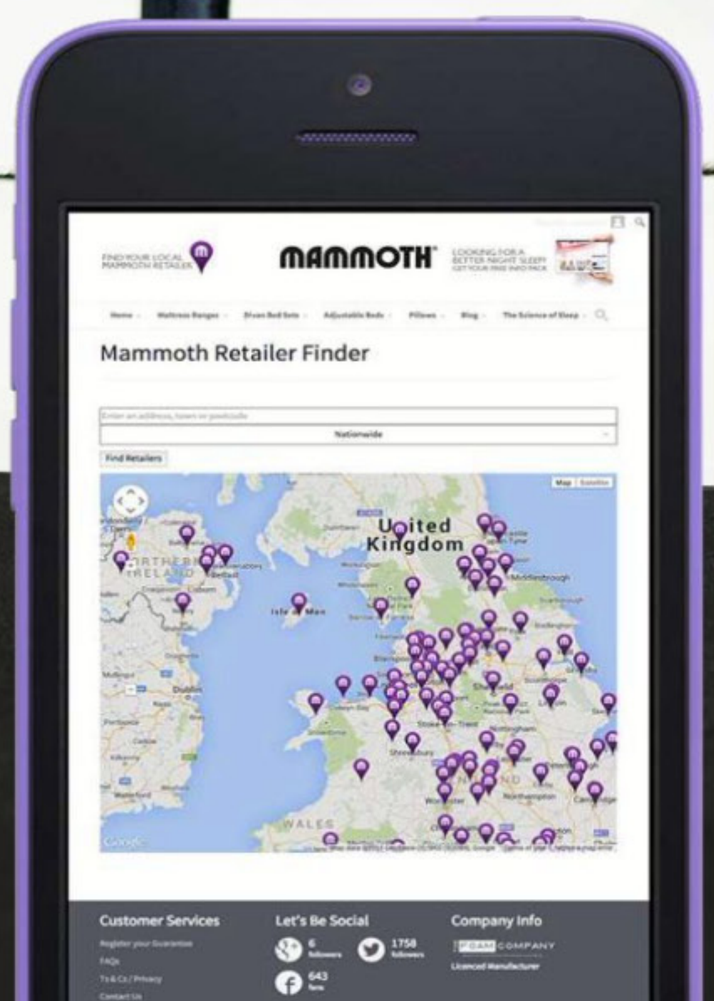
Olympic, European and Commonwealth Champion Greg Rutherford, MBE

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# LISTEN

## BBC RADIO PROGRAMMES

WITH TIMANDRA HARKNESS

1 MAY

### Britain's Hidden Talent: Female Engineers

BBC Radio 4, time TBC

ONE-QUARTER OF Sweden's engineering workforce are women. In Britain, 6 per cent of engineers are female. Susan Marling asks historians, educators and some of the UK's prominent women engineers what's happening, and meets employers and universities trying to change the gender imbalance.

6 MAY

### The Truth About Aids

BBC World Service, various times

How has HIV changed lives?

IT WAS ONCE a mysterious and unstoppable killer, but HIV/AIDS is now giving ground to medical research and changing sexual behaviour. This six-part series, presented by researchers, doctors, psychologists and a politician, looks at the history, science and policy challenges.

19 MAY

### The Origin Of War

BBC Radio 4, 8.15pm

ARE WE HARD-WIRED for war? Evolutionary biologist Steven Pinker, famously critical of The Blank Slate thesis of human nature, thinks not. Geoff Watts presents this documentary weighing the evidence for and against the evolutionary origins of warfare.

26 MAY

### The Business Of Genetic Ancestry

BBC Radio 4, 11am

DO YOU HAVE any Viking in you? Want to find out? Send off for a genetic home-testing kit and science will tell you. Or will it? Presenter Adam Rutherford unravels the extravagant claims of ancestry companies.

Geneticist Adam Rutherford: Viking?

ONLINE

### Understanding Ebola

bbc.co.uk/programmes/p02m8zk9

STATISTICAL SUPERSTAR HANS Rosling and Ebola expert Margaret Lamunu join Tim Harford to talk about fighting the disease in West Africa. This is part of a BBC World Service Ebola season that also includes a visual guide: bbc.co.uk/programmes/p02mrlx5

# TOUCH

## SMARTPHONE & TABLET APPS

WITH KATE RUSSELL

### Changers $CO_2$ Fit

iOS 7.0 or later, iPhone/iPad, Android 4.0.3 or later, Changers, free

ACTIVITY TRACKERS ARE all the rage. But if you're not really that interested in your fitness levels, then how about using the health of the planet as an incentive to get yourself moving? That's the idea behind *Changers $CO_2$ Fit*. This innovative app encourages you to travel by foot, bicycle, or skateboard – basically anything that doesn't emit $CO_2$ – instead of jumping in the car. The app then rewards you for green behaviour with 'Recoins'. You can't spend these coins on anything other than offsetting any $CO_2$-emitting journeys you make, but the idea to help 'gamify' living a carbon-neutral life is a good one. You can even compare yourself with other people.

### Pocket Universe

iOS 5.1.1 or later, iPhone/iPad, John Kennedy, £2.29

STARGAZERS CAN USE the *Pocket Universe* app to tour the planets in the Solar System, or use the virtual sky feature to identify celestial objects above. The app even tells you what you're looking at – although the synthesised voice does sound a little crazed, especially if you move your viewpoint around too quickly. The app has loads of extra features and it links to the latest astronomy news, so you need never miss another meteor shower... provided that the clouds clear long enough to catch it.

### Earth Primer

iOS 7.0 or later, iPad, Chaim Gingold, £7.99

ON A HAZY summer's day it's hard to imagine that we're hurtling through space on what is, essentially, a fiery ball of molten lava covered with a thin crust of metal and rock. It's a lot easier to picture this when you start exploring the interactive pages of *Earth Primer*. This brilliantly visual app helps you discover how things work using playful animations and rich sound effects. Starting at the Earth's core, you're encouraged to push and prod with your fingertips to see how the forces of nature react over thousands of years of evolution.

**KATE RUSSELL is a technology journalist and BBC *Click* presenter**

PHOTO: ISTOCK X3, THE INSTITUTE OF ART AND IDEAS, CONOR CAHILL, BBC,

# VISIT

## EVENTS & EXHIBITIONS

WITH JHENI OSMAN

UNTIL **MARCH** 2016

### Wellcome Image Awards 2015

MOSI, Manchester, free, mosi.org.uk

GET UP CLOSE and personal with a greenfly's eye and a cat's tongue at this exhibition of 20 award-winning science images.

**8** MAY - **6** SEPTEMBER

### Myths And Monsters

Natural History Museum, Tring, Hertfordshire, free, nhm.ac.uk/tring

FIND OUT MORE about the animals that inspired tales of mythical beasts like unicorns and dragons.

**9-10** MAY

### Imperial Festival

Imperial College, London, imperial.ac.uk/festival

HERE'S YOUR CHANCE to hear from some of the country's top scientists about projects such as robotics (pictured).

**12** MAY

### The Planet Mercury, Newly Revealed

Royal Astronomical Society, London, 1pm and 6pm, free, www.ras.org.uk

PROF DAVID ROTHERY discusses the volcanic eruptions and thermal contractions that have shaped Mercury.

**18** MAY

### Fascination Of Plants Day 2015

Various locations across the UK, free, plantday.org

CELEBRATE THE MAGNIFICENCE of all things green at one of the many events taking place across the country.

**21** MAY - **31** MAY

### HowTheLightGetsIn 2015

Hay-on-Wye, £12 (site pass), howthelightgetsin.iai.tv

THE PHILOSOPHY AND music festival is sprinkled with thought-provoking science, including Aubrey de Grey on ageing, Colin Blakemore on the human brain, and Roger Penrose on what came before the Big Bang. A pass gets you into the site to watch free concerts, but talks cost extra so it's best to book in advance.

Cheltenham always brings out science's big guns

EDITOR'S CHOICE

**2-7** JUNE

### Cheltenham Science Festival

cheltenhamfestivals.com/science

PROF BRIAN COX, Prof Alice Roberts, Dr Jim Al-Khalili and Dr Adam Rutherford are all making an appearance at Cheltenham this year. Here's a taster of 2015's events...

### Dinosaurs: What Did They Really Look Like?

Join Prof Alice Roberts and a team of experts as they chat about how our image of dinosaurs changes all the time.

### Martin Rees: Mars To The Multiverse

Explore the cosmos with Prof Martin Rees as he reveals exciting astronomical developments.

### Why Take The Risk?

Neuroscientist Vince Walsh and behavioural scientist Nick Chater take a closer look at dangerous careers.

### Can We Build A Quantum Computer?

This talk investigates how a quantum computer could one day solve problems that would take a modern PC the age of the Universe to complete.

### Anne Glover: Science In The Political Arena

It was a black day when the post of EU Chief Scientific Adviser was ditched. At this talk, Anne Glover – the last person to hold the role – explores what happens when science meets politics.

### Back To The Future At 30

Hitch a ride on a DeLorean with Dr Adam Rutherford and Gia Milinovich to find out how 2015 compares to the hoverboard-and-self-tying-shoelaces world of *Back To The Future*.

# READ

THE LATEST SCIENCE BOOKS REVIEWED

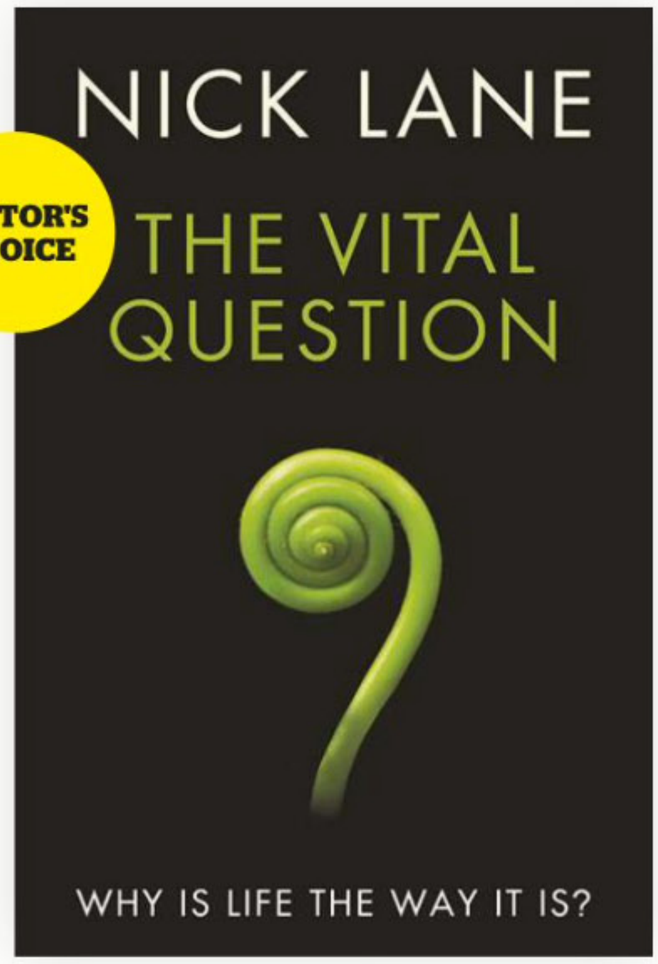
H Hardback P Paperback

## The Vital Question

### Why Is Life The Way It Is?

Nick Lane
Profile Books H £18.99

EDITOR'S CHOICE




EVERY ONE OF the millions of species on Earth uses DNA to make the genes that code for the proteins that constitute our cells and bodies. This tells us that all life – from single-celled bacteria to yeast, mushrooms, jellyfish, insects, plants, birds and mammals – can be traced back to a single common ancestor that, we now know from fossils, arose some time around 3.5 to 3.8 billion years ago.

But why does all life on Earth have only this one common ancestor? That's the 'vital question' at the heart of this book. Why have simple bacteria evolved into complex life just once in nearly four billion years? Why aren't there other forms of life with different basic chemistries? In Nick Lane's carefully researched new book, he argues that the answer lies in the way in which cells produce energy.

Lane identifies a particular chemical process – the proton pump – that is shared across all life. This process – a kind of electricity, except with protons flowing instead of electrons – is the principal source of a cell's energy. Lane suggests that if other, more efficient processes were possible, then natural selection should have allowed bacteria to discover them by now. After all, bacteria are notoriously versatile, and they've had 3.8 billion years to come up with a better solution.

So how did bacteria make the leap to becoming complex life? Lane suggests that the breakthrough happened around 1.5 to 2 billion years ago, when a single bacterium took up residence inside another unicellular organism, creating the little energy powerhouses – mitochondria – that are found in most of our cells today. These mitochondria could then proliferate in cells, liberating orders of magnitude more energy than a bacterium could produce on its own.

It's no mere accident then, argues Lane, that we all stem from a common ancestor. Complex life requires colossal amounts of energy, and the chemistry that allows our cells to deliver it could not have happened in any other way. He even goes as far as to say that were we to find life elsewhere in the Universe, it would be fundamentally similar to our own.

This readable account of life's origins is unlikely to be the last word on this controversial subject, but it will intrigue the scientifically curious and challenge the biochemically literate.

**"Why have simple bacteria evolved into complex life just once in nearly four billion years?"**

PHOTO: WIDE-EYED ENTERTAINMENT LTD

**MARK PAGEL is a professor at Reading University and author of *Wired For Culture***

## MEET THE AUTHOR

**Nick Lane**

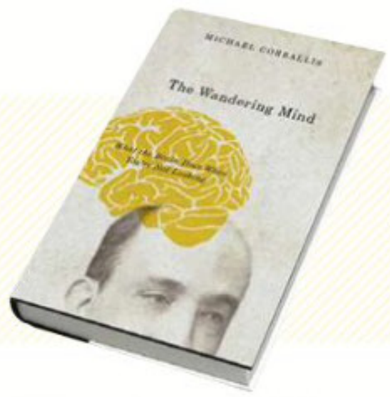
**How did life make the leap from simple bacteria to more complex forms?**
In my book I argue that it was a bit of a freak accident about 1.5–2 billion years ago. A bacterium somehow got inside another single-celled organism, and this led to the development of mitochondria – the power packs of most of our cells today. This event removed the energy constraints that had kept bacteria simple.

**So it was a lucky accident?**
We know for a fact that complex life only evolved once [in four billion years]. It could be that [similar events] happened on multiple occasions but that existing complex life outcompeted any nascent life forms. However, we think that it was a genuinely rare event.

**Do we have evidence for this event?**
If we look at our own genomes, we can see that a lot of our genes come from bacteria, and almost certainly from the bacteria that went on to become our mitochondria. We also see evidence from the mitochondria themselves, which have always retained their own bacterial DNA.

**How would you answer the question in the book's subtitle, after writing it?**
I'd say life is the way it is because there are energetic constraints on evolution that have largely been overlooked. For the last 60 years we've thought about evolution in terms of DNA only – but that doesn't predict why life has the peculiar history that it does. If we bring the requirement for energy into evolution, we begin to see that life has taken its peculiar path for a fundamental reason. This should apply to life elsewhere in the Universe, too.

**MORE ON THE PODCAST**
Listen to the full interview with Nick Lane at sciencefocus.com/podcasts




## The Wandering Mind

### What The Brain Does When You're Not Looking

Michael Corballis

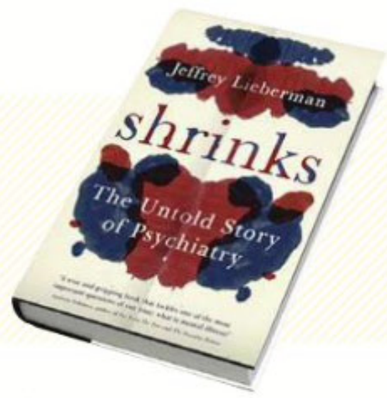
University of Chicago Press H £14

WE SPEND AT least half our lives off-task, our minds wandering into distant, imaginary worlds. We're taught from a young age that this is a bad habit, that we must pay more attention. But Corballis argues mind wandering isn't just important for creativity – it's an essential part of what makes humans unique.

Corballis uses the topic of the wandering mind to explore hallucinations, memory, dreams, creativity and more. Aptly enough, his prose style has an unfettered quality – a constant stream of facts, observations and asides. He is especially fascinating on the question of why we dream (perhaps it's to simulate real-life threats?) and on the drugs and other situations, such as sensory deprivation, that induce hallucinations.

Anyone who has studied psychology will find much that is familiar here, but there was certainly enough that was new to stop my own mind from drifting off. My favourite section is Corballis' demolition of the myth that 'right-brained people' are more creative. "We should relinquish our obsession with brain duality, and let the whole brain get on with it," he writes. Amen to that.

**DR CHRISTIAN JARRETT is author of the *Rough Guide To Psychology***




## Shrinks

### The Untold Story Of Psychiatry

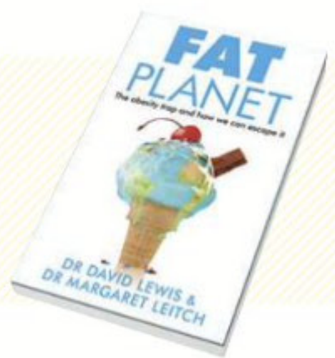
Jeffrey Lieberman

Weidenfeld & Nicolson H £20

IN RECENT YEARS, psychiatry has been under siege. In this book, former President of the American Psychiatric Association Jeffery Lieberman admits that psychiatry's past is strewn with dubious treatments like lobotomies, insulin coma and morphine therapies. But he argues that the discipline has cast off its unscientific past and matured "into a scientific medicine of the brain". ECT machines and psychiatric medicines effectively target discrete brain diseases; short-term therapies reprogram cognitive networks, while MRI scans record the real causes of mental distress.

The trouble is, this 'untold' story is one we have heard many times. Lieberman talks up the role of neuroscience in helping patients and oversells advances in treating mental disorders, while ignoring inconvenient truths such as the problem of over-prescription, the destructive effects of taking psychiatric medications long-term, or psychiatry's compromising financial ties to Big Pharma. His selective, one-sided account should be read more as a PR exercise than as a serious evidence-based contribution to the debate.

**JAMES DAVIES is a reader in psychotherapy at the University of Roehampton, London**




## Fat Planet

### The Obesity Trap And How We Can Escape It

Dr David Lewis and Dr Margaret Leitch

Random House P £12.99

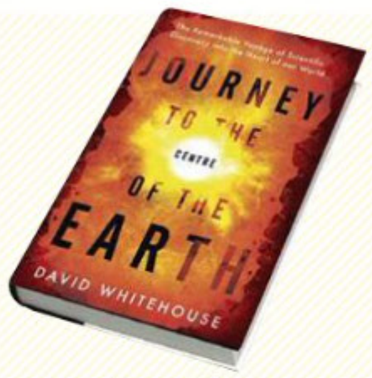
*FAT PLANET* IS a review of the science of obesity and a look at the challenges people face when trying to losing weight. As the authors point out, the causes of obesity are complex; we need solutions that go beyond "eat less, move more".

We are born fat – human babies have nearly seven times as much fat beneath the skin as elephant seals – and get fatter. Why? Primarily, it seems, because we have big brains, and to fuel those brains we need large energy stores. The ability to lay down lots of fat was a great advantage to our ancestors, but for us it can have unfortunate consequences.

Genes and the wrong gut bacteria can contribute to the problem, but it is impulse control that the authors identify as one of the key things to focus on. They point to research which shows that by improving sleep and exercise habits and minimising stress, we can develop better self-control. But as they ruefully acknowledge, 'bolster your cognitive resources' is not a great slogan.

Broadly, their solutions are centred on ways to reduce temptation at either state or individual level – though I found some more convincing than others.

**MICHAEL MOSLEY is a science writer, doctor and BBC science presenter**




## Journey To The Centre Of The Earth

### The Remarkable Voyage Of Scientific Discovery Into The Heart Of Our World

Dr David Whitehouse

Weidenfeld & Nicolson H £20

WE KNOW MORE about the cosmos above our heads than about what's beneath our feet. The closest we've come to Earth's core is when three men dived 10km to the bottom of the Mariana Trench. While volcanic lava holds mineralogical clues, and seismographs and neutrinos reveal strata secrets, great unknowns remain about what lies beneath. What is the mantle made of? How does the core generate Earth's magnetic field? How deep can life survive?

Author and broadcaster David Whitehouse delves into these questions using Jules Verne's *Journey To The Centre Of The Earth* as a background narrative. Serving up intriguing information about the first seismoscope and so-called 'deep diamonds', he travels from the crust to the core, explaining everything from continental drift to the dynamo theory.

The book slightly lacks structure, and the chapter on 'underworld' theories through the ages doesn't sit easily with the rest. But overall, Whitehouse does a good job of explaining how our planet's internal organs mould its continents.

**JHENI OSMAN is a science author whose books include *The World's Great Wonders***

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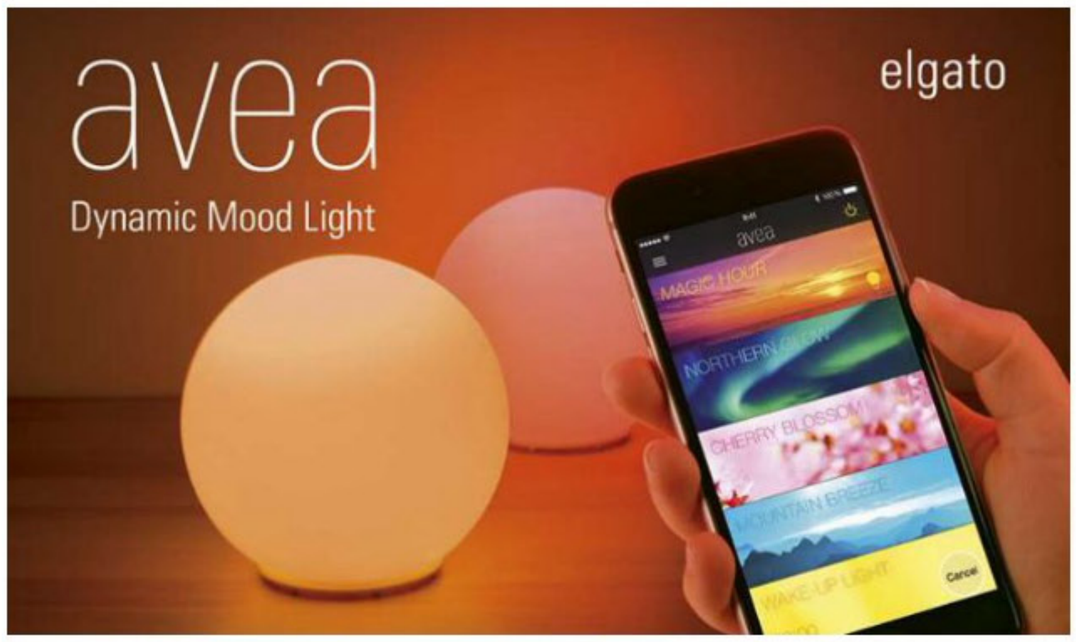


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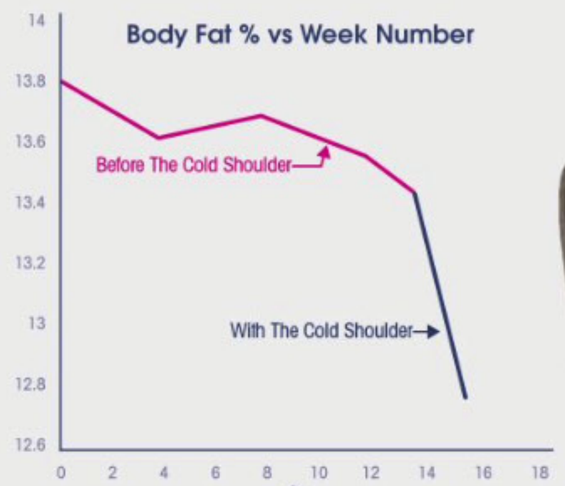


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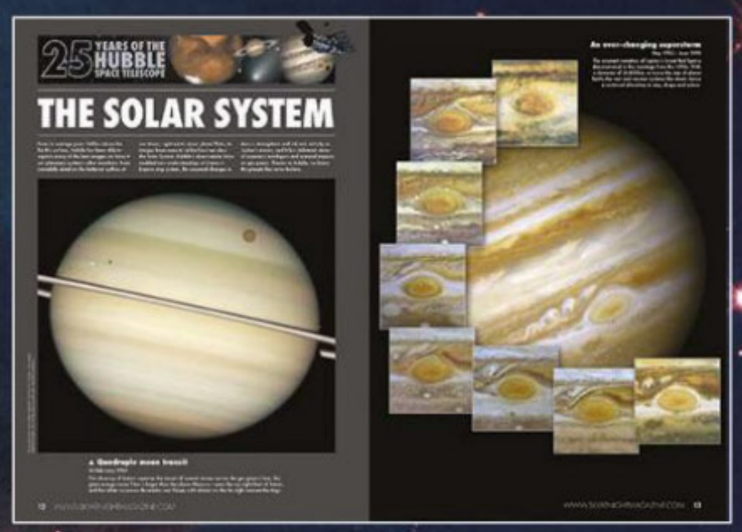


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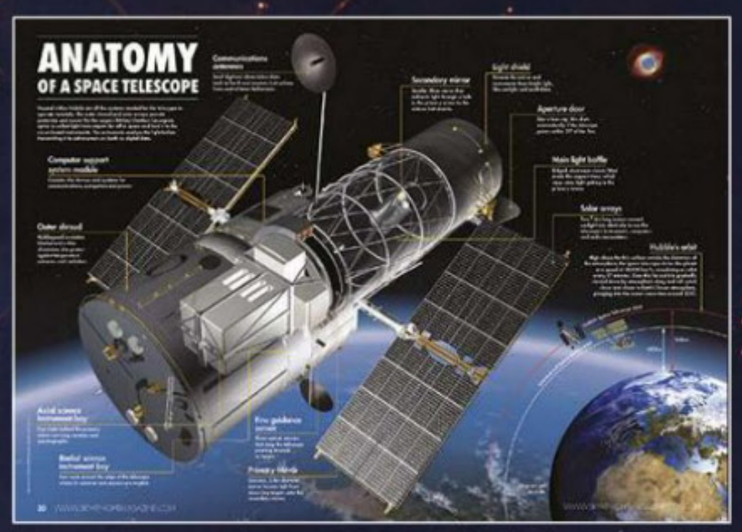


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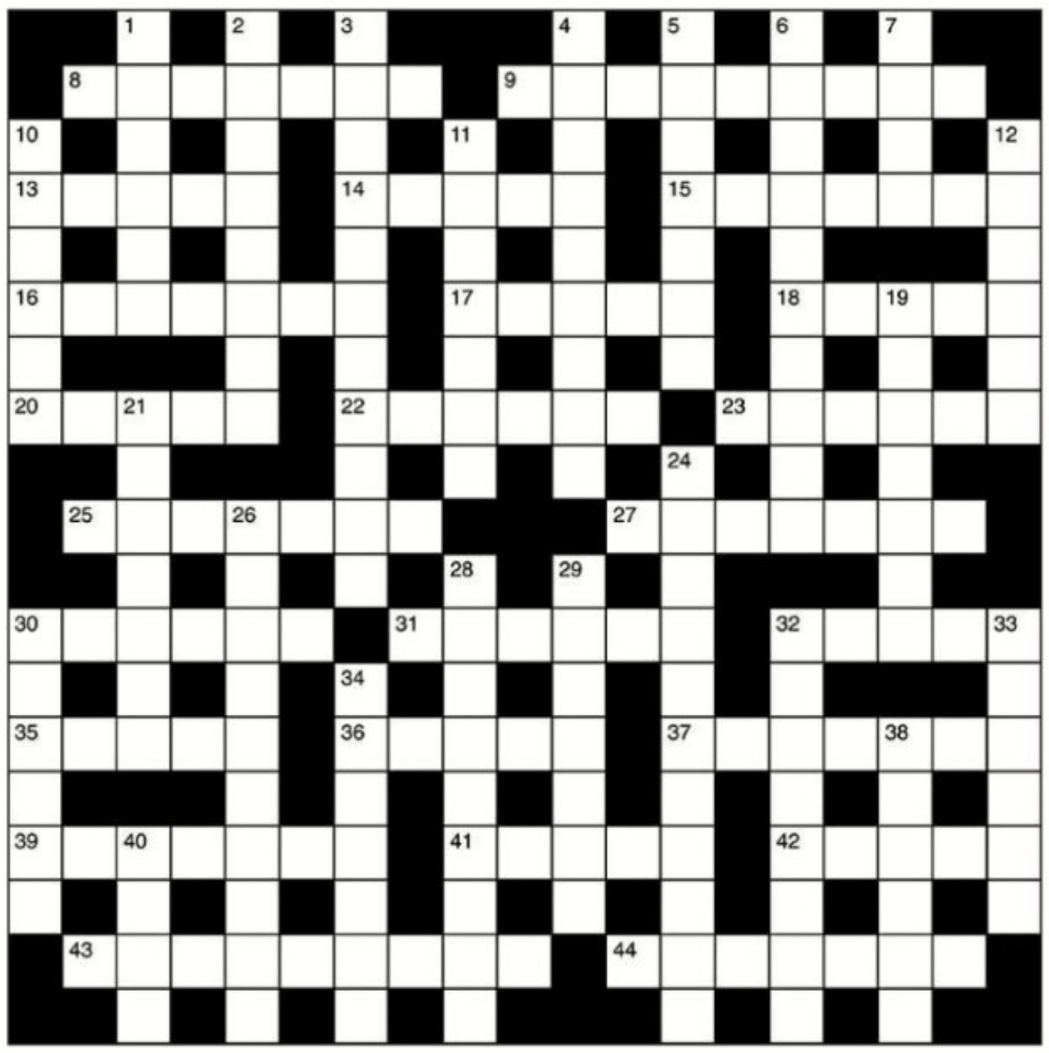
# FOCUS CROSSWORD No 177

**More online** Solve puzzles from BBC's *Only Connect* hosted by Victoria Coren Mitchell at http://bbc.in/1vCOzuY



## ACROSS

**8** Neural network around old bit of seed (7)
**9** Soldier takes middle tree to set limit (9)
**13** A riot out of proportion (5)
**14** Rural deity joins a group of animals (5)
**15** Decay terribly rife in aquatic creature (7)
**16** Mushrooms from island finally in crop rotation (7)
**17** Old aristocrat puts one article inside another (5)
**18** Deer flocking round one duck (5)
**20** Attach a smidgeon around gap (5)
**22** Rascal finds part of play leaves an impression (6)
**23** Mark, in Germany, makes a different sound (6)
**25** Not glib, ordering a snack (7)
**27** Attempt to find one record among set of books (7)
**30** Pat and Ian ran from snake (6)
**31** Bilge written about river rodent (6)
**32** Wager on the Spanish climber (5)
**35** Reportedly influenced by material (5)
**36** New aim – to leave an idealised picture (5)
**37** Quarry contains gold and a form of debris (7)
**39** Some light has energy – it's an inflammation (7)
**41** Canoe unsuitable for so much water (5)
**42** Generate small piece (5)
**43** Roast tuna prepared for distant traveller (9)
**44** Skull found around a ruin gets confused with my head (7)

## DOWN

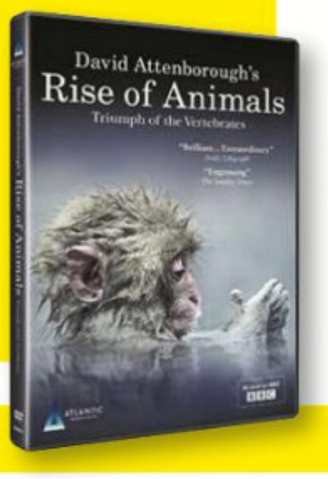
**1** Overcoat of unusual lustre (6)
**2** Rue mixing drug and element (8)
**3** Numerical factor makes firm streamlined (11)
**4** Almanacs delivered to a city (9)
**5** Transmitter in a bag (7)
**6** Set with different graduate is using our own heat (10)
**7** Part of tree in field falls, initially (4)
**10** Subject includes right line of latitude (6)
**11** Secondary genre of U-boat (7)
**12** A traitor captures artist by mountain (6)
**19** Current doctor treats a thug (7)
**21** Poisonous ingredient in a new range of products (7)
**24** Use a rein primly in qualifying round (11)
**26** Path to carry jet away (10)
**28** Gauge demo to have been arranged by agitator (9)
**29** Terribly bad sign from the middle (7)
**30** It's been sneezed in, that's the matter (6)
**32** Crooner Rod's managed inside to get a natural sound (8)
**33** Gothic supporter writes message with hesitation (6)
**34** Begins engagement with a tonic (7)
**38** Doomed flier takes one vehicle to America (6)
**40** Point a set out (4)

## SOLUTION TO CROSSWORD No 174

Lesley Champion, Ian Thompson, Celia Fukes, Steven Barnett and Brian Duncan each correctly solved issue 278's puzzle and receive a copy of *Tony Robinson's World War 1* (Discovery, £14.99).

### WIN! *DAVID ATTENBOROUGH'S RISE OF ANIMALS: TRIUMPH OF THE VERTEBRATES*

The first five correct solutions drawn will win a copy of *David Attenborough's Rise Of Animals: Triumph Of The Vertebrates* (Go Entertain, £8.99). Entries must be received by 5pm on 28 May 2015. See below for more details.

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**Post entries to** *BBC Focus Magazine*, June 2015 Crossword, PO Box 501, Leicester, LE94 0AA or email a scan of the completed crossword or a list of answers to june2015@focuscomps.co.uk by 5pm on 28 May 2015. Entrants must supply name, address and phone number. Immediate Media, publisher of *BBC Focus Magazine*, may contact you with details of our products and services or to undertake research. Please write 'Do Not Contact' on your email or postal entry if you do not want to receive such information by post or phone. Please write your email address on your postal entry if you would like to receive such information by email.

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# HOLLYWOOD SCIENCE

Separating science fact from movie fiction

## Immortality in The Age Of Adaline

IN THIS MONTH'S film *The Age Of Adaline*, a young woman drives her car into a ditch and becomes immortal. Just like that. But don't go trying it at home. You're as likely to find the secret of eternal youth in a smeggy pond as you are in a jar of face cream.

Some researchers have speculated that there's no theoretical limit to the human lifespan. Cells may wear out, and genetic mutations and disease build up, but it's nothing that regular trips to the regenerative medic won't be able to fix. In 2004, Aubrey de Grey, now Chief Scientific Officer at the 'anti-ageing' SENS Research Foundation, speculated that the first person to live to 1,000 was probably already alive. Ageing, he claimed, was a medical condition that would become treatable – a very bold claim indeed.

**"In the meantime, the best we can do is aspire to be a naked mole rat or a jellyfish"**

A decade later, the field is more circumspect. Slashing calories in lab mice and worms has been shown to extend their lifespan. But attempts to reproduce the findings in primates, including us, have proved disappointing. It's just as well, as there's no joy in a life bereft of biscuits. Scientists have moved away from attempting to cure ageing to trying to slow it down. "Researchers are more focused on improving the quality of later life," says Prof Chris Mason from University College London. "It's not necessarily about adding on extra years."

Big, shiny biotech companies like Google's Calico and J Craig Venter's Human Longevity are springing up in the hope of harnessing the power of 'Big Data' to improve our experience of later life. "It's about getting millions of data points from thousands of people, then crunching all that data together to find the mechanisms in cells that contribute to ageing," says Mason. These could then be targeted with drugs, leading to therapies that will help our ageing cells stay healthy and prevent age-related diseases such as cancer and Alzheimer's. It'll be some time, though, before the findings translate into a clinical product.

In the meantime, the best we can do is aspire to be a naked mole rat or a jellyfish. The naked mole rat, a wrinkly eyesore of a rodent, lives to the grand old age of 30 – five times longer than expected for an animal of its size. Plus, it never gets cancer (no one knows why). The aptly named 'immortal jellyfish' (*Turritopsis dohrnii*), meanwhile, can keep morphing back into a sexually immature version of itself and then grow up all over again. It's the equivalent of you or I flitting endlessly between our adult and prepubescent selves which, come to think of it, isn't such a good idea. ■

**HELEN PILCHER** is a science writer and comedian. She tweets from @Helenpilcher1

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