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REGULARS AND OTHER FEATURES

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THE SCIENCE ILLUSTRATED CREDO
We share with our readers a fascination with science, technology, nature, culture and archaeology, and believe that through education about our past, present and future, we can make the world a better place.

Practice run: NASA rescues its Orion space capsule

When NASA sends the first humans to Mars, they will be travelling in the Orion space capsule, which offers 50% more space than did the Apollo lunar landing capsule, and can carry four astronauts. Next year, an unmanned version of the capsule will be launched using NASA's new SLS rocket, but before that time the US Navy will be practising rescues of the 5-metre-diameter capsule for when it returns to Earth. In the photo, a copy of the capsule is being rescued by a specialised vessel that allows water to enter its lowest deck.

Photo // Tony Gray

NASA

A new light: The Blue Mountains in infrared

This false-colour infrared photo shows Jamison Valley in the Blue Mountains, west of Sydney, in February 2019 during a summer of record-breaking heat. Infrared imagery can help scientists assess the variety and health of vegetation, since chlorophyll in plant leaves strongly absorbs visible light and reflects near-infrared, giving the rainforest canopy this snow-like appearance. Carbon dioxide and other greenhouse gases in the atmosphere act like a blanket, absorbing infrared radiation, which gives the sky its night-like appearance in this image.

Photo // Steven Saphore

Patients get chemotherapy without side effects

In the future, a small filter will cleanse cancer patients' blood of chemo drugs, so they can avoid nausea and fatigue.

MEDICINE Fatigue, nausea, diarrhoea and heart attacks are all side effects of chemotherapy. Although the treatment can save severely-ill cancer patients, its side effects are a major problem, as the cell toxin doesn't only attack cancer cells but also the healthy cells of the body. Scientists from the US University of California have found a solution to the problem.

Some of the side effects can be avoided by injecting chemo drugs directly into a blood vessel right beside the cancer tumour, meaning that the medication is not sent through the entire body, but rather travels directly into the tumour. This doesn't solve the entire problem, however, as there will still be medication in the blood that travels around or through the tumour – and that is true for 50-80% of the medication that is injected.

So the American scientists have developed a small filter that collects medication in the blood. The filter is 3D-printed and shaped like a cylinder that is 3cm long with a diameter of 0.5cm and an internal grid structure which is lined with a resin-like material that binds to chemo drugs. In the lab, the scientists tested different varieties of filter, and have now found a sufficiently fine-meshed structure that collects as much medication as possible without the filter increasing the patient's risk of blood clots. The scientists also experimented with different chemical make-ups for the lining of the filter.

Finally, the scientists implanted the filter into the blood vessels of pigs, then injecting a special type of liver cancer drug, Doxorubicin, into the blood stream a few centimetres from the filter. The experiments demonstrated that on average the filter absorbed 64% of the chemo medication included in the blood that passed through it.

The scientists hope that their new invention can be tested on humans within a few years.

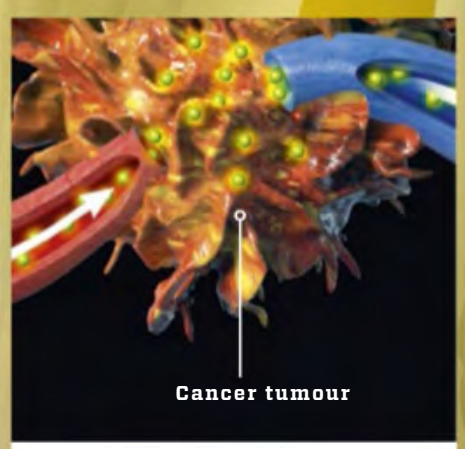
Grid cleanses the blood of toxin

The new filter will be placed in a blood vessel close to the cancer tumour being treated. The small grid will capture most left-over medication in the blood.

HEE JEUNG OH ET AL./ACS

DRUG INJECTED

1 The chemo drug flows into a blood vessel as close to the tumour as possible, so the drug does not affect healthy cells before reaching the tumour.



TUMOUR ATTACKED

2 Cancer cells in the tumour are influenced by the drug, but some of the medication continues through the blood stream.

1: Three: A, C, and E.

2: 8 is the number.

3: The twisted church spire and the crane hook are inverted, and the crane driver cabin does not have a window.

4: The figure can be divided in countless ways with straight lines through its centre.

5: 7. The total of the numbers in the two horizontal and vertical rows is 16.

6:

7:

17	24	1	8	15
23	5	7	14	16
4	6	13	20	22
10	12	19	21	3
11	18	25	2	9

8 There are twenty 5s – 5, 15, 25, 35, 45, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 65, 75, 85, and 95.

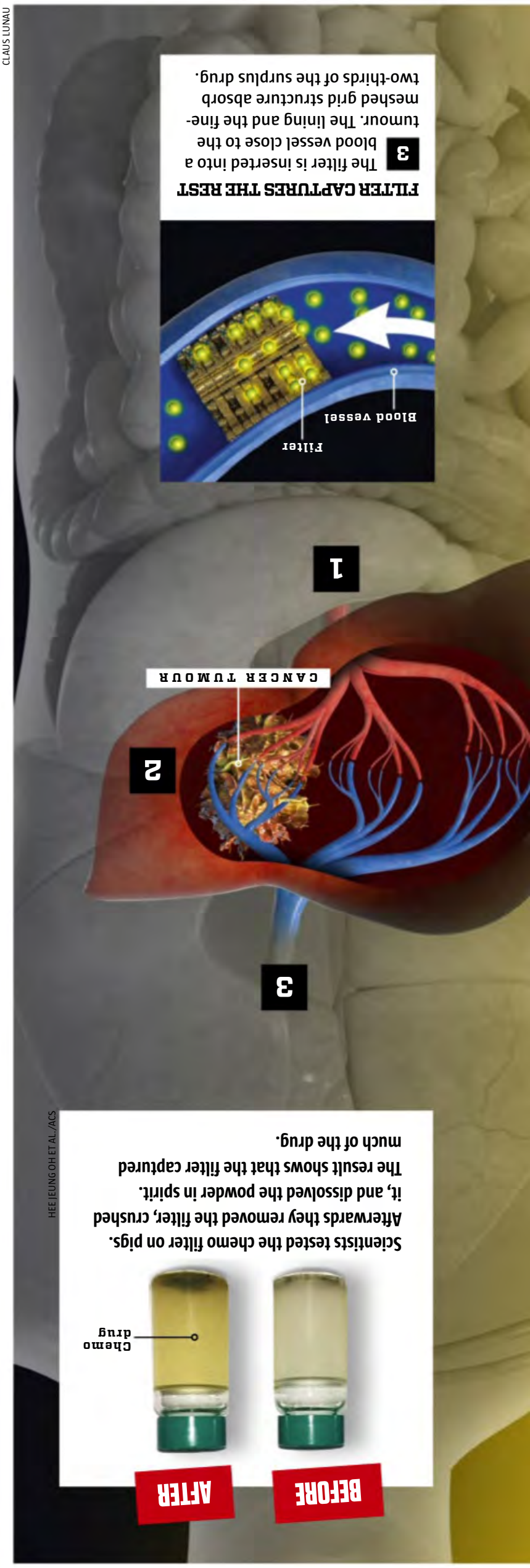
9 The left half of the third piece of each row equals the sum of the dots in the left half of the two preceding ones. The right half of the third domino equals the first piece's right-hand value minus the second one's right hand value.

10: 11cm. The first page of book 1 is adjacent to book 2: so first 0.5cm through the cover of book 1, then 10cm through books 2 & 3, finally 0.5cm through the first cover of book 4.

11: C. From one clock to the next, the big hand moves 5 minutes, the hour hand 3 hours.

12: Five rabbits. Add the number of animals on the two top scales: three dogs + five cats = four cats + two dogs + five rabbits. Then deduct two dogs and four cats on each side of the equation: One dogs + one cat = five rabbits.

Test yourself Answers to p80/82. No peeking!

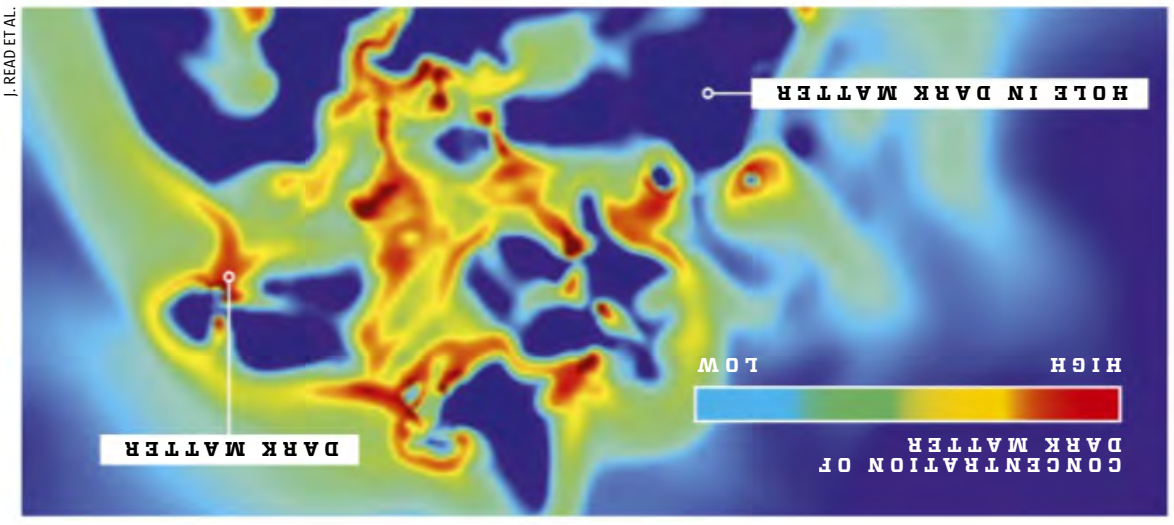


CLAUS LUNAU

HEE JEUNG OH ET AL./ACS

Young stars push dark matter

The computer simulation shows that the galaxy's interior, which is full of young stars, blows large holes in the dark matter.



J. READ ET AL.

ASTRONOMY We know almost nothing about the dark matter of the universe — where it comes from, what it consists of, the qualities it has. We only know that it exists because we can see that gravity from dark matter influences visible matter. But now at last we are learning something new.

Astronomers have wondered why the dark matter of a galaxy is not distributed in the way that computer models predict. Dark matter should unite into dense, ball-shaped structures at the centre of a galaxy, and in looser clouds further out. But that is not the case. In many galaxies, the dark matter is more common on the outskirts than in the interior regions. A team of astrophysicists has found an explanation: a galaxy's age determines the distribution of dark matter. The scientists studied the distribution of dark matter in 16 dwarf galaxies, which they divided into two categories. The first contained old galaxies, in which star formation stopped billions of years ago. The other involved younger galaxies in which star formation stopped recently or is still going on.

The scientists discovered that there was a marked difference between the distribution of dark matter in the two categories. When a galaxy is young, many new stars are formed, particularly in the inner regions. The intense radiation and solar wind of particles from the young stars blow dark matter away from the centre. Once the galaxy has grown older and star formation stops, the dark matter collects in the interior of the galaxy again, just as the computer models predict. If this explanation proves to be correct, we will know at least that dark matter is influenced by star radiation and solar wind.

BY THE WAY

A CAR WITH LEGS

The carmaker Hyundai has developed a brand new car concept: vehicles that will be able to walk, as well as driving on wheels. The wheels are mounted on four legs that have five joints, allowing the car to leave the road and enter other environments, even climbing through difficult terrain. In cities, it can be used to carry disabled people with their wheelchairs right to their doorsteps.

HYUNDAI

AND TALKING OF CARS...

CARAVANS BECOME TRANSPARENT

The truckmaker GMC has invented a system that allows you to see through your trailer or caravan. The system collects information from cameras on the back of the car and trailer to produce an image that shows the outline of the trailer (so you don't forget it's there), but also the road behind it.

GMC

CONTROL YOUR CAR WITH THE POWER OF THOUGHT

The carmaker Nissan aims to develop a system that allows you to steer your car safely through traffic without using either arms or legs. The driver has electrodes on his head that decode brain signals, sending the data on to the car's steering gear. So far, the system has only been tested in simulators...

NISSAN

HYDROGEN ENGINE ENSURES GREEN TRUCKS

While other companies are developing electric trucks, ULEMCo of the UK has developed a green alternative: a hydrogen engine that delivers enough horse-power for a heavy truck. The hydrogen engine is a combustion engine, unlike the fuel cells that are otherwise gaining ground in hydrogen vehicles.

ULEMCO

SHUTTERSTOCK

Honey fungi are not very impressive, but below the ground, one single fungus might stretch over several square kilometres.

Underground fungus has grown twice as big

BIOLOGY One of the world's oldest and biggest inhabitants – a honey fungus – has spread tremendously.

Scientists from the University of Missouri in the US have studied a famous honey fungus, *Armillaria gallica*, which grows in the state of Michigan, stretching across an underground area of 0.75km² – corresponding to more than 100 soccer fields. The fungus was discovered by the same scientists back in the 1980s, when they estimated it to be around 1,500 years old. Now, they have monitored the fungus for three years, revealing that it is twice as large as the original estimate. Moreover, the scientists think that the fungus must be at least 2,500 years old, based on how quickly it is growing. The scientists also studied how often genetic mutations take place in the fungus, finding them to be surprisingly rare when compared to other organisms such as plants and animals, perhaps the reason why the fungus has lived for so long and grown so big. According to the scientists, the low mutation rate might be due to the fact that most of the fungus is located under the ground and so is protected from ultra-violet solar radiation, the cause of many mutations.

In Washington and Oregon, biologists have discovered other honey fungi covering even larger areas, such as an *Armillaria ostoyae* which takes up almost 10km². According to calculations, if removed from the ground and weighed, it would tip the scales at over 7,500 tonnes — the world's heaviest organism.

7,500 t

– is the weight of the fungus considered to be the world's largest organism, corresponding to 54 blue whales.

Satellite to produce artificial shooting stars

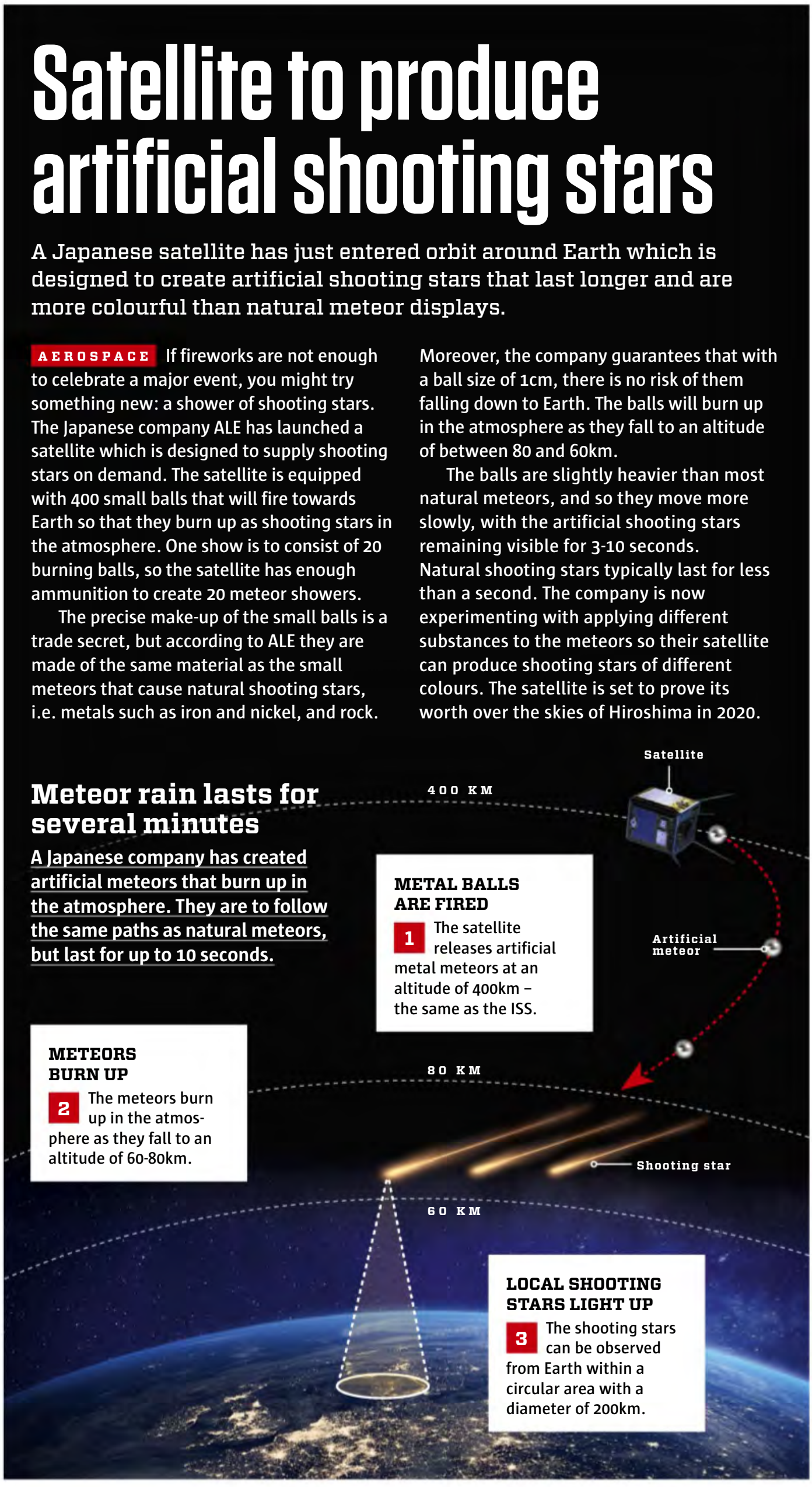
A Japanese satellite has just entered orbit around Earth which is designed to create artificial shooting stars that last longer and are more colourful than natural meteor displays.

AEROSPACE If fireworks are not enough to celebrate a major event, you might try something new: a shower of shooting stars. The Japanese company ALE has launched a satellite which is designed to supply shooting stars on demand. The satellite is equipped with 400 small balls that will fire towards Earth so that they burn up as shooting stars in the atmosphere. One show is to consist of 20 burning balls, so the satellite has enough ammunition to create 20 meteor showers.

The precise make-up of the small balls is a trade secret, but according to ALE they are made of the same material as the small meteors that cause natural shooting stars, i.e. metals such as iron and nickel, and rock.

Moreover, the company guarantees that with a ball size of 1cm, there is no risk of them falling down to Earth. The balls will burn up in the atmosphere as they fall to an altitude of between 80 and 60km.

The balls are slightly heavier than most natural meteors, and so they move more slowly, with the artificial shooting stars remaining visible for 3-10 seconds. Natural shooting stars typically last for less than a second. The company is now experimenting with applying different substances to the meteors so their satellite can produce shooting stars of different colours. The satellite is set to prove its worth over the skies of Hiroshima in 2020.



SHUTTERSTOCK

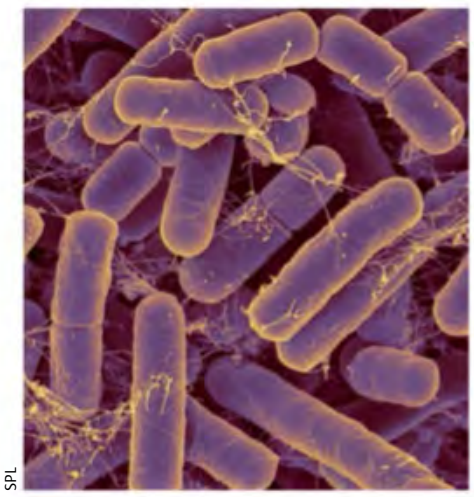
Gut bacteria reveal your body's age

BIOLOGY Your intestinal bacteria keep a close check on whether your body is ageing, according to a new study made by scientists from Insilico Medicine in the US. The scientists studied the gut bacteria of samples from 1,165 people all over the world. They noted which bacteria were contained in the samples, and the quantity of the different kinds. In this way, the scientists produced an accurate set of data for 95 different bacterium species in each of the test subjects.

Subsequently, they fed a computer data from 90% of the samples, together with information about the subjects' ages, allowing the computer to guess the age of a person based only on his/her gut bacteria. When the scientists fed the computer gut information from the last 10% of the samples, the computer could guess their age with a margin of error of only 4%.

Of 95 bacterium species, 39 were particularly important for determining age. The quantity of the *Eubacterium halii* increases with age, or vice versa with some other species.

The new scientific database can be used in other research projects for a quick impression of our biological age, to find out if diseases influence the ageing process, or if a new type of medication might have side effects which speed up ageing.



SPL

The quantity of the *Eubacterium hallii* bacterium in the intestines increases as we grow older.

The Sahara will be fertile in 10,000 years

CLIMATE Fossils in the bone-dry Sahara Desert reveal that the sand dunes are located in what was previously a moist, fertile region. Scientists used to believe that the Sahara switched between dry and moist climates with the ice ages, at a rhythm of some 100,000 years. But according to new scientific research, it happens much more frequently.

Scientists read the climate change in sediments on the ocean floor off the coast of Africa, as large quantities of sand blow from the desert to the ocean. Previously, scientists used the thickness of the layers to estimate how dry the Sahara was at different times. The more dry the climate, the more sand, and the thicker the ocean floor sediments. Now, US scientists have used a more accurate method by researching drill cores from the ocean floor covering the past 240,000 years. Sand grains from the Sahara attract small quantities of thorium as they fall down through the water column to rest on the ocean floor. The greater the concentration of thorium in a layer, the more moist the climate. The few sand grains left from periods with a moist climate have attracted more thorium, as more thorium was available to each of them.

The new method gives us a fresh impression of climate change in the Sahara as occurring once every 20,000 years, following the rhythm of Earth's axis.

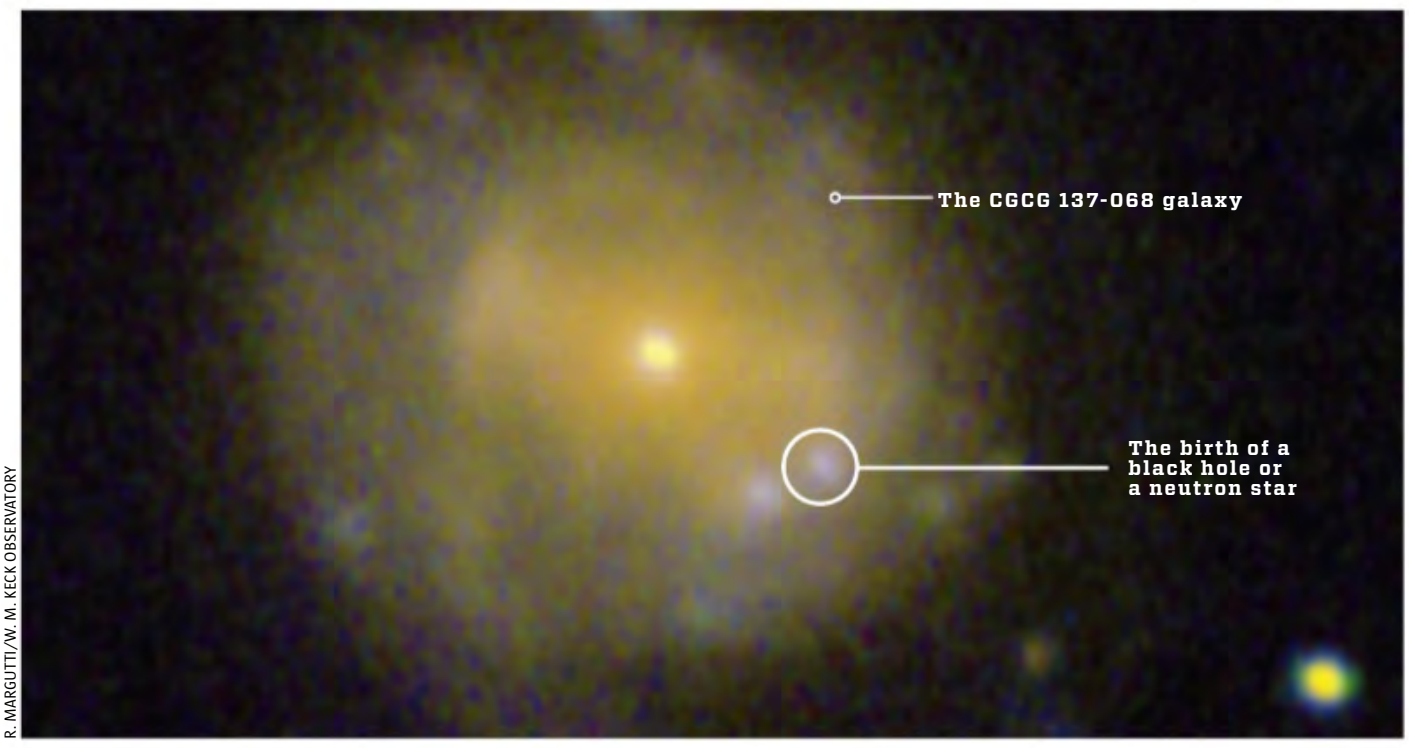
SAHARAN SAND IS BLOWN AWAY

- The world's biggest desert occupies 8.5 million km^2.
- Sand from the Sahara can blow as far away as the Amazonian rainforest.
- Central Sahara receives 11 hours of sunlight a day.

SHUTTERSTOCK

Saharan sand absorbs thorium as it blows away and falls through the ocean. The sand grains reveal the climate history of the desert.

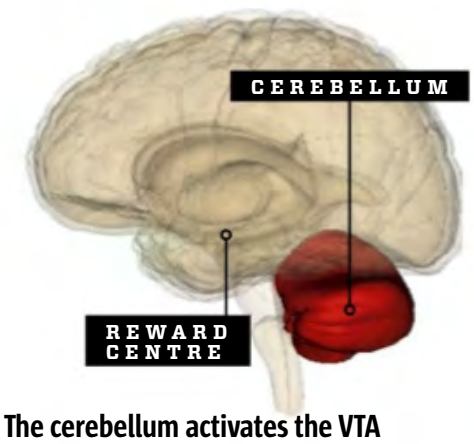
SHOOTING STAR



R. MARGUTTI/W. M. KECK OBSERVATORY

Astronomers spot sensational star death

In June 2018, astronomers observed light flashes from what they believed to be a supernova some 200 million light years away. Now, they have discovered that they witnessed the birth of a black hole or a neutron star. Both can occur when a star that is 10 times heavier than the Sun runs out of fuel and collapses.



The cerebellum activates the VTA reward centre when we are in the company of other people.

LIFE SCIENCE DATABASES (LSDB)

Cerebellum – the original social medium

BRAIN Under the cerebrum sits the fist-size cerebellum, which used to be considered a centre of motor functions. But now scientists are discovering that it has many other important functions – such as making sure that we like being in the company of others.

We already know that the cerebellum is probably an important player in conditions such as schizophrenia and autism, both of which can affect social behaviour. So, US scientists studied how the cerebellum was connected with other brain regions. They used a method that makes active brain cells light up. The scientists carried out their experiments on mice and found that the cerebellum has nerve cells with strong links to an area at the centre of the cerebrum known as VTA. This centre is a part of the brain's reward system that releases the dopamine neurotransmitter to make us happy when we do certain things. Subsequently, the scientists studied what was required to activate these nerve links. It happened only when the mice were in the company of peers. When the scientists blocked out the signals, the mice no longer sought out the company of others. The results indicate that the cerebellum helps ensure that we seek out other people's company.

Bone robot shows the first steps on dry land

Our earliest ancestors adapted more quickly to life on dry land than scientists used to think, according to a robot that scientists have built from old bones and new tiny motors.

EVOLUTION Modern robot technology can now show us how one of our very early ancestors moved about on Earth. Palaeontologists have long wondered which gait the first amniotes used. Amniotes originated some 350 million years ago, and they are the ancestors of reptiles, birds and mammals. Amniotes differ from amphibians by not needing to live the first part of their lives in water (as do frogs, say, as tadpoles).

Scientists from the Humboldt University in Germany have made CT scans of a remarkably well-preserved fossil of the *Orobates pabsti amniote*, which lived some 285 million years ago. Subsequently, they recreated its skeleton, so they could see into which angles the bone joints could be turned, before they built motors to fit into the joints. The scientists also had a series of well-preserved footprints that had been discovered near the fossil, so they could experiment with the robot's step length, spinal column flexibility and speed in order to find the correct gait.

The result shows that the early amniote moved in a way that palaeontologists believed to have appeared only much later in evolution. It walked with relatively stretched legs and a less pronounced twist of the spinal column than do reptiles such as salamanders today. So the amniote saved energy as it moved about.

The scientists now aim to use their method to solve other evolutionary mysteries, such as how the first flying animals took flight, how our own ancestors got up and stood on two legs, and how some mammals took the leap from dry land to water to become marine mammals.

Early ancestor moved like an alligator

Scientists have created a robot which reveals that the reptile-like amniote's gait was more developed than formerly thought, outcompeting modern salamanders.

AMPHIBIANS CRAWL

A salamander places its feet far away from each other. The body is only just above the surface, and the gait requires that the animal twist its spinal column from side to side, almost flinging its feet forwards.

REPTILES RISE ABOVE THE GROUND

The alligator places its feet under the shoulder joint, keeping its body above the ground. This type of gait requires less twisting of the spinal column, saving energy.

CLAUS LUNAU

A highly well-preserved fossil and amniote footprints helped scientists to recreate the animal's skeleton, and then gait.

THOMAS MARTENS, TOMISLAV HORVAT & KAMILO MELO

What makes up a massive star?

The universe includes heavy stars that are much bigger than the Sun. What materials make up these stars?

COSMOLOGY A star is born when a large cloud of gas and dust collapses under its own gravity. Pressure and temperature increase so much that hydrogen cores fuse into helium, liberating major quantities of energy. This is the process that makes the star bright.

When a star has a mass of more than eight times that of the Sun, it is known as a 'massive' star. Massive stars have higher temperatures and pressure in their cores, making the hydrogen fuse even faster. When the hydrogen of the core is about to reach depletion, helium fuses into carbon and oxygen in the core, whereas hydrogen nuclei merge in a surrounding shell. When the helium runs out, the core collapses, making pressure and temperature rise explosively. The core shrinks, and its density greatly increases. Carbon begins to fuse in the core, whereas the helium fusion takes place in a surrounding shell. The process continues, and still heavier elements are produced inside the star. A kind of 'onion' structure emerges, in which the fusion takes place on the borders between the different layers — the beginning of the end of the star.

The carbon, neon, oxygen, and finally silicon all fuse. The silicon fusion produces radioactive nickel, which will quickly decay into iron. The core is now exhausted of energy, and the massive star's core consists of massive iron, which will finally collapse, making the star explode into a supernova.

The heaviest star

R136a1 is the heaviest star ever discovered. Its mass is around 265 times that of the Sun, and it is 10 million times brighter.

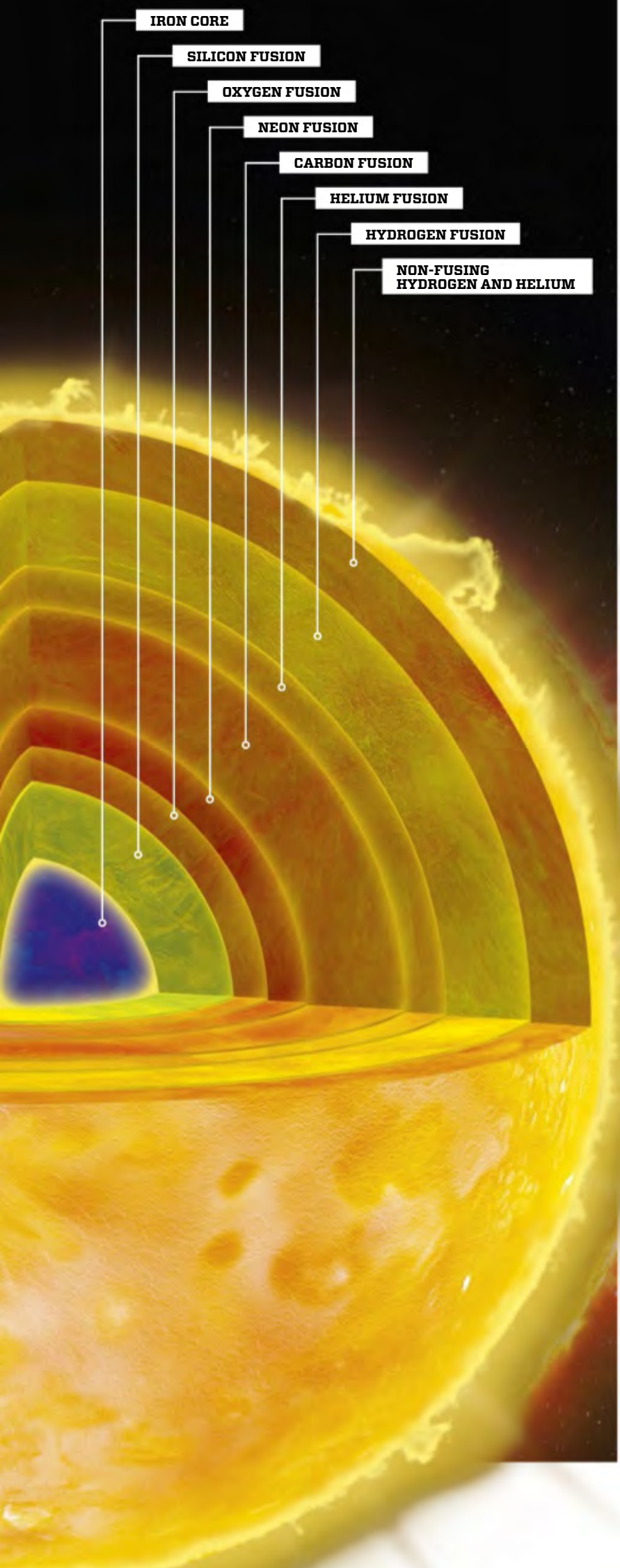
MASSIVE STARS DIE YOUNG

The greater the mass of a star, the faster it will 'burn' out. The Sun will live 3,000 times longer than stars that are 60 times heavier.

STAR MASS	LIFESPAN
The Sun (1 solar mass)	10 billion years
1.5 solar masses	3 billion years
3 solar masses	370 million years
10 solar masses	32 million years
30 solar masses	11 million years
60 solar masses	3 million years

The dying twitches of a massive star

Just before its death, a massive star consists of an iron core surrounded by 'onion' layers of elements that merge (fuse) into heavier elements.



CLAUS LUNAU

TOP 5 · Which creatures are the most numerous?

SHUTTERSTOCK

1 Roundworms

10 sextillion individuals. The huge number of roundworms is primarily due to the fact that they exist in all environments – including the ocean. According to some studies, roundworms make up some 80% of all Earth's animals.

INSECTS
10 QUINTILLION INDIVIDUALS

2 Although insects rank second in absolute numbers, they come in more species than any other group – at least a million different species.

DUST MITES
100 QUADRILLION INDIVIDUALS

3 The most common sleeping partners of humans probably cause more cases of allergy throughout the world than any other organism.

EARTHWORMS
100 QUADRILLION INDIVIDUALS

4 Earthworms have been studied so carefully that the estimate of their numbers is quite accurate. 1 m^2 of soil contains approximately 1,000 earthworms.

KRILL
800 TRILLION INDIVIDUALS

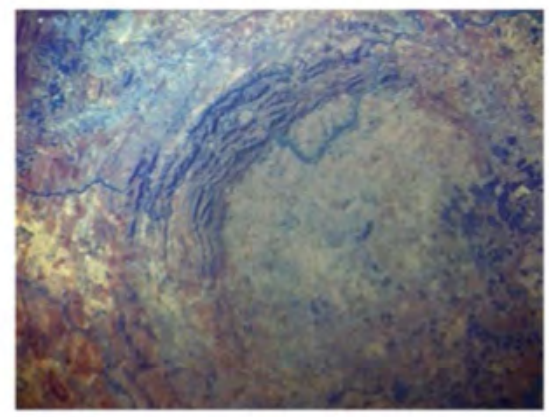
5 Krill is the most common marine animal, existing in larger groups than any other animal — so large that they can be seen by satellites.

Where do meteors go after they hit?

GEOLOGY Meteors rarely survive the impact — most parts evaporate during the collision with Earth, when their kinetic energy is converted into heat, making the temperature rise to thousands of degrees, so that even rock is converted into gas.

If parts of the meteor do survive the impact, they will settle as heavily modified fragments within or outside the crater. Sometimes a large section of meteor can be located beneath the central parts of the crater, but even this is often difficult to find, as it can become merged with the bedrock.

The biggest meteors, such as the one which caused the 380km-wide Vredefort Crater in South Africa two billion years ago, probably made it all the way through the Earth's crust into the soft, underlying mantle.



NASA

The meteor that created the Vredefort Crater probably sank through to the Earth's mantle.

Does Etna create air pollution?

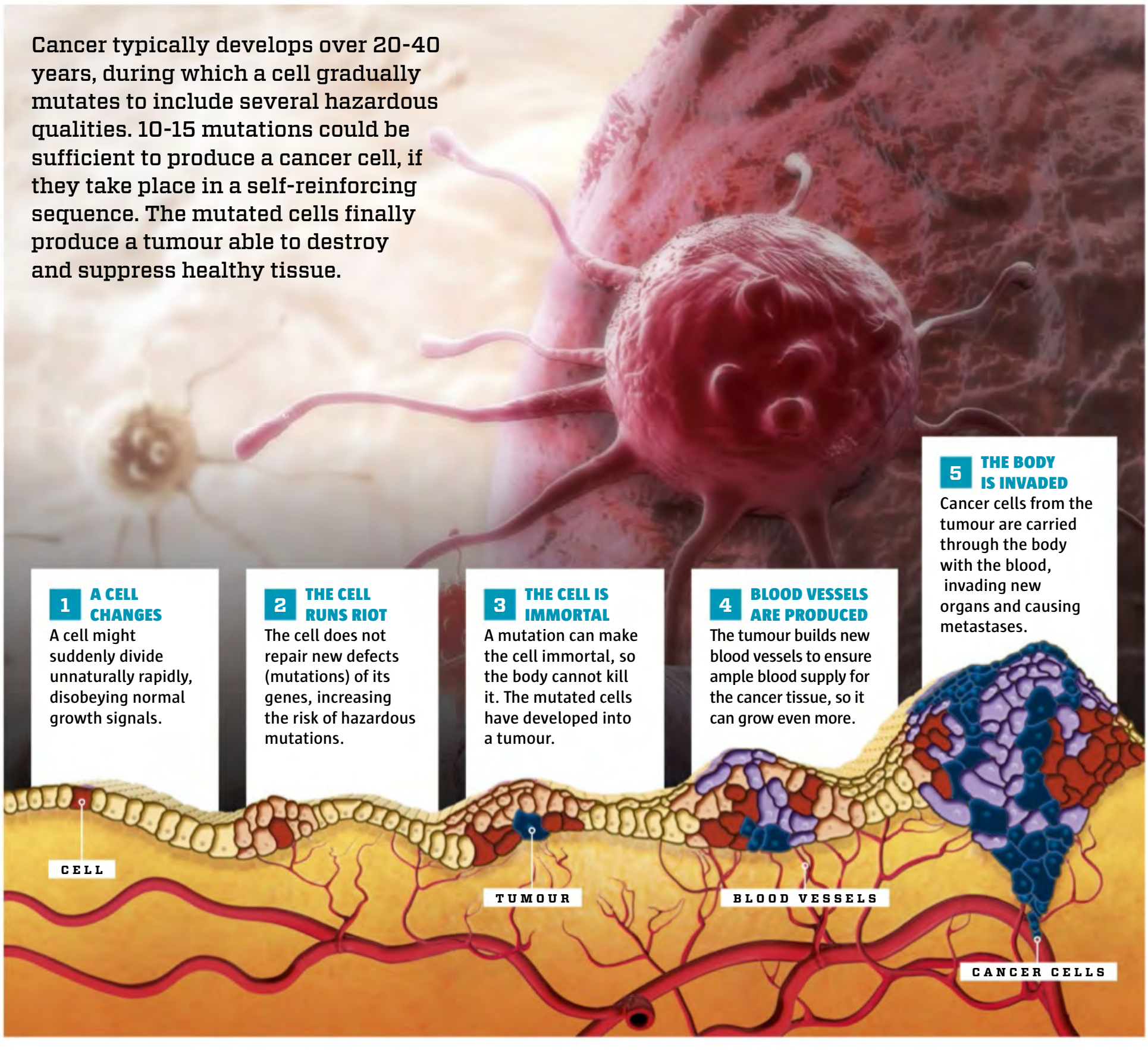
GEOLOGY Volcanoes emit many substances that would be referred to as 'pollution' if they were caused by factories and traffic. Mount Etna in Sicily emits as much sulphur annually as all France's heavy industries combined. As volcanoes have always been this way, nature near them is made up of species that thrive under such conditions. When it comes to CO_2, volcano emissions cannot be characterised as pollution either. If the CO_2 of our atmosphere was not constantly maintained via volcanoes, Earth would become ever colder, because different chemical processes keep removing CO_2 from the air. Total volcanic CO_2 reaches 0.6 billion tonnes annually, whereas emissions from human sources total approximately 36 billion tonnes.

Etna is Europe's most active volcano, constantly emitting sulphur and CO_2 into the atmosphere.

SHUTTERSTOCK

INSIDE THE BODY · How does cancer originate?

Cancer typically develops over 20-40 years, during which a cell gradually mutates to include several hazardous qualities. 10-15 mutations could be sufficient to produce a cancer cell, if they take place in a self-reinforcing sequence. The mutated cells finally produce a tumour able to destroy and suppress healthy tissue.

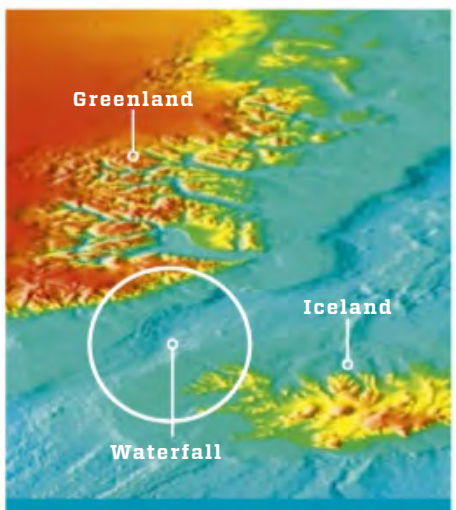


THINKSTOCK & CLAUS LUNAU

WORLD RECORDS

How high is the world's highest waterfall?

The world's highest waterfall is located in the Denmark Strait, where a deep ocean current passes across a kind of geological step 600m under the surface. The ocean current water is salty and cold, heavier than the surrounding water. The heavy water flows over the step and falls 3,505m to the floor of the North Atlantic.



NOAA

3,505

metres is the height of the submarine waterfall.

Denmark Strait

WHY: A cold, salty ocean current carries water from the Gulf Stream back south via a waterfall.

HOW MUCH: 5 million m^3 of water flows through the waterfall per second – 2,000 times Niagara Falls.

Are endorphins also released in animals?

Are feel-good agents produced in animal brains, in the same way they are in people?

ZOOLOGY Endorphins are bodily 'feel-good' agents that make both animals and humans ignore pain. The agents are liberated in response to discomfort, such as injury or a stressful escape from a predator. Apart from their pain-relieving effect, endorphins are relaxing and cause a sensation of optimism. All vertebrates release endorphins in their brains, but invertebrates such as insects and snails do not have such well-developed nervous systems or hormone mechanisms, so they do not use feel-good agents.

Endorphins are also released from the brain's pituitary gland, or hypothalamus, in connection with sex or other kinds of physical activity. When people subject themselves to intense physical exercise such as long-distance running, the physical strain could trigger a major dose of endorphins in the brain, causing 'runner's high'.

How endorphins influence animals

Animals benefit from the pain-relieving and feel-good endorphins in several different ways:

CAUSE FAMILY BONDING

WHEN MONKEYS GROOM each other, endorphins are released to cause a relaxed feeling of well-being, so the grooming boosts family bonds.

REDUCE FEAR

WHEN AN ANIMAL IS HUNTED, the stress causes the release of endorphins. An injured animal can use it to ignore the pain and continue its flight.

REDUCE METABOLISM

WHEN BEARS HIBERNATE, the blood supply to the internal organs and the brain is reduced without harming their brains and hearts, as the endorphins curb cell metabolism and reduce the oxygen requirement.

SHUTTERSTOCK & MANOJ SHAH/GETTY IMAGES & THINKSTOCK

Why does a dishwasher not dry plastic?

PHYSICS After a dishwasher cycle, the plates and glasses are usually dry, whereas plastic boxes and cups remain wet. The difference is due to the different materials' ability to absorb heat, also known as heat capacity.

Porcelain, glasses and cutlery have a much higher heat capacity than does plastic, while glasses, porcelain, and cutlery generally also consist of thicker materials than plastic, and can hence contain much more heat. Plastic is also a relatively poor heat conductor and so the thermal energy is not passed effectively to the surface. Porcelain, stainless steel and glass are good at conducting heat, so they can make the last water evaporate from the surface.

PLASTIC IS A POOR HEAT CONDUCTOR

- **Plastic:** 0.42-0.5W/(m × K) (*watts divided by the material's mass multiplied by the Kelvin temperature*)
- **Glass:** 1.05W/(m × K)
- **Porcelain:** 1.5W/(m × K)
- **Stainless steel:** 16W/(m × K)

ANNE LYKKE

Plastic is a relatively poor conductor of heat compared with porcelain, so not all water has evaporated from the plastic by the end of the dishwasher cycle.

WHAT IS THIS? · Beach foam is produced from proteins

The white beach foam is due to fat and protein in ocean water, which the surf 'whips', just like whipped cream.

1 Animals and plants in both salty and fresh water constantly liberate fat and protein molecules. As waves wash up on the shore, the substances are whipped into foam.

2 The algal foam is produced because proteins merge into long chains or polymers. Algal protein can be harvested and used to make reusable thermoplastics.

3 Particularly durable foam could collect into major 'bands' on the beach, even fly through the air. The durability is often due to high concentrations of dead Phaeocystis algae.

BROCKEN INAGLORY

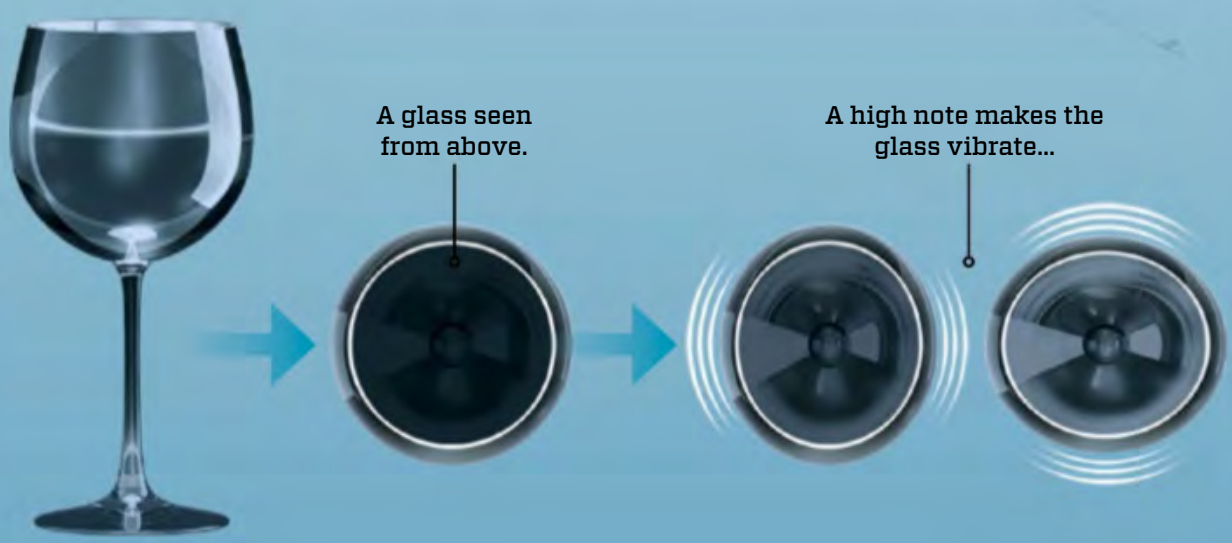
... you can break a glass with your voice?

In cartoons and comedies, the voices of female opera singers are sometimes so high-pitched that they make wine glasses shatter. Is that really possible?

PHYSICS Sound waves with the right pitch and vibration can indeed make glasses break. If you flick a wine glass, it 'rings' with a specific note, the natural frequency of that glass.

Forceful singing or playing of a note close to this could produce resonance, by which the glass begins to vibrate. In other words, the sound waves from the voice make the glass vibrate, and if the note is particularly intense, the glass can vibrate so intensely that it splinters. It is possible to make a glass shatter in this way with only the human voice, without the use of an amplifier. Experiments have demonstrated that crystal glass suffers a particularly high risk of shattering when a nearby opera singer or heavy metal vocalist uses a powerful voice to produce a note that matches the natural frequency of the glass.

Vocal coach Jaime Vendera is an expert on making glasses shatter by producing a high-pitched, powerful note that makes the glass vibrate at its natural frequency.

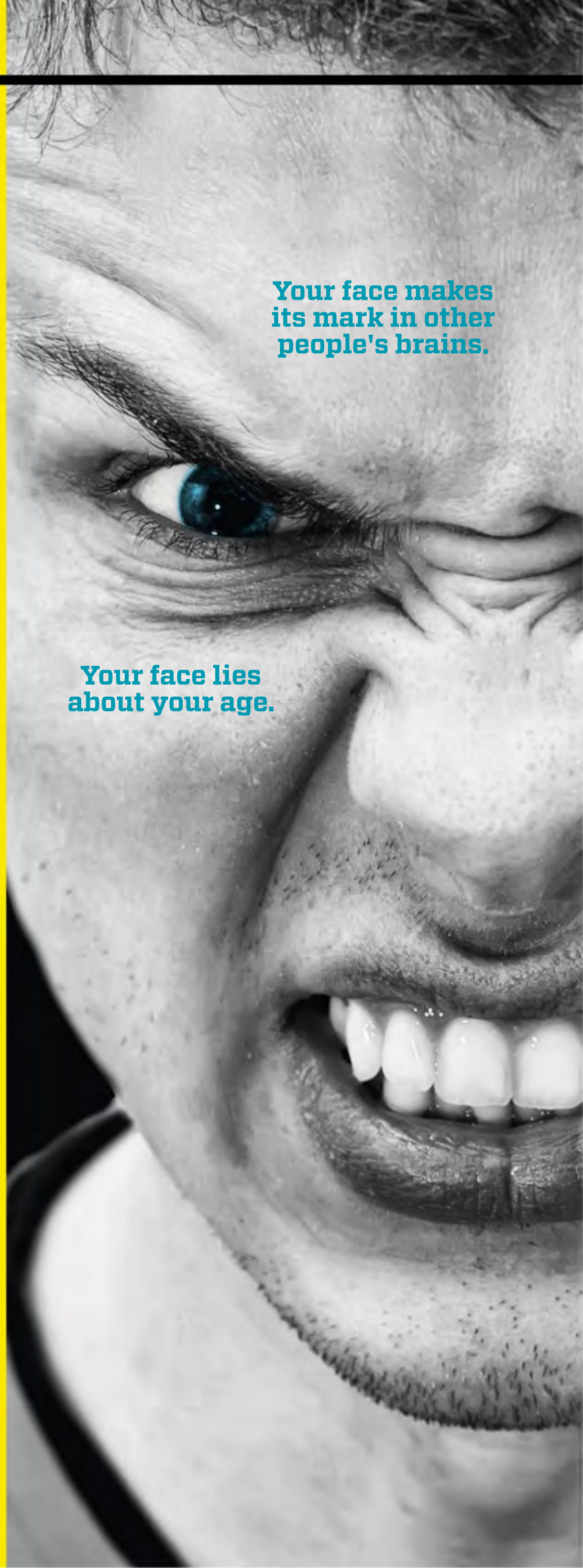


JAIME VENDERA & SHUTTERSTOCK

IN YOUR FACE!

According to a new theory about the function of the face, its primary purpose is to manipulate other people. Others maintain that our facial expressions reflect our innermost emotions. Now, detailed 3D scans, extensive DNA analyses, and observations of isolated peoples are finally about to solve the mysteries of the face. So, what secrets are we revealing, and can we better control them?

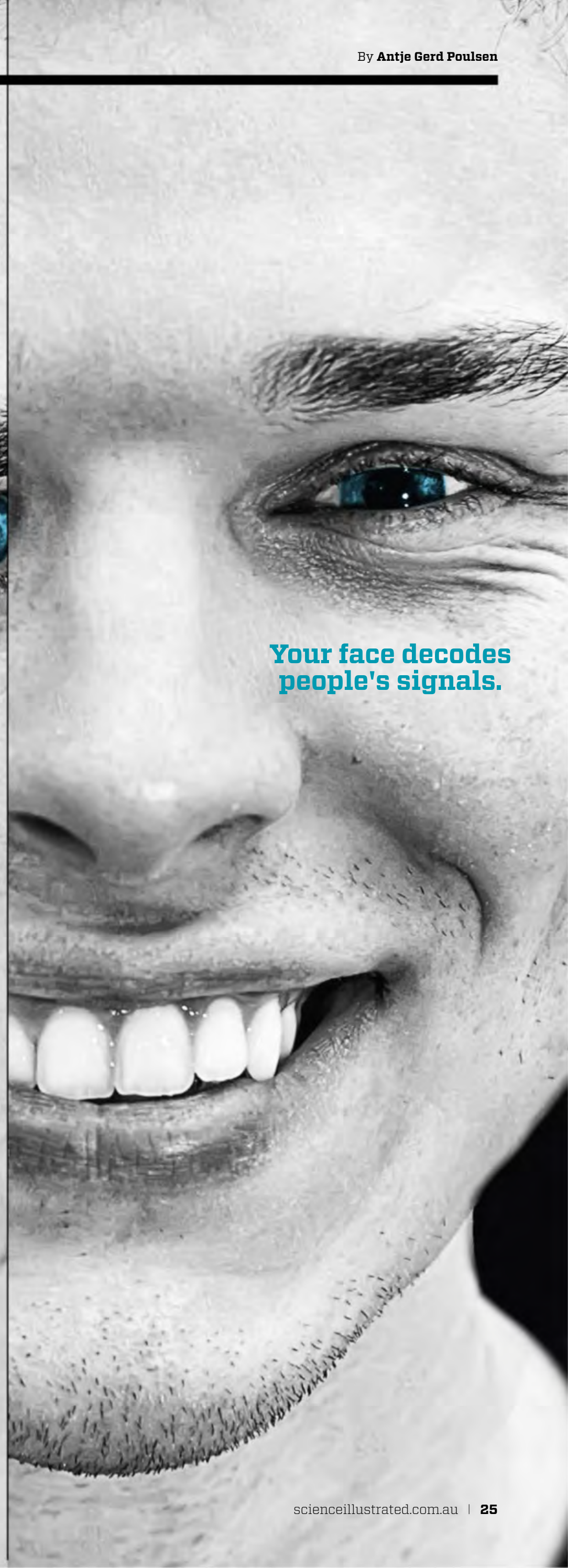
SHUTTERSTOCK



By **Antje Gerd Poulsen**

Your face manipulates other people.

Your face decodes people's signals.



It is 1839. In his home in Kent, England, Charles Darwin cannot take his eyes of his newborn son. The young scientist is overwhelmed with paternal emotions – and also with scientific curiosity. He notes everything about the baby's first grimaces.

"From his eighth day and for a while after that, I observed the first signs of a burst of screaming… As soon as the screaming began, all the muscles around the eyes contracted heavily, and the mouth opened wide," Darwin says about his son in 'The Expression of the Emotions in Man and Animals'.

The work attracted a lot of attention when it was published in 1872. It contained the first scientific theories about face development and the meaning of facial expressions.

Darwin had collected notes, photos, and other data from scientists throughout the world to show how dogs, cats, and chimpanzees have facial expressions reminiscent of those in humans. His aim was to place humans in an evolutionary context. In the work, he also identifies six facial expressions reflecting basic emotions that are recognisable in all cultures: anger, disgust, surprise, joy, sadness, and fear. Darwin was trying to find the answer to two important questions: why does the face look the way it does, and what do the different facial expressions mean? These apparently simple questions are not easy to answer. Today's generation of scientists are working hard to uncover the secrets of the face, using algorithms, DNA technology, and 3D image processing. And they have found a series of surprising answers to Darwin's basic questions.

Scientists search for 'facial DNA'

It is 2015. Anthropologist Mark Shriver from Penn State University in the US looks at two very special portraits in his office. One is of himself; the other is his six-year-old son as he may look at the age of 25. Both portraits were made by a computer, based on DNA tests.

The picture of himself bears some resemblance to the original. It's harder to assess the accuracy of the portrait of his son, but Shriver already knows that it will not be perfect, because as yet it is still only possible to identify a few, coarse features based on DNA – eye and hair colour, gender, ethnicity, and age. But these kinds of portraits are expected to become more accurate as scientists gain more knowledge about the face.

The method is, of course, already used in the investigation of criminal cases and missing persons – and for population monitoring. A 2015 Hong Kong campaign to promote cleaner streets saw authorities extracting DNA from chewing gum and cigarette butts left in city streets to generate portraits that were published on large posters in a public-shaming exercise – a modern version of pillory.

Mark Shriver and other scientists around the world are trying to identify all the genes that are responsible for the huge variation of the human face. The field is growing rapidly thanks to new technology. Scientists sequence ever more genes that are involved in producing facial bones, cartilage, soft tissue, and skin. So far, about 50 have been identified, and some of them are associated with multiple traits. However, scientists still do not know if they are searching for hundreds or thousands of genes – only that our faces are tremendously complex.

We have 43 facial muscles, and the number of possible facial expressions is prodigiously high. Some 10,000 have been registered in the Facial Action Coding System (FACS), an index identifying facial expressions that are common throughout the world. The total pool of human facial expressions is, however, far more extensive because our faces are asymmetrical, and because we change markedly with age.

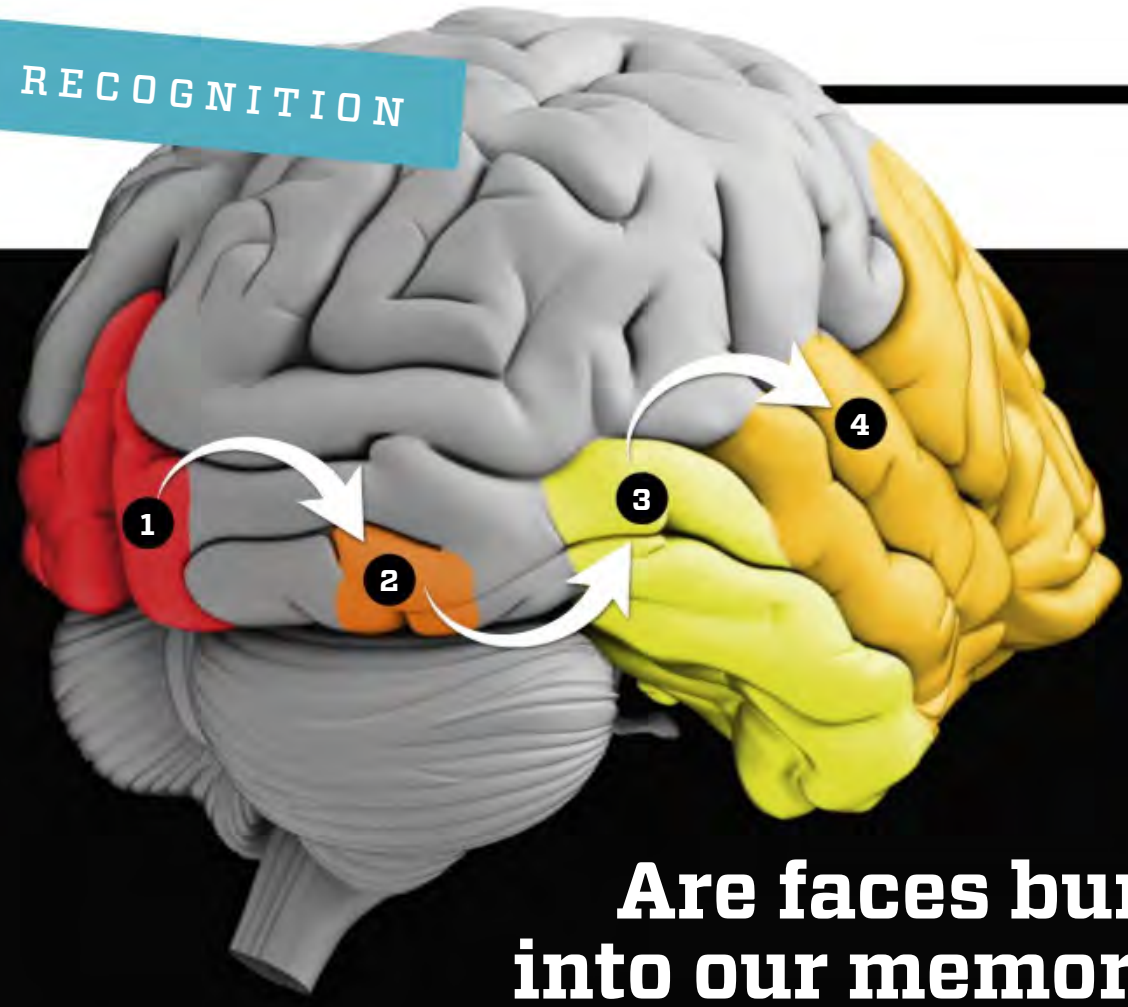
The face reflects the past

Modern humans, or at least humans looking about the same as we do now, appeared in Africa around 200,000 years ago. Our close relatives – gorillas, chimpanzees, and the earliest human species – had a flat forehead, a small brain, and a large, protruding jaw. But modern man has a round head with a large brain and a smaller jaw. We have a flat and naked face, in which eyes, nose, and mouth are located vertically above each other. It's a highly unusual arrangement compared with most other mammals. ▶

BABY FACE

Just like us, chimps have flat faces when they are young. Unlike them, we keep the characteristic throughout life.

SHUTTERSTOCK & GETTY IMAGES



SHUTTERSTOCK

Are faces burned into our memories?

Your neighbour can recognise your face among thousands of others. Natural selection has made the human face easy to recognise – and the brain an expert in storing faces in memory.

Penguins look the same. They tell each other apart by means of sounds. Other animals use their sense of smell to find each other or, like chimpanzees, they focus on the bottom. People recognise each other based on the face. And according to new research, we have developed an immense variation of facial features because easily recognisable faces provided our ancestors with an evolutionary advantage. Moreover, our brains have developed specialised centres that can differentiate between and then store faces. The system is very efficient. In 2018, English psychologists asked 25 students to write down all the faces that they could think of – friends, family, neighbours, the news-stand owner, and celebrities. They didn't need to remember the names. The scientists concluded that each of us remembers 1,000-10,000 faces at any given time.

The face ends up at the back of the head

1 When you see a face, 100 million light-sensitive photoreceptors in your eye will send an image to the centre of vision at the back of your brain.

Brain centre seeks out eyes and mouth

2 The occipital face area in the occipital lobe seeks out the eyes, nose, and mouth of the visual impression to decide if it is a face.

Nerve cells make a detailed map

3 In an area at the bottom of the temporal lobe, each nerve cell reacts to one distinct facial characteristic, such as skin colour or the distance between the eyes. The cells' total activity produces a map of each tiny detail of the face you are seeing.

The brain saves your face

4 The facial data is stored in the brain. The hippocampus and the frontal lobe play a particularly important part in the storage.

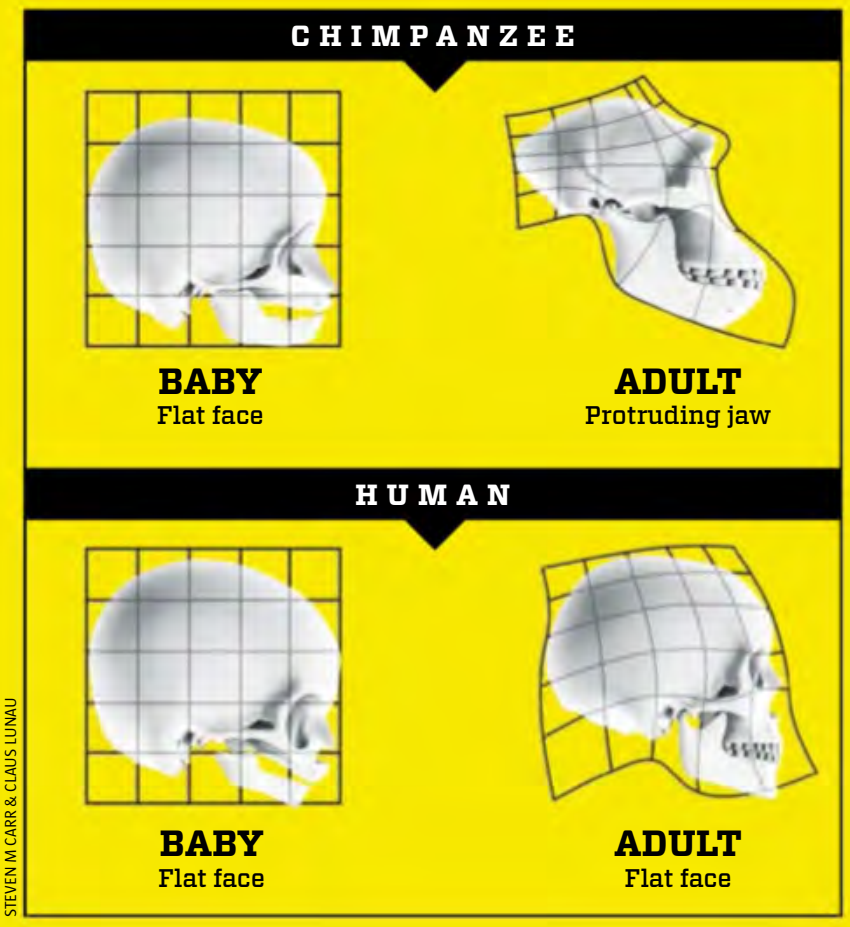
Your face lies about your age

You have a baby face. When compared with our closest relatives, we look like young children.

Our pets are often cute versions of their wild ancestors. They have large eyes and short snouts – characteristics that are otherwise only observed in baby animals. The maintenance of childish features in adulthood is known as neoteny, and it is particularly observed in pets. But the phenomenon is completely central to human evolution.

At birth, chimp and human skulls are very much alike. Both have flat faces. Over time, the chimp's jaws grow and the skull changes dramatically. But humans, like pets, keep their baby faces throughout life.

According to some scientists, we are attracted to youthful facial expressions. Others think that it is a side effect caused by the fact that we have chosen partners that are not aggressive, and this has caused a change to our hormones that has affected face development.



STEVEN M CARR & CLAUS LUNAU

Palaeontologists who research human origin and evolution are shedding new light on our odd faces by means of fossil skulls. The fossils tell a story of how the modern face formed through diet, climate, migration, and encounters with other groups of people. When we began to cook our food, jaw and molars shrank; chewing consumed less energy. Fights over food and mates might have contributed to our strong cheeks and forehead bones, able to protect against bone fractures.

The climate also played a role in shaping the face. Anthropologists from the Pennsylvania State University have studied 3D images of 467 noses, measuring their length, width, and height and comparing them to the climate of the regions in which the nose owners live. The scientists found that wide nostrils are related to high temperatures and air humidity, whereas narrow, high nostrils are mostly found in humans that live in a cold, dry climate. The explanation is that narrow nostrils make the air flow pass closer to and more slowly past the moist, warm nose mucosa, where it is adapted to the body's internal conditions before it is inhaled into the lungs. So, narrow nostrils are advantageous in cold regions – and vice versa in warm places.

> **It is possible to see when a person lies in a split second, based on small motions of the facial muscles.**

Further, it seems likely that our ancestors' lives and surroundings not only influenced the shape of the face, but also influenced the motions of faces – our expressions.

Facial expressions are reflexes

Facial expressions that served practical purposes in our ancestors remain today, even though they may no longer have the same functions. When we raise our eyebrows and open our mouths in surprise, it might be because when our ancestors spotted a predator, they raised their brows to expand their field of vision and opened their mouths to get sufficient oxygen to run.

The expression is so closely connected with the body's reaction to the unexpected that we still do it today. The same mechanism is known from the animal kingdom. Dogs move several times around themselves before they lie down, which might be because their ancestors formed a "bed" in the grass in this way. Some scientists believe that most of our facial expressions are reflexes that go all the way back to the ancestors of mankind.

If that is true, then all people throughout the world might share the same expressions when subjected to similar situations. That was what Darwin claimed when he identified the six universal facial expressions that reflect our basic emotions. And in 1968, American psychologist Paul Ekman visited a remote people in New Guinea, to test whether Darwin was right.

The world smiles with you

It is 1968. Paul Ekman and his team are struggling through the wilderness in the rugged mountain region that is the home of the Fore tribe. The people live isolated and primitive lives and know nothing about the Cuban Missile Crisis, the Lunar race, or Hollywood. Unspoiled by Western culture, the people live a life closely related with nature – perfect, then, for Ekman's experiment.

The scientists bring photos of people with different facial expressions and ask the locals to choose, from a list, the description that goes with each expression. The conclusion is that Darwin was right. A smile is a smile and expresses joy throughout the world. And the same is true for Darwin's five other basic expressions.

The result proved to be controversial, with several anthropologists of the time believing that facial expressions are acquired and culture-based. Still, Ekman's discoveries gained traction in the following years as he and other scientists carried out the experiment in 21 countries, with the same results. Several decades later, new studies also support Ekman. Analyses of 4,800 photos of athletes with and without eyesight, made by American psychologist David Matsumoto from the 2004 Olympics, indicate that a facial expression is instinctive. All athletes had the same expression of joy when they were on the podium, and athletes with silver medals smiled the 'social smile', which differs from a genuine smile by not causing laugh lines to appear.

According to Paul Ekman, our facial expression is so closely and instinctively linked with our emotions that it is possible to see when a person lies in a split second, based on small motions of the facial muscles. This part of Ekman's work is often used by the US intelligence and security services of the CIA

A specific variant of the KCTD15 gene produces a nose that is bigger than the average.

PAUL MICHAEL HUGHES/ GUINNESS WORLD RECORDS

Mutations cause a flat forehead or a big nose

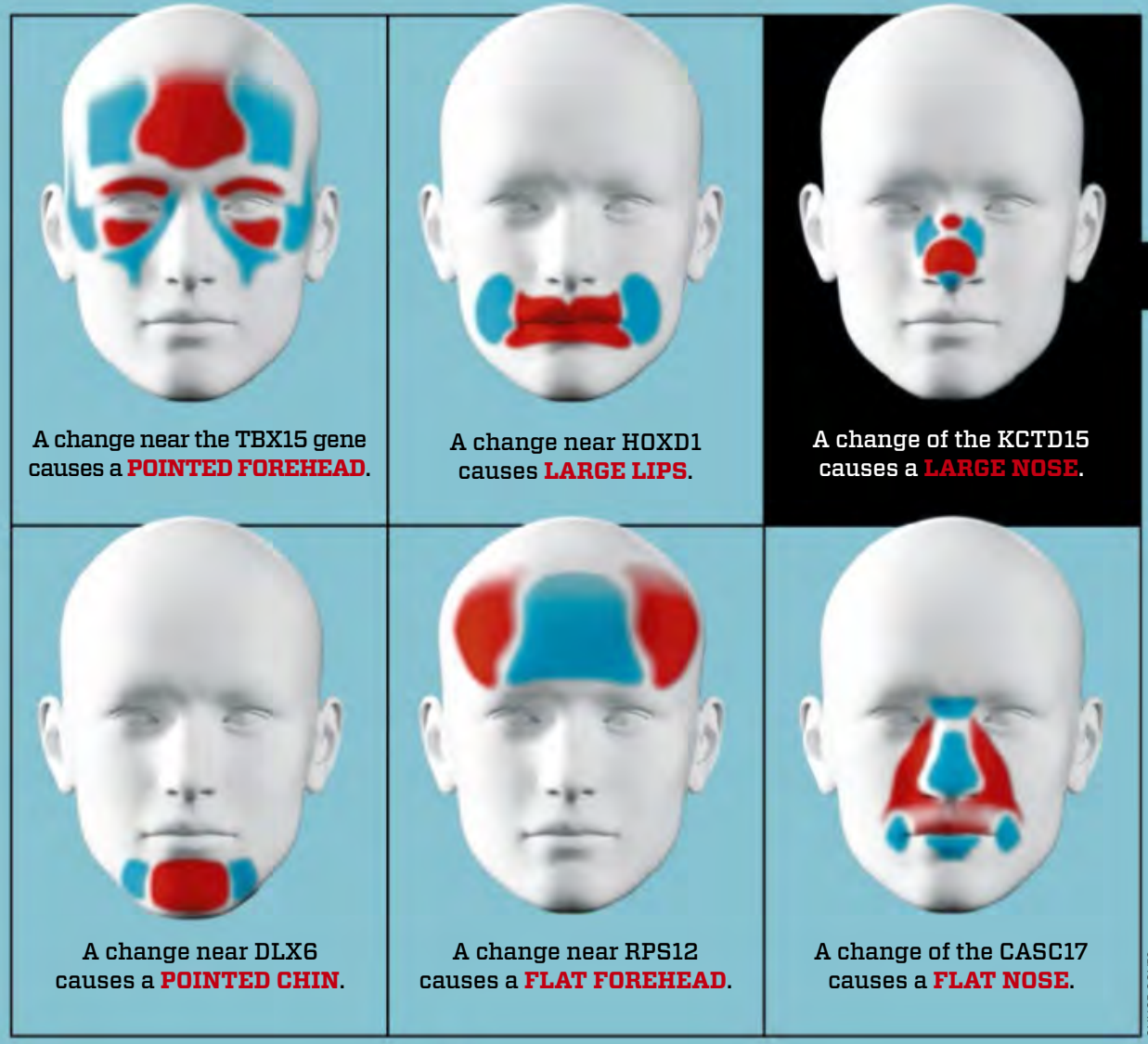
Scientists are finally cracking the code concerning facial shape. Based on a small DNA sample, they can now predict whether the DNA's owner will have a large nose tip or a pointed chin.

The small depression under the nose testifies to the puzzle taking place in the womb as the face is formed: it is where all the major characteristics of the face are united. The process is extremely complex, and yet so accurate that your nose can have almost the same shape as your father's nose.

Only now are scientists beginning to understand how your genes contribute to shaping your face. Previously, it was only possible to take a look at a few genes and compare them to a few selected traits such as the width of the mouth or the distance between the eyes. But now scientists can analyse the complete set of genes from thousands of test subjects and compare the information with accurate 3D facial scans.

In 2018, American and Belgian scientists set a new standard in the field. They used DNA and 3D images from 2,329 Europeans to study whether there were DNA sequences linked with specific facial features. Initially they found 38 sequences that were very probably connected with one or more facial features. Subsequently they tested the result on 1,719 new faces, reducing the quantity to 15 sequences.

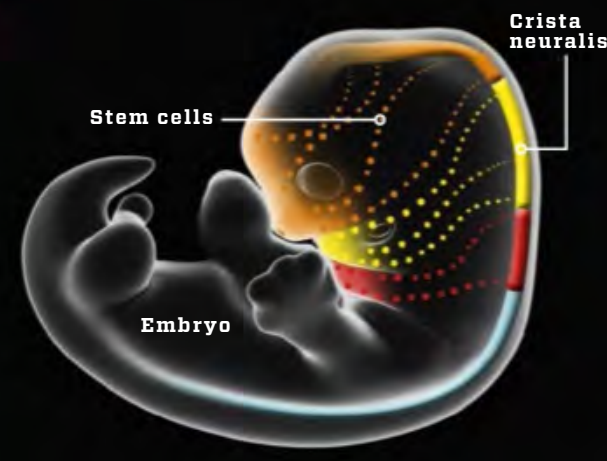
They discovered that people with the DNA base of guanine in a specific place close to the KCTD15 gene had a more projecting nose tip than people who had the adenine base in the same place of their DNA. A total of seven of the 15 sequences had to do with nose shape – and this is a potentially very useful result, as the nose shape is difficult to deduce from the skull, and so the new discovery will be a major help in criminal cases, or when we would like to reconstruct early humans.



CLAUS LUNAU

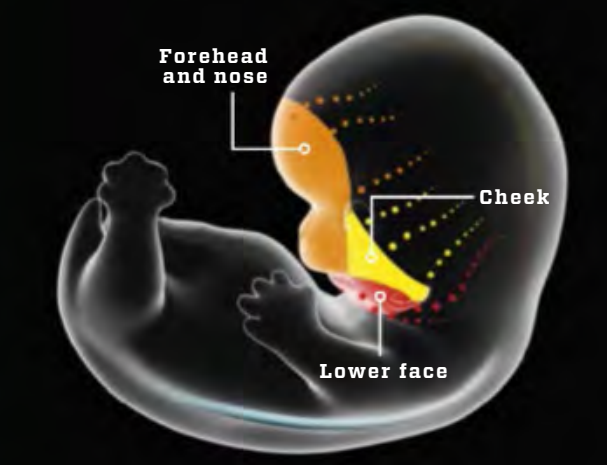
Genes influence face formation

- Cells that form forehead and nose
- Cells that form cheeks
- Cells that form the lower part of the face



Stem cells migrate in embryo

1 The KCTD15 gene, which scientists have just linked with nose size, contributes to controlling formation of stem cells in the crista neuralis early in embryonic development. When the baby is about a month old, the stem cells migrate from the back to the front of the embryo.



Neurotransmitters distribute tasks

2 By means of neurotransmitters, the stem cells coordinate which will form which parts of the face. Some cells form the forehead, others the chin. Some turn into bone, others cartilage or glandular tissue. The genes control the formation and release of neurotransmitters, hence controlling face.

Genes fine-tune the face

3 The genes divide, and the number of cell divisions in the different areas determines the shape of the individual parts of the face. According to scientists, the KCTD15 gene may contribute to controlling how much the cartilage cells of the nasal septum divide and so how large the nose grows.

CLAUS LUNAU & SHUTTERSTOCK

DECODING

Your muscles mirror facial expressions

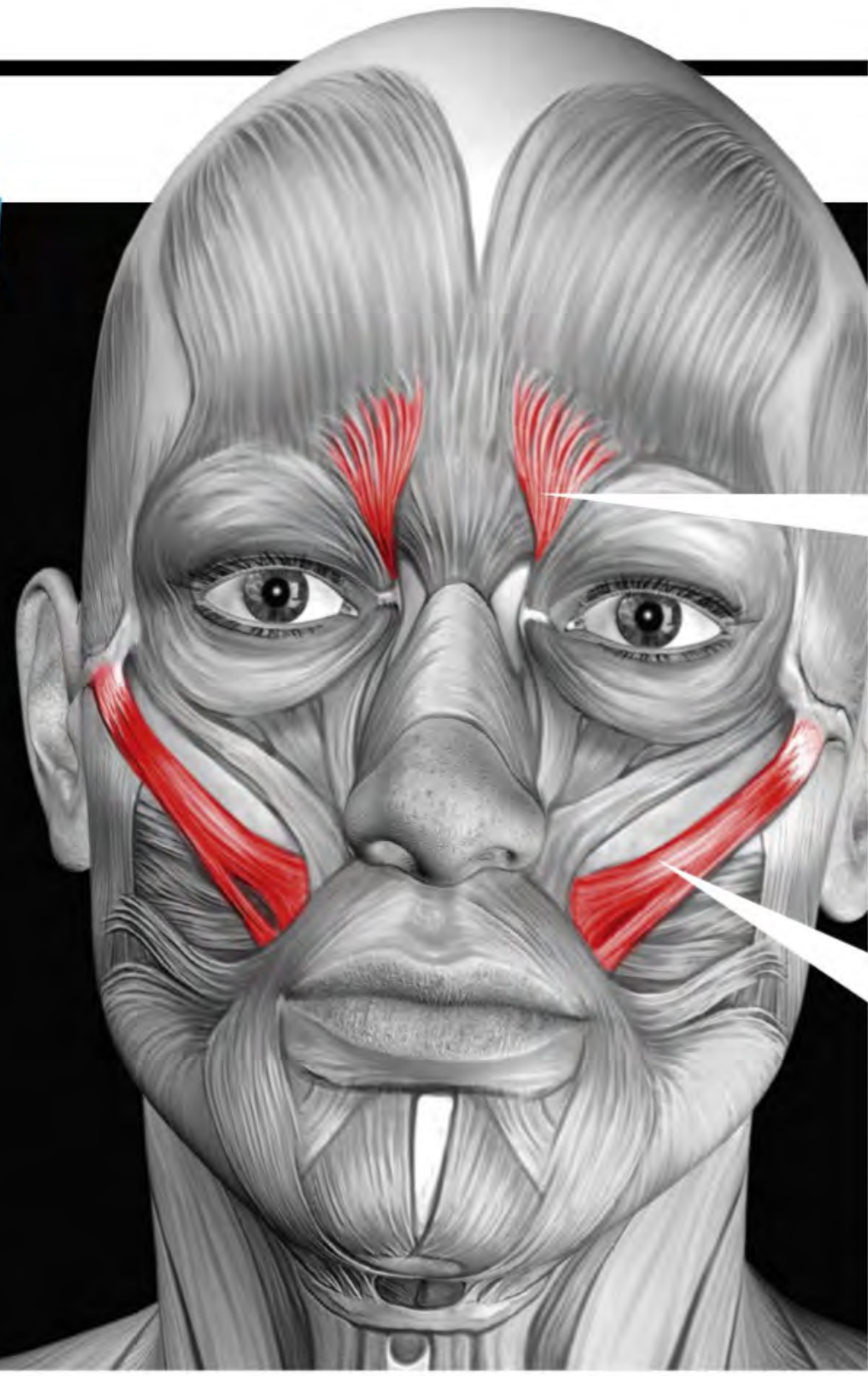
If your face is paralysed, you might find it difficult to decode the faces of other people. Several experiments indicate that our face muscles play an important role in the interpretation of other people's facial expressions.

You automatically react to the facial expressions of other people by mirroring them. You may have noticed this when the person next to you yawns, but it is also true for much more discreet motions. Even when your face doesn't seem to react as you see another person's facial expression, scientists can measure that your facial muscles still mirror the expression you are looking at.

According to some scientists, the mirroring helps you understand other people's emotions. When you mirror an expression, it triggers the emotion that the expression represents, and so you experience empathy. The theory is supported by an experiment in which people had Botox injections, partly paralysing their faces, and they were less able to understand the emotions of other people. Another experiment concluded that the muscles of the left side of the face most help you feel empathy, so that you could be paralysed on the right side without having difficulties decoding emotions.

Botox injections paralyse the muscles, which can make it difficult to interpret others' facial expressions.

SHUTTERSTOCK



and FBI. When you meet a suspicious customs officer at the airport who scrutinises your face, he or she might very well have been trained according to Paul Ekman's methods.

But Ekman's theory of a face being the mirror of emotions is now challenged by several scientists, who criticise the basic methodology of Ekman's original experiment.

Fear becomes a threat

It is 2014. Fifty-four members of the Namibian Himba people, from two isolated villages, participate in an experiment. In the US, 68 Americans participate. American psychologists Maria Gendron and Lisa Feldman Barrett are responsible for the experiment, which is designed to test the method that Paul Ekman used in Papua New Guinea. Both experimental groups are divided in two, and all are introduced to photos of people with the six facial expressions that Darwin and Ekman worked with. One half of the two groups has to categorise the photos according to a list of Darwin's six basic emotions – as in Ekman's experiment. The other half categorise the photos any way they want. The result shows that the Americans and Africans get the same result when they choose from the list, but different results when they can choose freely. The psychologists conclude that Ekman's method produces a guided result.

Psychologist Carlos Crivelli also criticises Ekman. He tested people in Mozambique and Papua New Guinea to find that young people from PNG interpret the expression of fear in people with eyes and mouths wide open very differently than do Westerners. They see it as a threatening expression. In 2017, another team of scientists analysed a total of 50 studies on the link between facial expressions and emotions, concluding that only a small portion of our facial expressions reflect our emotions. Only smiling and laughter were almost always expressions of joy.

If the results are correct, it means that our facial expressions are acquired. They are not instinctively linked with our emotions, and they are not a window on our soul. Indeed, many scientists even think that the primary aim of facial expressions is to manipulate others in order to get our own way.

Many scientists do, however, still support Ekman's theories, and the truth is probably somewhere in between the two camps. A new approach might help us come closer to the answer. By forming a new face from scratch, we can perhaps learn more about the secrets of our own faces.

Robots face up to the mysteries

It is 2018, 179 years after Charles Darwin began to study facial expressions, and Japanese robot researcher Hiroshi Ishiguro introduces the most recent of his robots, Ibuki.

"Hi, I am Ibuki – meaning life," says the human-like robot in a boyish voice, which seems to emanate from somewhere other than his silicone mouth.

Ishiguro is one of the world's leading robot developers. He has a robotic copy of himself, and he works on imitating humans in his robots in order to learn more about being a human being. Ibuki has the face of a 10-year-old boy and moves

Your face mirrors the emotions of other people

When you see an **ANGRY PERSON**, it triggers activity in the corrugator supercilii muscle, pulling your eyebrows downwards.

When you see a **HAPPY PERSON**, the zygomaticus major muscle is activated. This muscle is involved in pulling the corners of your mouth upwards when you smile.

his lips, jaw, and eyes as he speaks. In his eyes are cameras which can recognise a face, and he can react with a smile when someone smiles at him. But still, he does not seem human; Ibuki demonstrates how complex our facial expressions are. Other new robots, such as the Shaman of Songs in Disney World, Florida, achieve much more fluid motions, though they are not as independent as Ibuki.

The aim is to make the robots perform realistic motions and to use them at the right times. The first requires a robot able to mimic all the tiniest of motions of the human face. Disney's Shaman robot is close, thanks to a wealth of moving parts under its skin, but it is not completely successful. The second requires an understanding of how facial expressions are linked with our thoughts. We do not yet quite have this understanding, but scientists hope that the robots can learn from themselves. In 2019 scientists from New York, USA, created a robotic arm that taught itself to move objects. The next step might be a robotic face that can teach itself – and us – the secrets behind the human face. SCI

MANIPULATION

A sad face ensures sympathy

A group of scientists is challenging Darwin's old theories concerning the face. They think that the primary purpose of our facial expressions is to manipulate other people.

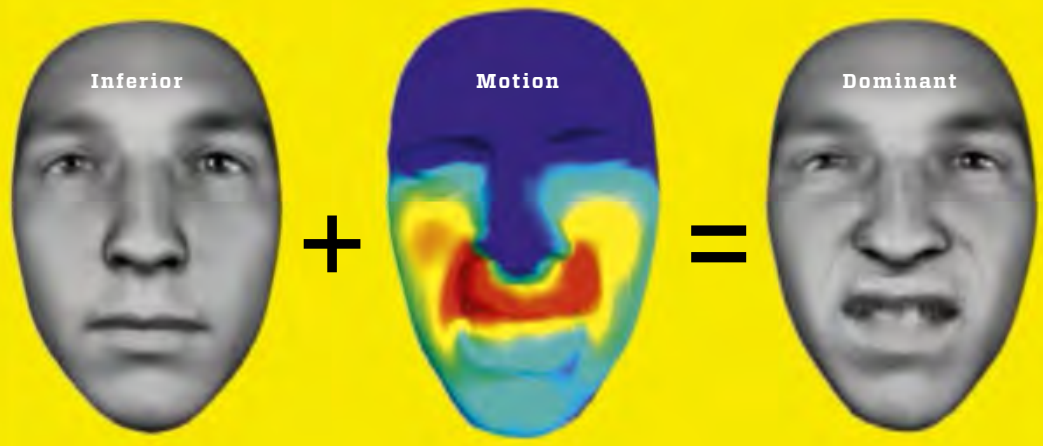
You do not cry because you are sad, rather because you want to arouse other people's pity. You do not scowl because you are angry, rather because you would like others to surrender. Several scientists believe that our facial expressions are less a window onto our emotions than a tool to get our way.

They refer to experiments showing that we adjust our facial expressions depending on who is looking. In this way, we are ensuring that the expressions have the desired effect on the receiver. Opponents of the theory point out that we also pull faces when we are alone, to which proponents reply that we are never entirely by ourselves, as we have still people on our mind. As both sides make a good case, there is a strong possibility that our facial expressions can both be honest and used for manipulation.

GUIDE: Give people a new impression

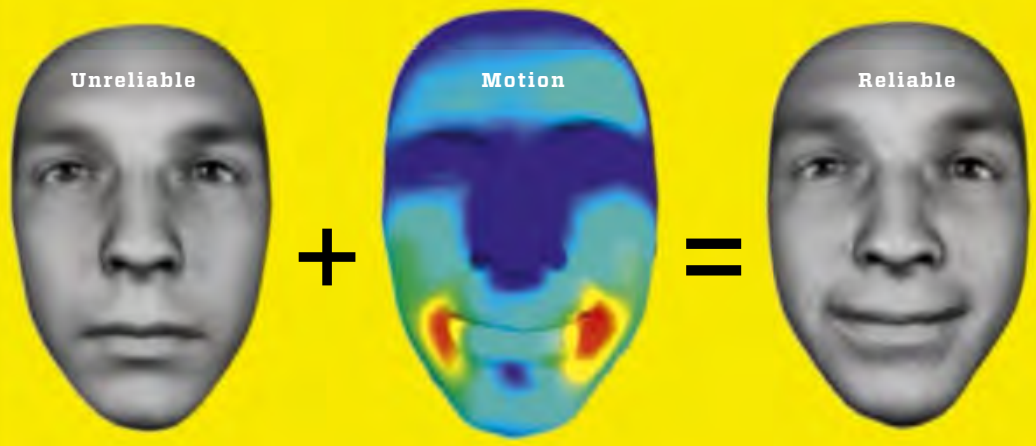
Scientists have mapped out the motions required to make inferior faces dominant and unreliable faces reliable.

RACHAEL E JACK & PHILIPPE G SCHYNS/CELL PRESS



Become dominant by raising your upper lip

The scientists first created a face that was considered inferior. Subsequently, they tested what was required for the face to be considered dominant instead.



Build confidence with a discreet smile

Scientists added minor changes – primarily at the corners of the mouth – to make an unreliable face seem reliable in the opinion of test subjects.

Cross the Atlantic at a speed of 6,000 km/h

The first non-stop, transatlantic flight was completed 100 years ago, in June 1919. Today the trip is a matter of routine, but change is in the air, with future planes able to fly at five times the speed of sound, or to orbit Earth 10 times consuming only a single litre of water...

Aerospace company Boeing aims to develop hypersonic aircraft that will carry passengers at a speed of 6,000km/h.

BOEING & GETTY IMAGES

By **Niels Halfdan Hansen**

100 YRS

The first transatlantic flight

On 15 June 1919, John Alcock and Arthur Brown were the first to complete a non-stop, transatlantic flight.

FLIGHT: IV2019 SEAT: 42B NEW YORK ✈ LONDON

Planes of the future soon to take flight

SHAPE
A "double-bubble" design and a flying wing: new shapes will markedly reduce fuel consumption.

SPEED
Ultra-brief travel times are guaranteed when future airliners fly faster than Mach 5.

PROPULSION
With an entirely new type of engine, future planes might fly solely on electrically-charged atoms.

SHAPE

Double hull causes less air drag

With shorter wings, engines located at the back, and a body that contributes to lift, the new Aurora D8 aircraft design will consume 66% less fuel than existing airliners.

Smaller wings save fuel

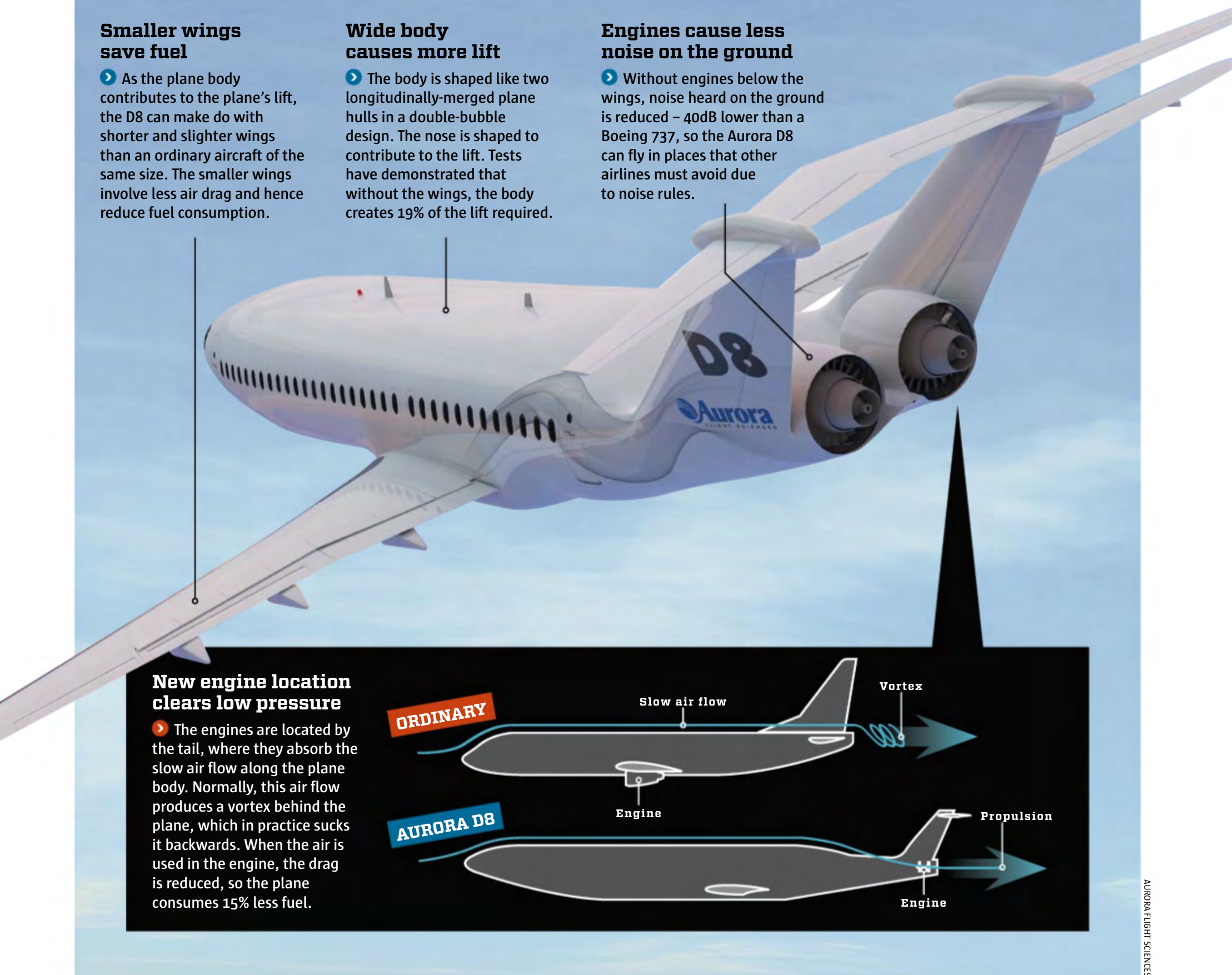
As the plane body contributes to the plane's lift, the D8 can make do with shorter and slighter wings than an ordinary aircraft of the same size. The smaller wings involve less air drag and hence reduce fuel consumption.

Wide body causes more lift

The body is shaped like two longitudinally-merged plane hulls in a double-bubble design. The nose is shaped to contribute to the lift. Tests have demonstrated that without the wings, the body creates 19% of the lift required.

Engines cause less noise on the ground

Without engines below the wings, noise heard on the ground is reduced – 40dB lower than a Boeing 737, so the Aurora D8 can fly in places that other airlines must avoid due to noise rules.



New engine location clears low pressure

The engines are located by the tail, where they absorb the slow air flow along the plane body. Normally, this air flow produces a vortex behind the plane, which in practice sucks it backwards. When the air is used in the engine, the drag is reduced, so the plane consumes 15% less fuel.

AURORA FLIGHT SCIENCES

Two sets of wings provided extra lift
Alcock and Brown crossed the Atlantic on a plane with two sets of wings to ensure sufficient lift with the weak engines and inefficient propellers of the time.
GETTY IMAGES

Cold and exhausted, the two men in the open cockpit stare down at the monotonous ocean below them. Some 16 hours ago, they took off from St. John's in Canada, heading for the British Isles.

The plane's generators have long since failed, disabling both the radio and the heating. The exhaust is broken as well, making the noise from the engine so loud that the two men have to shout to each other. They have travelled through dense fog and snow storm; the instruments are covered in ice, and for long periods of time the visibility was so poor that they did not know if they were on the right course.

But now, the pilot, John Alcock, and his navigator, Arthur Brown, spot the Irish coast in the distance. Against all odds, their mission has been accomplished – they are the first ever to fly non-stop across the Atlantic aboard a plane. Alcock prepares for landing, but as a last reminder that the two airmen have challenged technology to the extreme, the landing gear breaks down, and the plane ends up on its nose. Luckily, both men get to leave the craft unharmed shortly afterwards.

The two Brits' 3,000km-long trip across the North Atlantic in June 1919 was made at an average speed of 190km/h; it took 16 hours and 27 minutes. Today, the distances between European capitals and New York can be made on a jetliner travelling at a speed of 900km/h and offering all modern comforts. Yet for decades, the design of the large airliners has hardly changed. Now engineers have begun to design planes according to new and different standards, including novel engine types. In the decades to come, these planes will, just like Alcock and Brown, challenge technology so that the Atlantic could be crossed in a few hours, and with no more pollution than a short trip in a car causes today.

190

km/h was the average speed of the 3000km first transaltantic flight in 1919.

Engineers learn a tough lesson

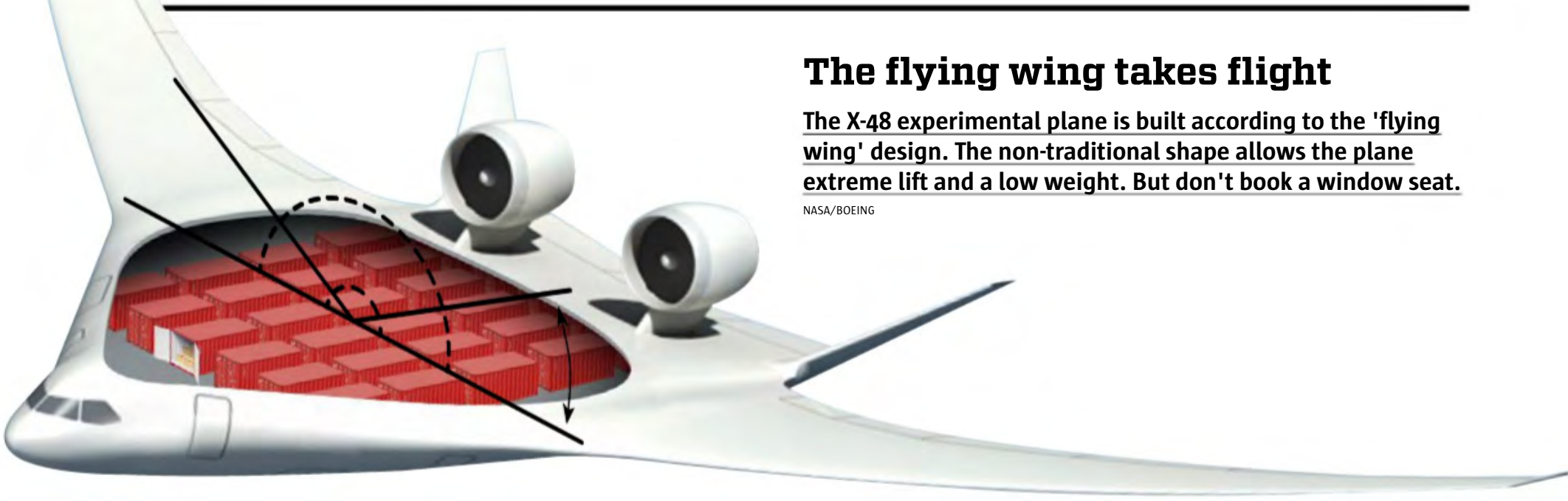
The dream of regular flight services across the North Atlantic carrying mail and passengers followed in the wake of Alcock and Brown's major feat, but the intervention of World War II meant that it was not until 1945 that the first planes entered a regular transatlantic service. The L-049 Constellation was the first civil plane with a pressurised cabin as we know them from modern airliners.

With a pressurised cabin, the pilot could climb to higher altitudes and fly above most weather systems to avoid turbulence, which had made flying a relatively lethal type of transport at the time. Although the propeller-driven Constellation took 17 hours from New York to Paris, the plane soon 'took off' by offering a much faster alternative to travel by ship.

However, the propeller aircraft's dominance of transatlantic transportation proved a brief one. The jet engine was introduced in airliners in 1952 with the de Havilland D.H. 106 Comet. The plane's new engine type markedly increased the top speed. The most modern and efficient propeller planes could just barely reach 500km/h, but the D.H. 106 Comet easily made 750km/h. The travel time from Europe to the US was reduced to about 10 hours.

Then in 1953 and 1954, several Comets fell apart shortly after take-off, for no apparent reason. After comprehensive examinations of the wreckage, experts concluded that the accidents were due to the previously unknown phenomenon of metal fatigue. The Comet's pressurised cabin had square windows, and experts discovered that the high speed and the powerful engines adversely affected the corners of the windows. Small cracks in the metal grew so large that the plane body suffered structural failure in the air. The Comet accidents are the reason that plane windows today are either oval or circular.

Supercomputers and complex mathematical models are used by today's planemakers and ▶



The flying wing takes flight

The X-48 experimental plane is built according to the 'flying wing' design. The non-traditional shape allows the plane extreme lift and a low weight. But don't book a window seat.
NASA/BOEING

PROS

The total volume of the plane body is much larger in a 'flying wing' than in a conventional plane design, markedly improving load capacity.

With more empty space in the cabin, the design can be built using 15% less aluminium. This means that the plane weighs less and consumes less fuel.

The entire body contributes to the lift, and the aerodynamic shape causes little air drag. So the 'flying wing' consumes 27% less fuel.

CON

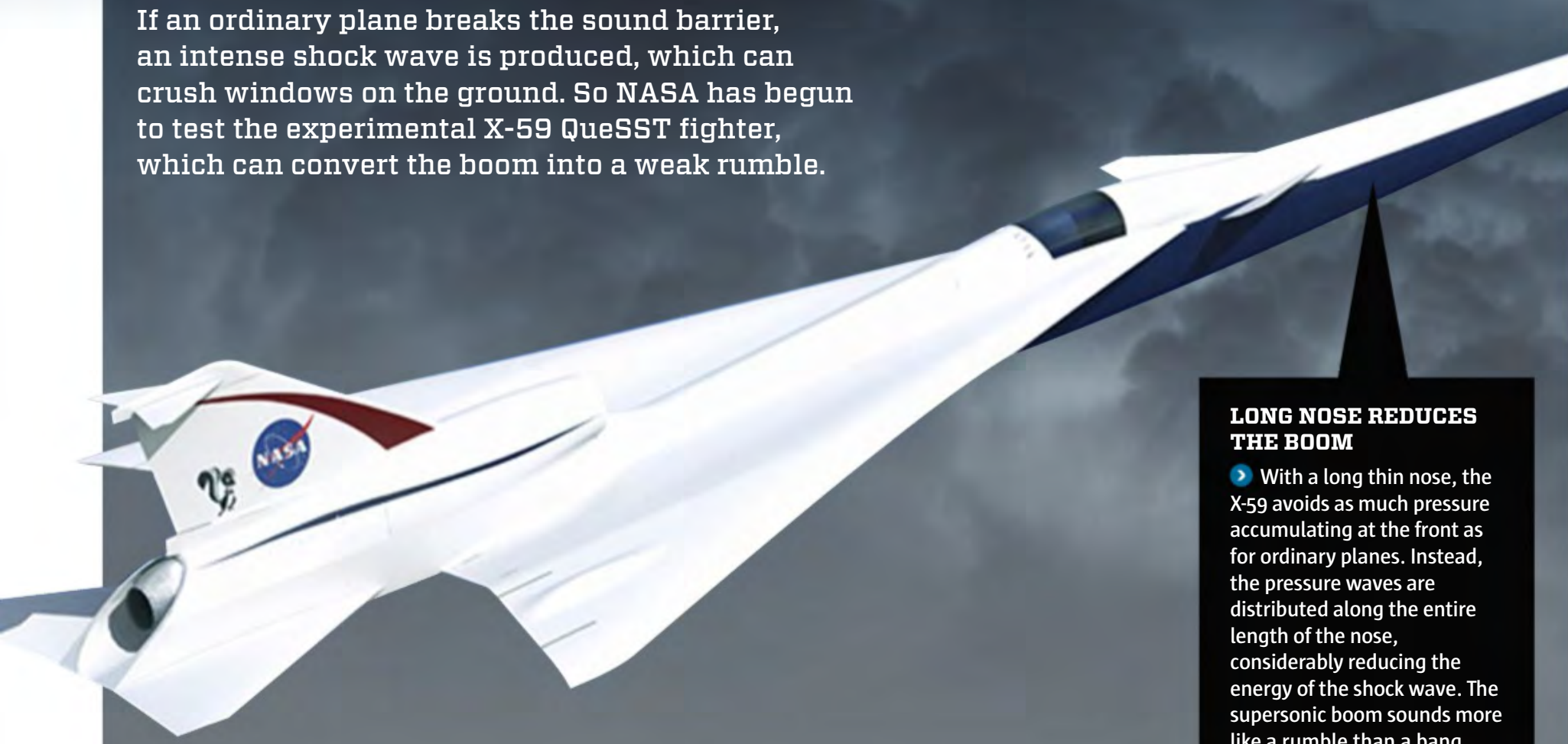
Away from the plane's centre axis, the amplitude of movement becomes intense when the plane tilts, making passenger discomfort an issue.

SPEED

Quiet boom allows a supersonic comeback

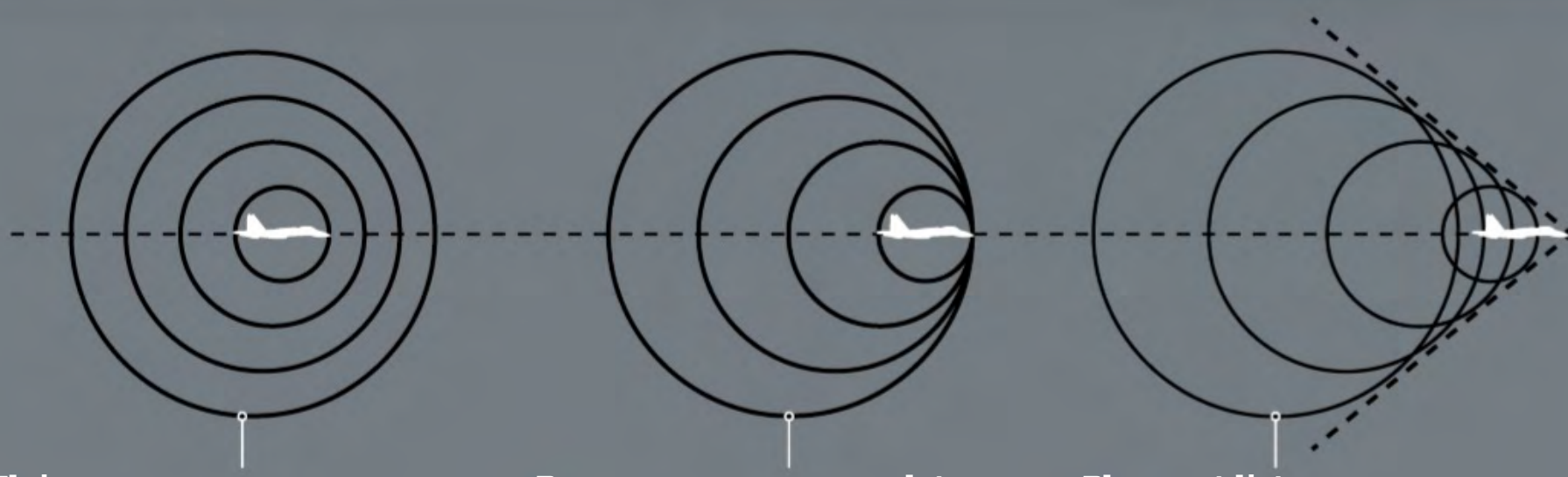
If an ordinary plane breaks the sound barrier, an intense shock wave is produced, which can crush windows on the ground. So NASA has begun to test the experimental X-59 QueSST fighter, which can convert the boom into a weak rumble.

NASA is working on reducing the supersonic boom of planes, which prevents supersonic flight above land.



LONG NOSE REDUCES THE BOOM

With a long thin nose, the X-59 avoids as much pressure accumulating at the front as for ordinary planes. Instead, the pressure waves are distributed along the entire length of the nose, considerably reducing the energy of the shock wave. The supersonic boom sounds more like a rumble than a bang.



Flying causes pressure waves

When a plane moves through the air, it constantly produces pressure waves around it which escape the plane at the speed of sound.

Pressure waves accumulate

As the plane approaches the speed of sound, the pressure waves in front of it cannot escape, and pressure accumulates in front of the plane.

Plane outdistances waves

When the plane flies faster than the speed of sound, it outdistances the accumulated pressure waves. The pressure changes, producing a shock wave – a boom.

LOCKHEED MARTIN

The Atlantic was crossed very slowly
The first transatlantic flight took Alcock and Brown about 16 hours travelling at an average speed of only 190km/h. The low speed saved fuel.
GETTY IMAGES

designers to test the airworthiness of their new creations. With such immense calculating power, they can simulate the strength of different materials down to the atomic level, and subject them to all kinds of stress long before the plane has been built.

Small changes – major effects

In recent years, planemakers such as Boeing and Airbus have come under increasing pressure from the outside world to develop new plane models that can reduce air transport's share of global CO_2 emissions.

This mirrors efforts during the first oil crisis in 1973, when fuel prices skyrocketed and engineers began to examine any adjustments that could allow planes to fly longer on the same quantity of fuel.

One of the most important innovations in this regard is the bent wing tip, now installed on almost all major aircraft. Also known as "winglets", this idea was introduced to aviation by engineer Richard Whitcomb from NASA's Langley Research Center. He proved that when the small, perpendicular bends were mounted, the way in which the air meets and passes the wing changes. Without a winglet, a powerful vortex is produced around the wing tip. The vortex forces the outer part of the wing downwards, and it produces low pressure in the air behind the wing, which then sucks the plane slightly backwards. With a winglet, the vortex becomes markedly smaller, and the plane's total fuel consumption is reduced by about 7%.

New materials, lighter planes

Engineers' long focus on fuel economy has led to the average airliner now consuming half as much fuel per passenger as some 50 years ago on a flight across the Atlantic. But when the 10,000th unit of the world's most popular plane, the Boeing 737, was completed in the spring of 2018, it was most of all a symbol of how little has changed in plane design over half a century.

Yet technological development has given the aerospace companies a series of new tools for changing radically the appearance of the modern airliner. One of these is composites, where different basic materials are united to form a new material that exhibits a combination of the best qualities of the originals.

For decades, plane bodies have been made of aluminium, due to the metal's low weight and relatively high strength. But by reinforcing plastic with carbon-fibre threads, engineers have managed to make a composite material that is both lighter and stronger than aluminium. In 2011, Boeing introduced its 787 Dreamliner aircraft, the first airliner in the world that is made primarily of composites. Boeing estimates that the 787 is 20% lighter than an aluminium equivalent. Lower weight means that the plane must produce less lift, and a lower lift requirement allows engineers to improve aerodynamics, so the plane saves fuel.

However, it is not just fuel on which planemakers aim to become less dependent. Many engineering teams are developing pilotless airliners. Global aviation expects a doubling of passenger numbers within the next 20 years. Some 200,000 pilots are currently employed in global aviation, but in 20 years 600,000 will be needed, so aviation companies have begun to prepare for a pilot shortage in the future, developing planes that can fly independently.

In theory, aviation is ripe for autonomous vehicles. The technology is even less demanding than that of a driverless car, as the airspace is less crowded and more structured than the ▶

2.72

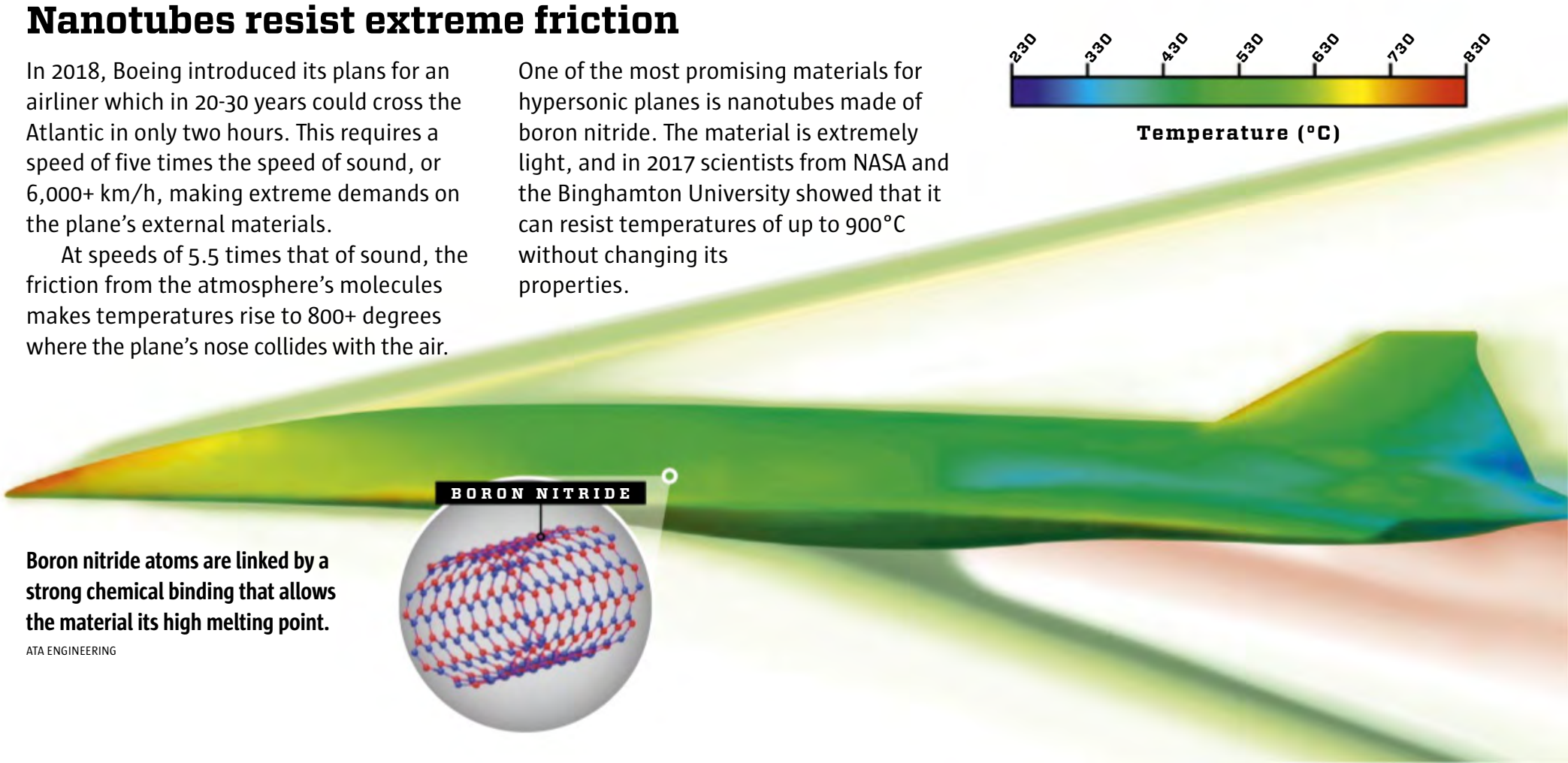
m is the height of an Airbus A330 winglet – the same as the world's tallest man.

Nanotubes resist extreme friction

In 2018, Boeing introduced its plans for an airliner which in 20-30 years could cross the Atlantic in only two hours. This requires a speed of five times the speed of sound, or 6,000+ km/h, making extreme demands on the plane's external materials.

At speeds of 5.5 times that of sound, the friction from the atmosphere's molecules makes temperatures rise to 800+ degrees where the plane's nose collides with the air.

One of the most promising materials for hypersonic planes is nanotubes made of boron nitride. The material is extremely light, and in 2017 scientists from NASA and the Binghamton University showed that it can resist temperatures of up to 900°C without changing its properties.



Boron nitride atoms are linked by a strong chemical binding that allows the material its high melting point.
ATA ENGINEERING

Airspace of the future is packed

Air traffic is expected to increase sevenfold by 2050, but with new satellite monitoring, air traffic controllers can use the global airspace more efficiently.

Pilots must avoid food poisoning

On long routes, several airlines have rules requiring that the captain and co-pilot eat different meals, due to the risk of food poisoning. The captain often gets the First Class meal, the co-pilot the Business Class meal.

CHICAGO
NEW YORK
ST. JOHN
CLIFDEN
PARIS

Curved route is always the shortest

When the route is indicated on a flat map,a flight from Chicago to Dubai apparently takes a major detour around Greenland and Northern Norway. But when the same route is presented on a 3D globe, it's clear that this is the direct route.

Jet stream allows pilots tail wind

Pilots often use the fact that they can get a major push from jet streams on east-bound trips across the Atlantic. In January 2018, a Boeing 787 flew from New York to London in five hours and 13 minutes, setting a new record for transatlantic travel time.

100

years is the age of the world's oldest airline, Dutch KLM. It first crossed the Atlantic in 1934.

Most global flights in a single day

On 29 June 2018, the Flightradar24 flight-tracking site announced that it had recorded 202,157 flights – the highest number ever. At the peak of traffic, **more than 19,000 planes were in the air at the same time.**

9,090,941

passengers flew between Melbourne and Sydney in 2017, making this the world's second busiest passenger air route.

Storm forces plane to take a detour

Almost all pilots try to avoid thunderstorms. The weather type is particularly dreaded due to micro-bursts, small pockets of descending air, which in brief jerks **can force the plane downwards at up to 240km/h.**

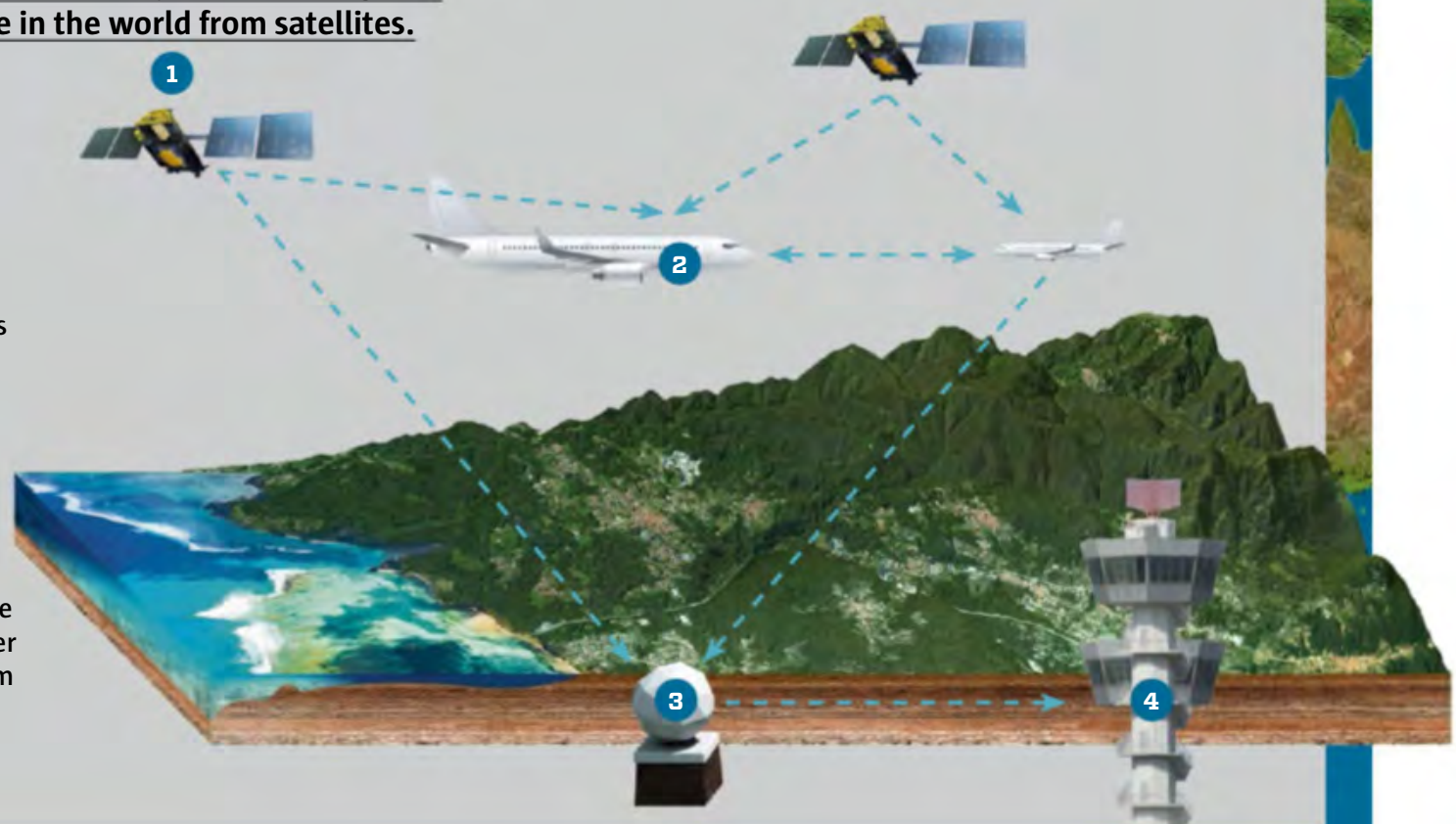
Desert air in cabin claims liquid

The air humidity of a flight cabin is 10-15% on long routes – in the Sahara, the air humidity is about 25%. So, passengers lose a lot of liquid breathing – **women can lose about 1.6 litres and men 2 litres during a 10-hour flight.**

IN THE FUTURE

Satellites monitor planes all the time

So far, passenger planes have been invisible to air traffic controllers when they pass across oceans, since radio towers on dry land have a maximum reach of 400km. But now a new system is rolling out, which monitors planes anywhere in the world from satellites.



1 **A global network** of communication satellites receive data from the planes and pass it on to stations on the ground.

2 **Planes also receive** radio signals from each other – such as for their automatic anti-collision systems.

3 **Ground-based** stations receive plane data from satellites, passing it on to air traffic controllers.

4 **Air traffic controllers** can use the new system to allow planes closer to each other and to use more optimum routes. On North Atlantic routes, this could save 300m litres of fuel a year.

KEN IKEDA MADSEN & SHUTTERSTOK

PROPULSION

roads of an average city. Unlike the driverless car, however, the challenge lies in pilotless planes being unable just to stop if the software fails or other acute problems occur. The plane must go on flying, and must land safely. Moreover, the software will be responsible for hundreds of passengers. Nevertheless, this development is well under way at Airbus. In December 2018, the company tested its VSR700 helicopter, which flew for half an hour and landed without a pilot.

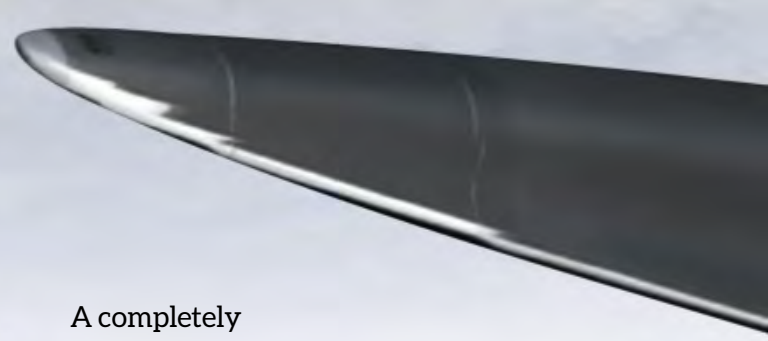
Fusion planes fly on a cup of water

But engineers have even wilder dreams. In 2018, American aerospace company Lockheed Martin had several patents approved concerning parts of a compact fusion reactor that could be used in planes. Fusion is the process in which two light atomic nuclei merge into one heavy one. This process triggers more than a million times more energy per kilogram of fuel compared with traditional fossil fuels. However, scientists have been searching in vain for this pollution-free and almost infinite energy source since the 1940s. One of the major challenges consists in the handling of the plasma at the millions of degrees necessary to make the reaction take place. If the company cracked the code and implemented its reactor on a plane, it would be the end of both pollution and fuel consumption. The aircraft would be able to remain in the air for a week and fly 10 times around the world using as little as one cup of water for fuel.

36,877

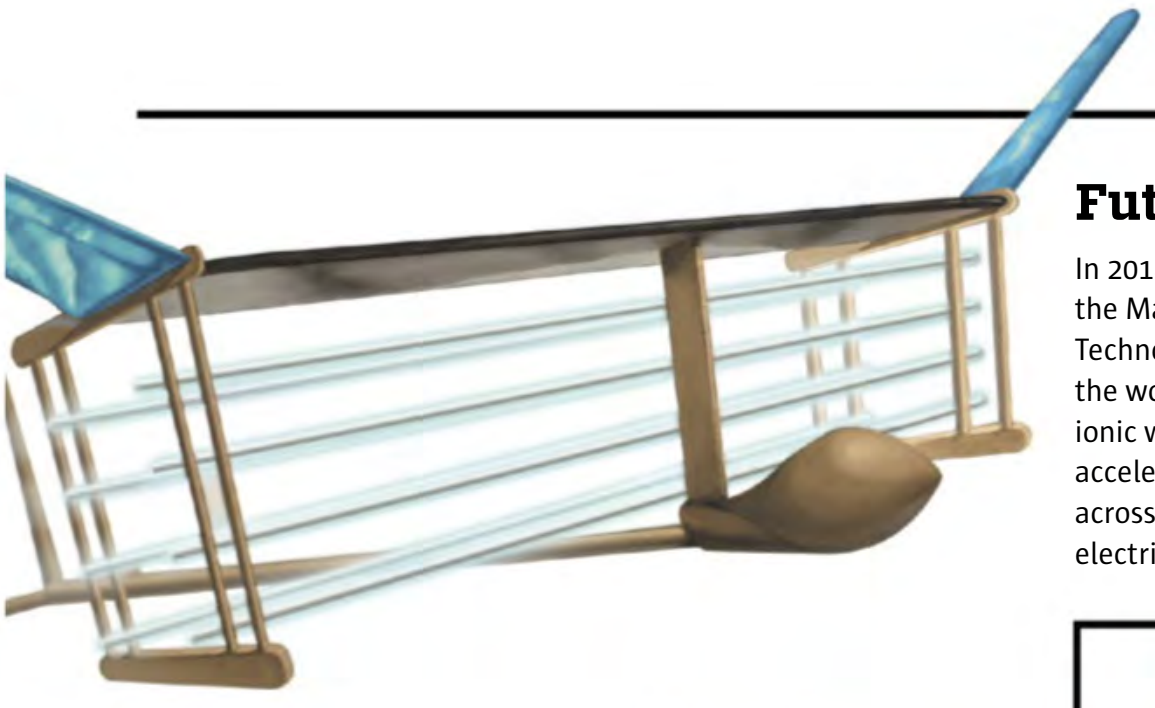
passengers use the world's busiest air route between the South Korean island of Jeju and Seoul every day.

According to the head of Lockheed Martin's fusion project, Thomas McGuire, a test version of the engine could function in the lab in the early 2020s, with the first tests in the air to be made five years later.



A completely different type of propulsion was introduced in 2018 by scientists from the Massachusetts Institute of Technology (MIT) in the US. The engine works by wires ionising air particles around them by means of a powerful current. Ionised particles can be influenced by an electric field, and when they are accelerated they push against the air's other non-charged particles, producing what scientists have named 'ionic wind'. The team behind the experiments has calculated that when the technology is mature, the efficiency of such an engine will be higher than that of a modern jet engine – and it will be silent, and electric.

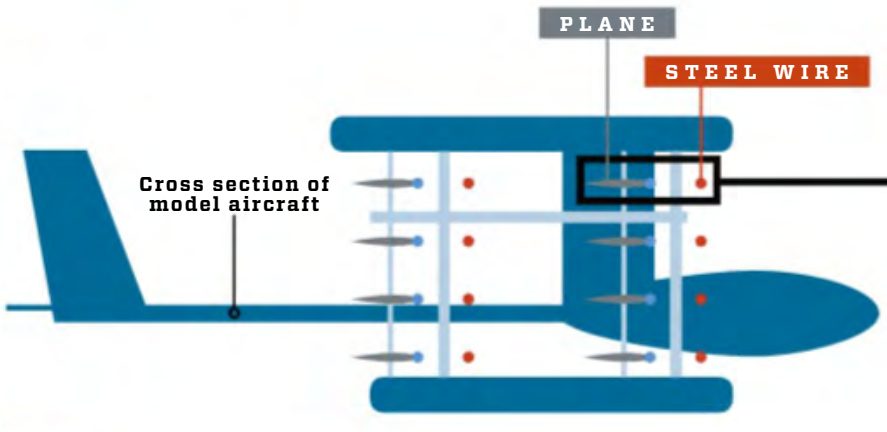
With these aviation transformations waiting in the wings, it might not be too long before a transatlantic flight could be completed within four hours, or Sydney to London in five hours – and all entirely CO_2 neutral. SCI



Future plane powered by ionic wind

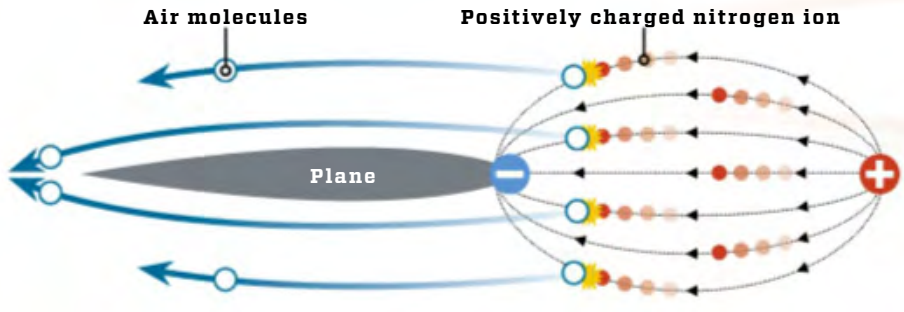
In 2018, a group of scientists from the Massachusetts Institute of Technology in the US demonstrated the world's first plane powered by ionic wind. The plane gets its lift by accelerating ions and air molecules across its wings by means of electricity. In this way, the plane does not need any engines or other movable parts to cause lift.

So far the plane has only been tested in a large hall, but the team behind the experiments has calculated that once the technology is mature, an ionic wind engine will be more efficient than a jet engine.



1 **UNDER THE IONIC AIRCRAFT** are rows of positively-charged steel wires and negatively-charged planes in pairs. The planes have the same aerodynamic shape as wings.

2 **A CURRENT IS DIRECTED** through the steel wires, producing a cloud of positive ions around it. The positive ions are attracted by the negative plane.



3 **ON THEIR WAY TOWARDS** the plane, the ions push the other air molecules. These are the molecules that make up the ionic wind, which propels the aircraft.

NATURE & KEN IKEDA MADSEN

Propellers made plane move forwards
With two propeller engines of 300 hp each and 4,000 litres of fuel, Alcock and Brown could barely make the trip across the North Atlantic.
OREN ROZEN

The company behind Skylon hopes to test its revolutionary engines for the first time in 2020.

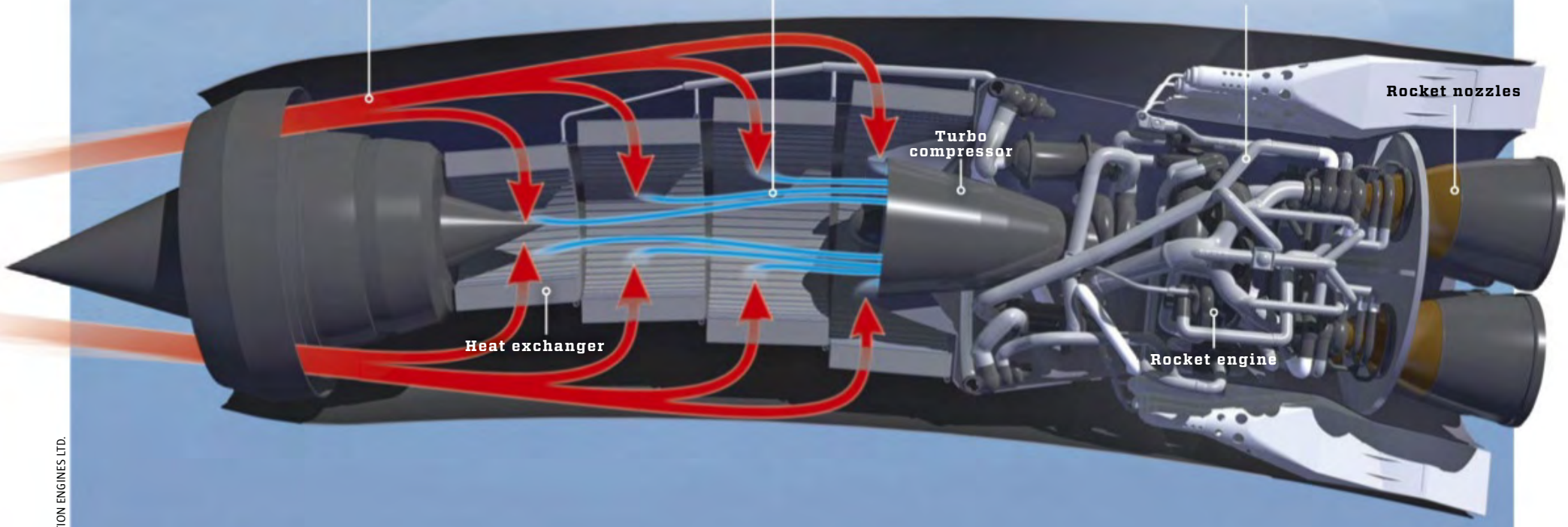
Hybrid plane travels around the world via space

With a combined jet and rocket engine, the Skylon plane can push itself forwards both in the atmosphere and in space. As the speeds can be much higher in space, passengers could be carried anywhere on Earth in less than four hours.

1 **Air at more than 1,000°C** is sucked into the engine. The air is so hot because the plane is travelling at five times the speed of sound.

2 **A heat exchanger** that consists of thousands of ultra-thin tubes with liquid hydrogen cools the air to -114°C in 1/125 of a second. If the air is not cooled, the rocket engine will fail.

3 **The air is compressed**, mixed with fuel, and ignited. The exhaust gas from the nozzles makes the plane move forwards. When Skylon gets into space, the jet intake is closed, and the rocket engine gets oxygen from a tank.



REACTION ENGINES LTD.

“Astronauts are not influenced by Earth’s gravity”

5 MYTHS ABOUT HUMANS IN SPACE

TRUE OR FALSE

Exploding bodies, time travel, and asteroids the size of tower blocks rushing past – there are plenty of imaginative myths about our trips into space.

In recordings from the International Space Station (ISS), we see how astronauts float about as they reach for fruit and other small objects that hang in the air. And that might be one of the reasons why the most diehard myth about humans in space still remains: that astronauts are not influenced by Earth’s gravity. On the contrary, astronauts experience 90% of the gravity to which we are subjected on Earth. The explanation of their acrobatics in the air is to be found in the constant free fall they are subjected to when in orbit around Earth. Although the space station is located some 400km above Earth’s surface, it is constantly moving towards the planet – it is in a free fall. But the space station’s high speed of 28,000km/h means that it will continue its orbit. In popular terms, it is falling in step with the curvature of the Earth – like a cannon ball that is fired from the top of a mountain at a sufficiently high speed. This is also true for the crew inside the space station, who are not moving in relation to the craft and will hence not hit the floor.

Although the effect of gravity will gradually decrease as we travel deeper into space, there is nowhere in the universe where it will disappear altogether. The force is also crucial when an object such as the ISS is to be launched into orbit – if gravity did not pull the object back towards Earth, it would continue deep into the universe.

Astronauts fly faster than they can fall

1 Earth's gravitational field is constantly pulling the ISS and the astronauts towards Earth.

2 The space station and everything in it move forward at a speed of 28,000km/h.

3 The combined effect of the two forces is a long, circular fall that never strikes Earth.

SHUTTERSTOCK

By **Sara Marie Dynesen** & **Kristian Bjørn-Hansen**

"Only three people have died in space"

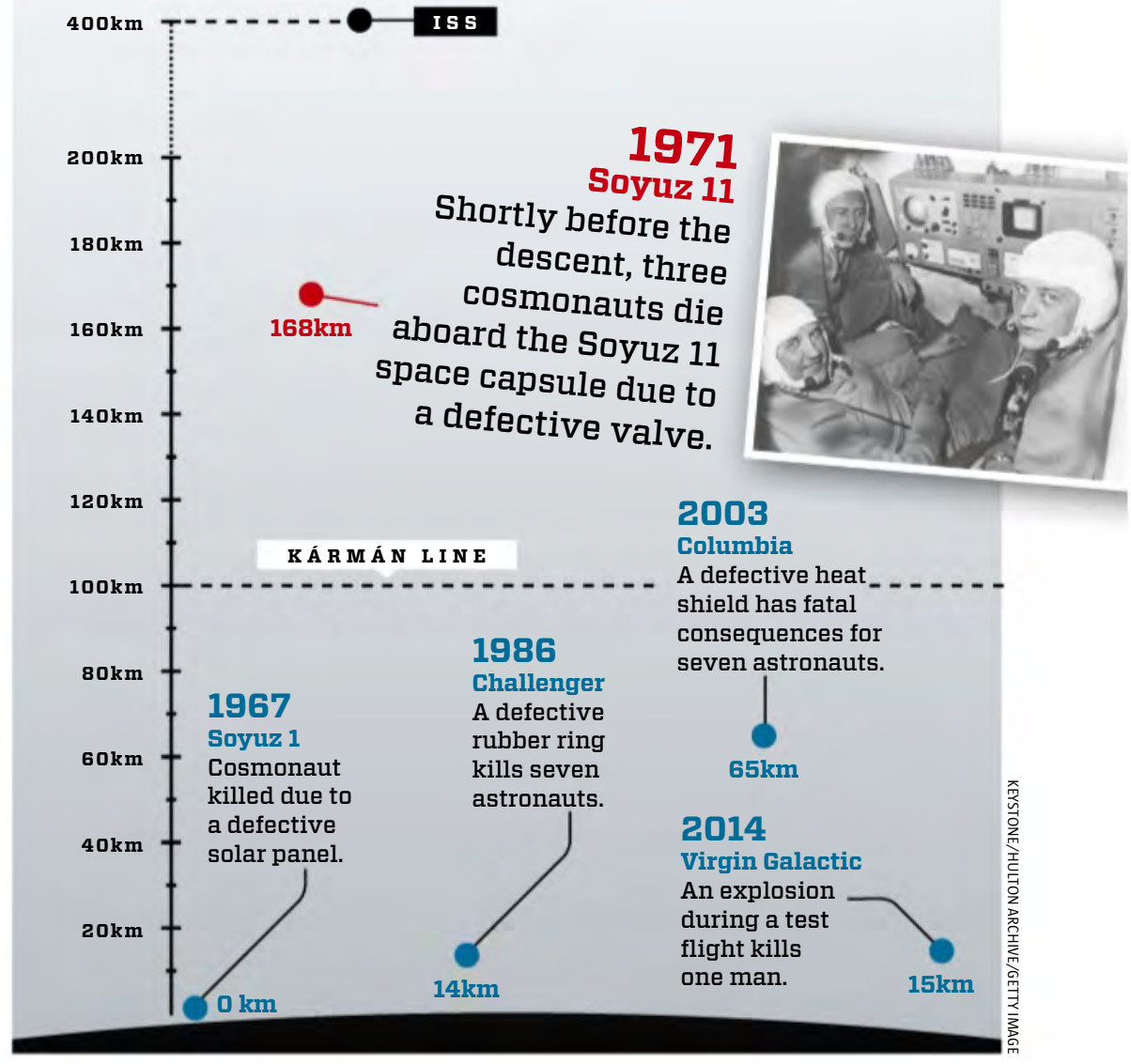
An open ventilation valve had fatal consequences for three cosmonauts who are still believed to be the only humans who have died in space.

MYTH 2 TRUE

On 30 June 1971, the Soyuz 11 space capsule made a perfect, automated landing. After 23 days in space, cosmonauts Georgy Dobrovolsky, Vladislav Volkov and Viktor Patsayev completed a successful mission aboard the world's first space station, Salyut 1. But when the crew on the ground opened the capsule, they found all three cosmonauts dead in their seats. It turns out that the low pressure of space and a ventilation valve opened 168km above Earth's surface claimed the three men's lives. Since then, other fatal aerospace accidents have happened, but the Soyuz disaster is still believed to be the only one that happened *in space*. Although the boundary between Earth's atmosphere and outer space is still very much debated, international organisations navigate according to the Kármán Line, located in the thermosphere 100km above sea level and named after physicist Theodore von Kármán. NASA has chosen to place its boundary 80km above Earth, but that does not change the number of lives lost in space.

The fatal Soyuz 11 mission

Aerospace history includes several fatal accidents, but as the boundary to space is defined as being located 100km above sea level, only three people have died in outer space.



KEYSTONE/HULTON ARCHIVE/GETTY IMAGE

MYTH 3

FALSE

"Space travel makes you younger"

Science-fiction novels are full of accounts of heroic astronauts who travel through space for hundreds of years without growing any older, and in some cases they return to Earth markedly younger. However, astronauts do not get any younger from space travel – they just age more slowly than people on Earth. The explanation is to be found in Einstein's relativity theory, which predicted that time is influenced by the speed at which an object moves: the faster it moves, the more slowly time passes. A spacecraft must reach speeds close to that of light before the time difference can be felt and seen. The astronauts of the International Space Station, ISS, age only a few milliseconds more slowly than people on Earth – though they are travelling at a speed of 28,000km/h.

In 2015, astronaut Scott Kelly (right) spent 11 months at the ISS. When he returned, he was 13 milliseconds younger than his twin brother.

What if astronauts travelled at the speed of light?

1 **DEPARTURE:** The astronaut says goodbye to his newborn baby.

2 **MISSION:** For 10 days, he travels at 99.9 % of the speed of light.

3 **ARRIVAL:** When he lands again, he can celebrate his child's sixth birthday.

NASA/SHUTTERSTOCK

"The Asteroid Belt is a hazardous place"

The Asteroid Belt is often described as a lethal region due to the millions of huge rocks in this one area. In reality, it is statistically almost impossible to collide with the rocks.

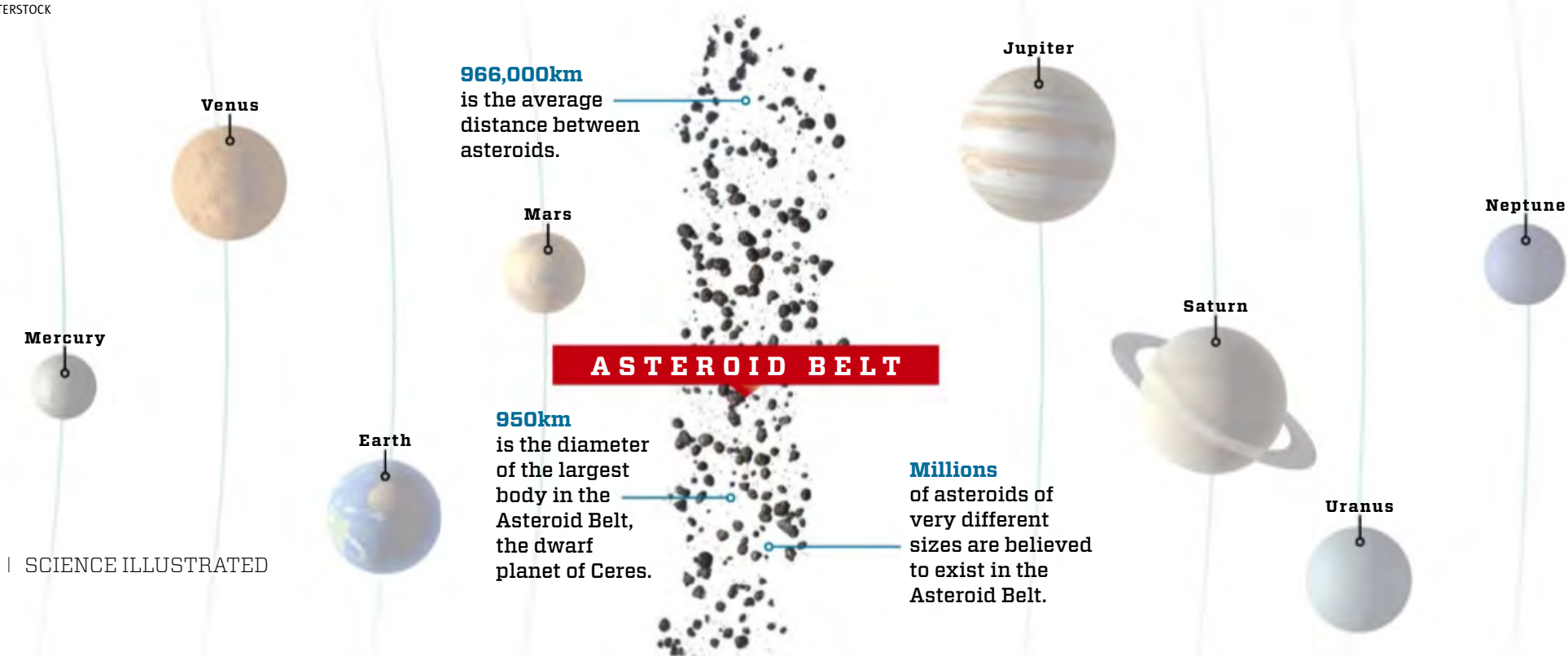
MYTH 4

FALSE

With millions of huge rocks in one region, the Asteroid Belt sounds like an obstacle course that could kill any astronaut passing through.

But in spite of the high number of asteroids, it is really a relatively deserted place for astronauts. This region between Mars and Jupiter stretches across millions of kilometres, and NASA estimates that the average distance between asteroids is 966,000km – more than 24 times the circumference of Earth. In other words the risk of colliding with an asteroid would be one in a billion. This point is confirmed by the US space agency's many missions to planets in the outer Solar System. All spacecraft passed through the region successfully, including the Voyager missions which were launched in 1977 to explore Jupiter and Saturn, and which are still operating in interstellar space. NASA has also carried out three missions with final destinations in the belt. In 2018 the agency ended its Dawn mission, a space probe studying the largest objects of the belt, the dwarf planet of Ceres and the Vesta asteroid, for 11 years – without any collisions.

SHUTTERSTOCK



MYTH 5

FALSE

"The vacuum of space makes your body explode"

In principle an astronaut could survive for several minutes without a spacesuit – but would suffer radiation sickness and organ failure.

The bloodshot eyes pop out of the skull at the moment the astronaut's helmet is removed. Then after a few seconds, his head swells beyond recognition before exploding into a bloody mass. Any number of Hollywood space movies have taught us that the human body is in deep trouble in deep space, outside Earth's protective atmosphere. Well that's certainly true – the few air molecules in space make the pressure low, almost so low that a total vacuum is produced. That lack of pressure will inflate the body to twice its size and make the organs exit through body openings. But no, the body will not 'explode' in the classic sense of the word. In reality, astronauts could survive for between 90 seconds and three minutes before they die, except that outside Earth's atmosphere and magnetic field, they would be burnt by UV radiation in a few seconds and develop radiation sickness from the powerful electromagnetic gamma rays.

You will swell to death outside your spacesuit

Astronauts would be left to fatal radiation, temperature fluctuations, and low pressure outside their 100+kg armour.

90 seconds in the vacuum of space

0-5 seconds

15 secs

90 secs

1. **Solar UV radiation** would immediately burn your skin, while gamma and cosmic radiation would cause nausea and diarrhoea.
2. **The low pressure** makes the oxygen in the lungs expand, causing them to burst.
3. **The organs of the body** are forced out through body openings because of the low external pressure.
4. **The extreme** pressure reduction produces gas in the blood that turns into bubbles.
5. **The skin is stretched**, and the body becomes twice as large due to the internal pressure from expanding oxygen.
6. **The surfaces of eyes** and mouth start to boil due to the low pressure.
7. **The blood can no longer** carry oxygen to the brain, and the astronaut becomes unconscious.
8. **The lack of external** pressure means that the astronaut can no longer keep oxygen in his body, causing death.

GETTY IMAGES/SHUTTERSTOCK

NEW SERIES

THE BATTLE OF THE BRAIN

The human brain is vulnerable to disease, but 170 billion brain cells fight for your survival, and scientists are ready to help them.

PART 1

ATTACK
Brain cancer

DEFENCE
Immune cells

PART 2
Electromagnets versus depression

PART 3
Stem cells versus sclerosis

PART 4
Pot versus concussion

PART 5
Antidote versus Alzheimer's

Doctors examine a brain cancer patient using a PET scanner to determine the exact location of a cancer tumour.

BSIP/SPL & SHUTTERSTOCK

By **Bo Karl Christensen**

HIGHLY TRAINED CELLS SPOT BRAIN CANCER

Your brain contains billions of auxiliary cells which ensure that your nerve cells work, but these cells can develop into cancer. Scientists have developed a strong weapon against sick cells.

Behind your skull, a huge army of nerve cells is at work. This is made up of 86 billion soldiers – but even this number does not give it a majority. Hidden between the nerve cells is another army that matches their numbers, an army of different cells with long, thin arms that wrap around nerve cells and blood vessels: the auxiliary cells of the brain.

The auxiliary cells decide which substances are allowed to enter and exit the brain; they supply the nerve cells with energy, make sure that the brain can send signals, control nerve cell activity, and protect the brain against viruses and bacteria. They are completely indispensable — but they could turn against you. About seven in 100,000 people each year develop severe brain cancer, and the auxiliary cells of the brain probably cause 80% of these cases.

Mutations can rapidly convert these important cells into cancer cells, and doctors lack efficient weapons to combat the cancer. Less than 10% of patients live more than five years after the diagnosis.

But a new treatment is being tested on people. Scientists send a group of highly 'trained' immune cells into the patient, and the focused elite unit seeks out the brain tumour, attacking the cancer cells. Early results are promising.

Barrier slows down medication

The brain's auxiliary cells include a number of different cell types such as immune cells (microglia), oligodendrocytes that function as insulation of the brain's electric circuits, and astrocytes, which carefully control the substances to which the nerve cells have access. Moreover, the brain contains different types of stem cells, which supply new auxiliary cells. Mutations in stem cells or ▶

BEFORE FIGHT

Star cells control the brain

They protect, provide nutrition, and tidy up. Star-shaped cells known as astrocytes are indispensable to your brain's activity.

CLAUS LUNAU

Cell arms guard brain entrance

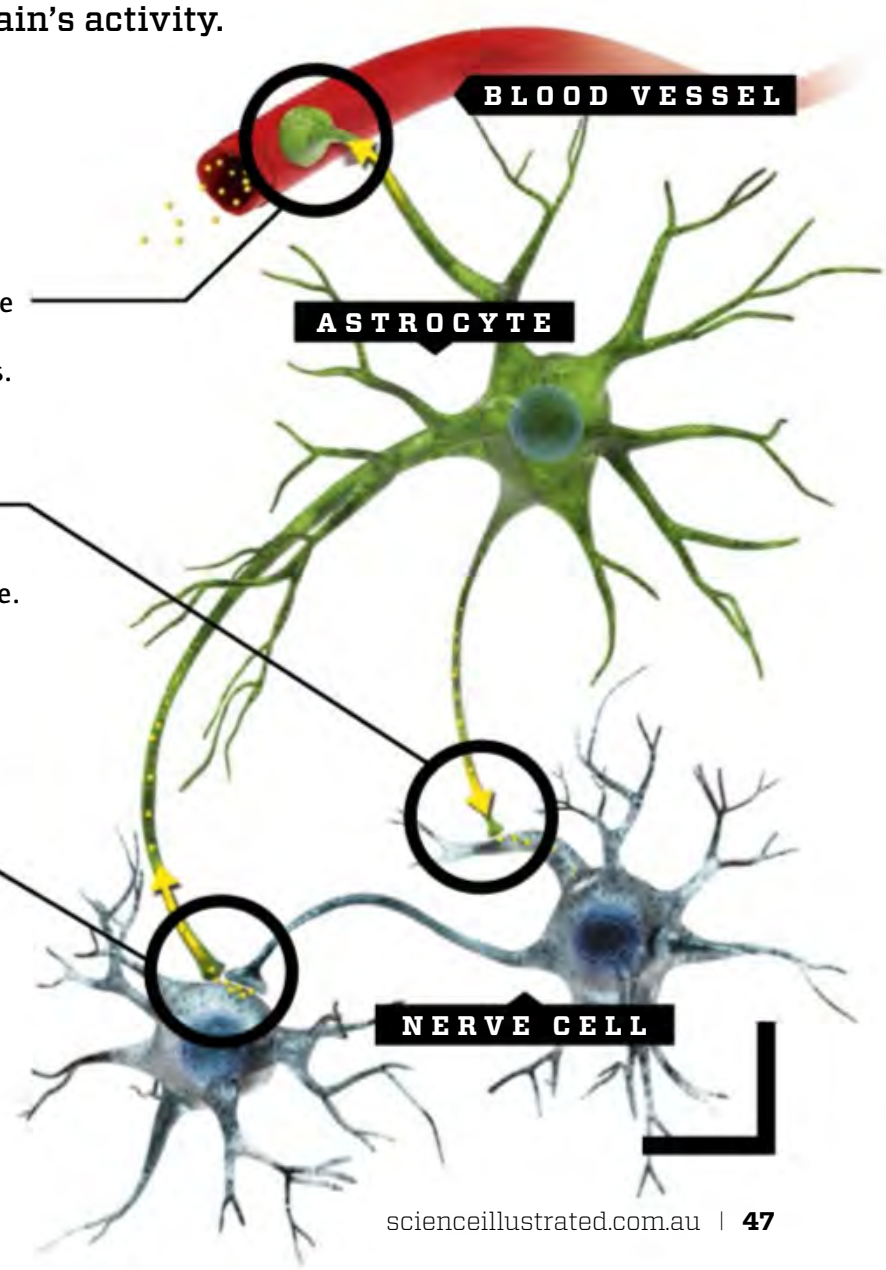
The astrocytes regulate the quantity of blood in the brain's blood vessels and contribute to controlling the substances that pass from the blood into brain cells.

Energy deposit feeds the nerves

The astrocytes store glucose and can convert it into lactate. When the brain lacks energy, the astrocytes liberate lactate, and the nerve cells use it as fuel.

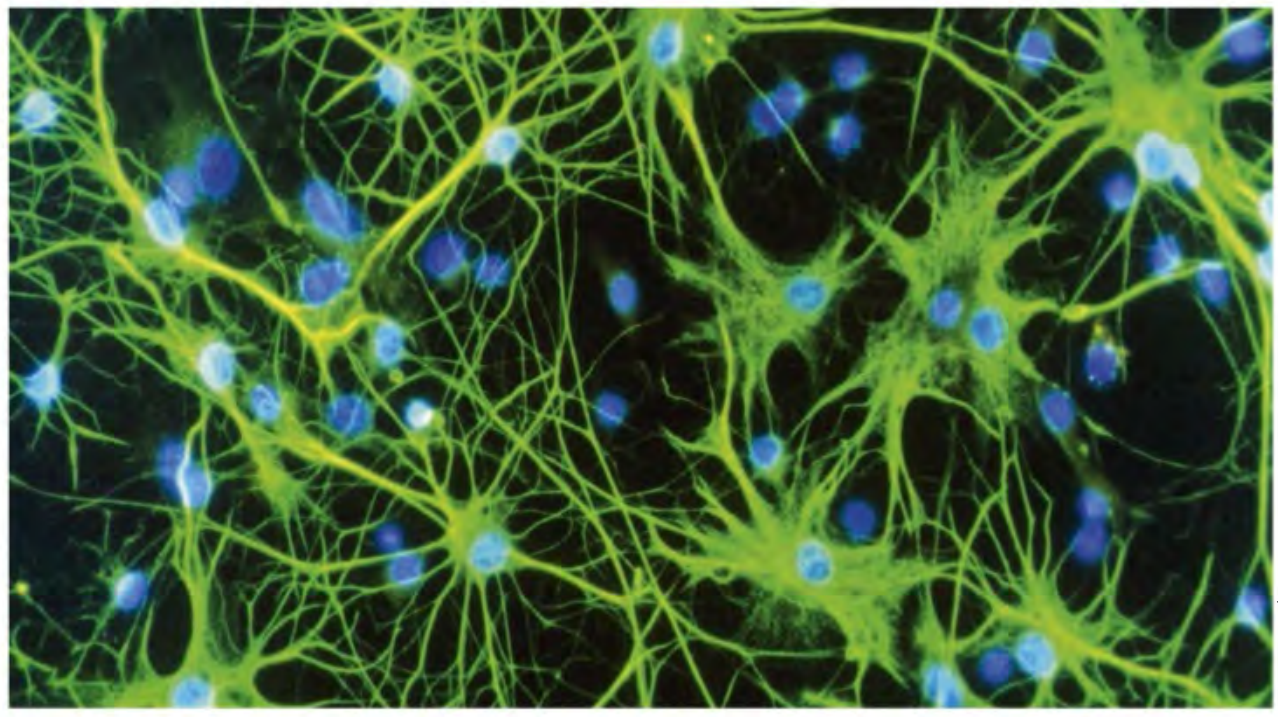
Vacuum cleaner clears up the brain

Nerve cells liberate neurotransmitters and ions when they send signals. In order to ensure that they can continue doing so, the astrocytes are constantly clearing up the brain.



▶ astrocytes are the most common causes of aggressive brain cancer.

The mutations make the cells divide out of control until they destroy the tissue around them – and in many cases, the result is death. Patients with brain cancer are generally worse off than other cancer patients, partly because it is difficult to perform brain surgery without harming healthy tissue or important blood vessels, and partly because the brain has a defence, the blood-brain barrier, that keeps out many drugs. The barrier surrounds the brain's blood vessels and consists of close-set cells that only allow specific substances to pass from the blood into brain cells. Water-soluble substances such as salts have particular difficulty passing through the blood-brain barrier, whereas fat-soluble substances such as oxygen can pass relatively easily. The aim of the barrier is to



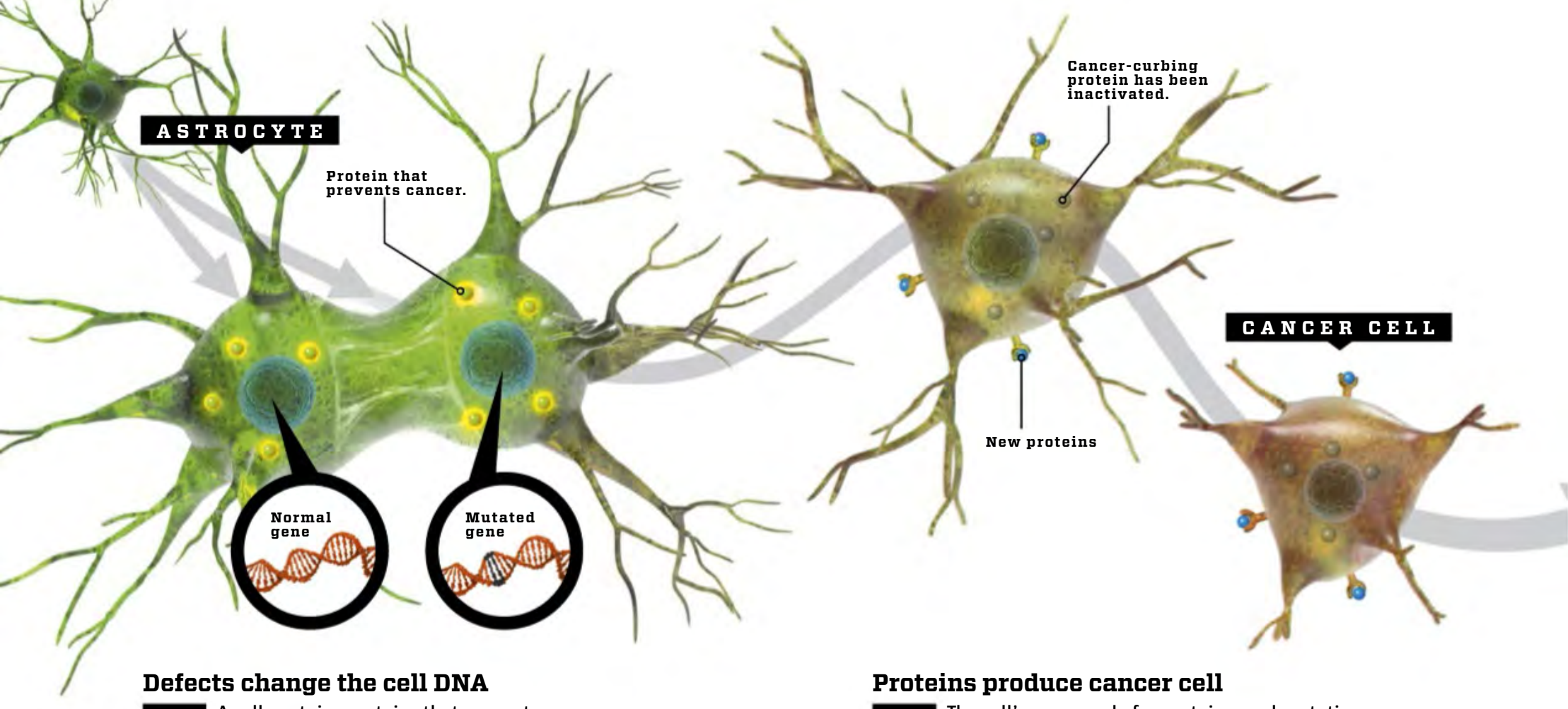
NANCY KEDERSHA/SPL

The brain's star-shaped auxiliary cells, the astrocytes (in green) can in rare cases develop into cancer cells.

Mutated proteins cause cancer

DNA defects produce new proteins, and the new proteins can convert the brain's auxiliary cells into cancer cells, which invade and destroy the brain.

CLAUS LUNAU



Defects change the cell DNA

1 A cell contains proteins that prevent cancer. They ensure that no defects, also known as mutations, occur in the DNA as the cell divides. Over time, mutations might accumulate in some cells, with the result that important genes become changed or suspended.

Proteins produce cancer cell

2 The cell's genes code for proteins, and mutations can cause changes in the cell's proteins. This might mean that proteins which used to prevent cancer are now inactive, or that new proteins are produced that change the cell's shape or make it divide intensely.

ensure the best conditions for the cells of the brain, but it is also the reason why 95% of the drugs that are tested in the struggle against brain diseases fail.

However, the challenges of brain cancer may not be impossible to overcome. Scientists are busy testing a new treatment that actively seeks to pass the brain's barrier, attacking the cancer cells without harming healthy tissue.

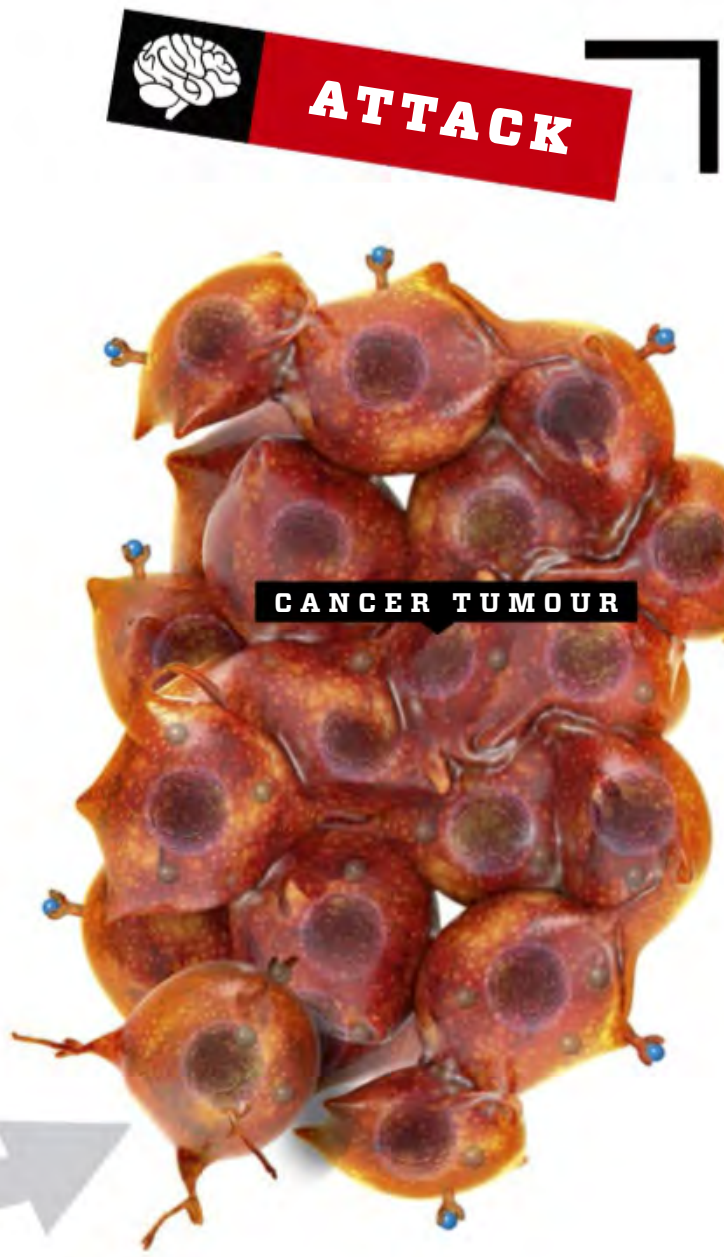
Scientists train immune cells

Today, doctors have three weapons against brain cancer. The first one is surgery, usually an option only if the disease is discovered early. Surgeons must be extremely careful when they operate, and it can be difficult to remove all cancer cells, so the surgery is often supported by two other weapons – radiation and chemotherapy – which are aimed at killing the remaining cancer cells. Unfortunately, none of the treatments are very efficient, and only about 4% of the patients with the most aggressive type of brain cancer, gliobastoma, live for more than five years after the diagnosis.

So, cancer researchers throughout the world are now developing a fourth weapon for doctors: immune therapy. The treatment uses immune cells to kill the cancer, and in 2018 a variant of the treatment earned its inventors a Nobel Prize. Scientists can inject substances into the patient to activate the immune cells, or they can extract immune cells from the patient and train them to recognise specific proteins on the surface of the cancer cells. The immune cells are able to seek out and kill the tumour, sparing healthy tissue in the process. The method has proved to be efficient, and several types of immune therapy have already been approved.

The problem is that the treatment rarely kills all cancer cells, so that the cancer begins to grow again after a while. One possible explanation is that the immune cells have so far been trained to recognise only a few proteins on cancer cells. But the cells in a tumour can vary, and so there will often be some cancer cells that do not have the proteins which the immune cells have been trained to spot. These cells survive, and might begin to produce a new cancer tumour.

A new type of immune therapy developed by a group of Danish scientists, including physician Walter Fischer, could possibly solve the problem. The scientists train immune cells from the patient to recognise a long series of proteins on the cancer cells, and the likelihood of some cancer cells escaping this attack is smaller. The treatment has already produced promising re**sults in human patients.** ▶



Tumour destroys the brain

3 The cell is now a cancer cell, and it begins to divide rapidly to produce a tumour. The tumour pushes the surrounding tissue, destroying its function – sometimes causing death.

Brain cancer challenges doctors

Brain cancer treatment is now twice as efficient as 50 years ago, but doctors still have great difficulties with the most aggressive types of brain cancer.

7 in 100,000
develop malignant brain cancer annually

Glioblastoma is the most common type of malignant brain cancer, and the most aggressive.

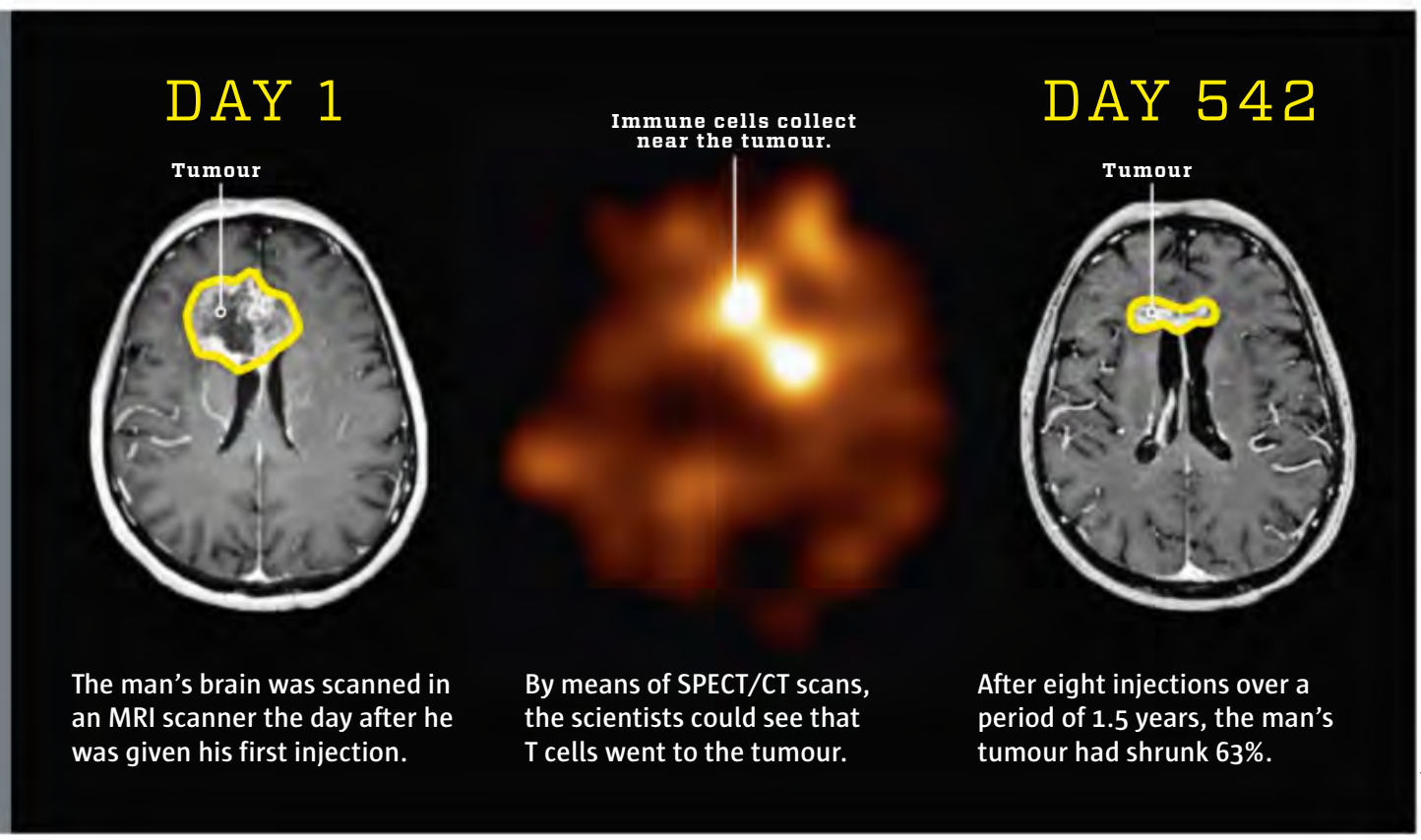
15 months
is the average survival rate after diagnosis

241,037
people died of brain cancer worldwide in 2018

SHUTTERSTOCK

Immune cells combat cancer tumour

A huge brain tumour in a 75-year-old man was bombarded with trained immune cells developed by physician Walter Fischer and his colleagues. The tumour shrank markedly, and the man felt better; he ended up surviving for almost two years after his first injection.



ALEXEI F. KIRKIN ET AL./NATURE

Cancer tumours shrink

Twenty-five patients volunteered to try the new immune therapy developed by Fischer and his colleagues. No previous treatments had effectively combated their brain cancer, and they had only a few months left to live. Fischer's experiment was a phase 1 trial, its primary aim to study side effects, and the treatment involved three injections with immune cells over a period of five months. Unfortunately, only 10 of the patients survived long enough to complete the entire planned treatment. Seven of these continued the treatment, receiving more injections. The cancer tumour in one of the patients stopped growing, and in three other patients, tumours began to shrink considerably.

Major improvements in patients with advanced brain cancer are rare, and the phase 1 trial shows that the new immune therapy apparently succeeds without substantial side effects. While the experiment by no means proves that the treatment is more efficient than previous treatments – that would require a more extensive experiment – Walter Fischer is optimistic. He observed how an elderly woman paralysed by her cancer ended up getting out of her wheelchair. Examinations of her brain showed that 1.5 years after the first injection, the brain was completely free of cancer cells. (Unfortunately, she later died of heart disease.) An elderly man went from having a huge cancer tumour in his brain to one that was markedly smaller. He became able to play music in his orchestra again, but after a few years his tumour grew back and proved terminal.

The scientists hope that the treatment will have an even better effect on patients where the cancer is not as advanced. So Fischer and his colleagues are now carrying out a phase 2 trial to test the effect of the immune therapy on 40 glioblastoma patients who are at an early stage of their disease. Aside from the immune therapy, the patients also receive a standard treatment consisting of radiation and chemotherapy. To be sure that any improvements in the patients are being caused by the immune cells, the scientists have included a control group of 20 people as part of the new trial, and these receive only the standard treatment.

Many scientists remain sceptical of the new immune therapy, so the results of the phase 2 trial are awaited eagerly by all parties involved. Fischer and his colleagues have already realised that the treatment might include weaknesses, believing that the lack of effect on some patients of the phase 1 trial could be because the cancer launches a counter-attack on the immune cells. This phenomenon is a challenge to all types of immune therapy – but a new discovery might produce a solution.

Gene change helps immune cells

Brain cancer makes the immune system's killer cells hide in the bone marrow. A new study carried out by US and Japanese scientists has revealed that patients with advanced glioblastoma have very few of the immune system's T cells in their blood. On the other hand, the T cells accumulate in the patients' bone marrow – with the result that they cannot combat the cancer. Experiments on mice have also shown that injection of new, fresh T cells does not solve the problem. After 24 hours, these also ended up in the bone marrow. This problem is highly relevant to Fischer's immune therapy and similar treatments.

The cause of the defective immune system is that the tumour forces the T cells to remove a specific receptor known as 'S1P1' from their surface. Normally, S1P1 helps the T cells find their way from the lymph system into the blood, but without it, they are stuck in the bone marrow. To solve the problem, the scientists created genetically-modified T cells that could not remove S1P1 from their surface. When the cells were injected into mice with cancer, they remained in the blood instead of hiding. Other types of genetically-modified T cells are already used in the struggle against cancer, so it is not unlikely that in the future we will see treatments against brain cancer that combine gene editing of S1P1 with the immune cells from Fischer and his colleagues. SCI

Immune cells save children

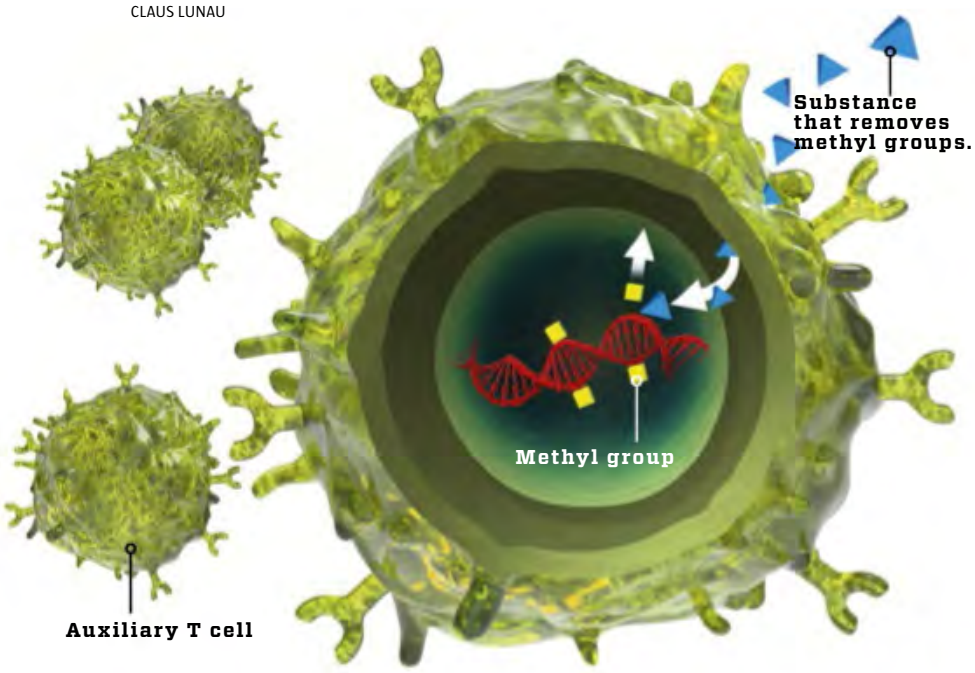
Genetically-modified immune cells already used today against cancer. Watch a video on how the treatment works at: youtu.be/mXADrg_ckhI

DEFENCE

Training immune cells to save the brain

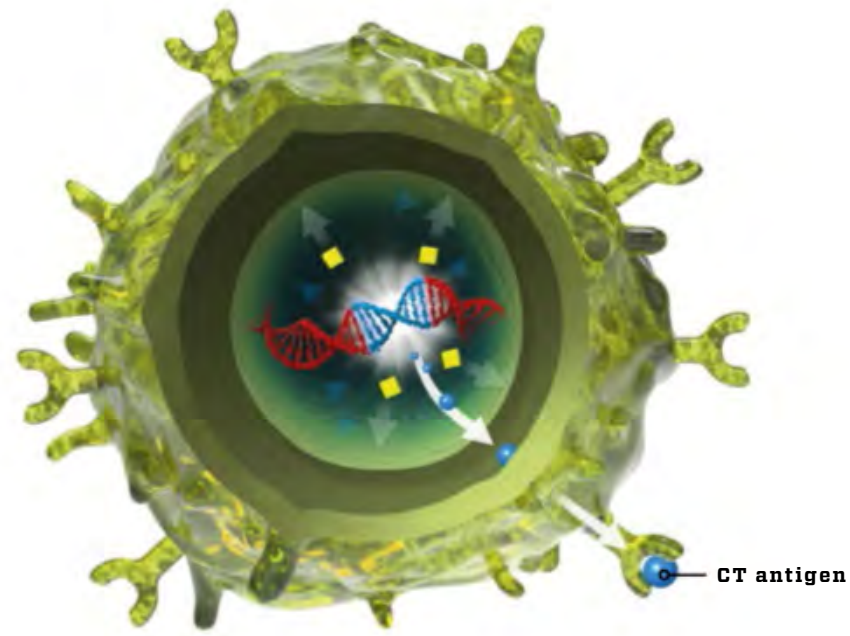
Physician Walter Fischer and his colleagues have developed a ground-breaking training programme which teaches the killers in our immune system to seek out cancer cells deep inside the brain.

CLAUS LUNAU



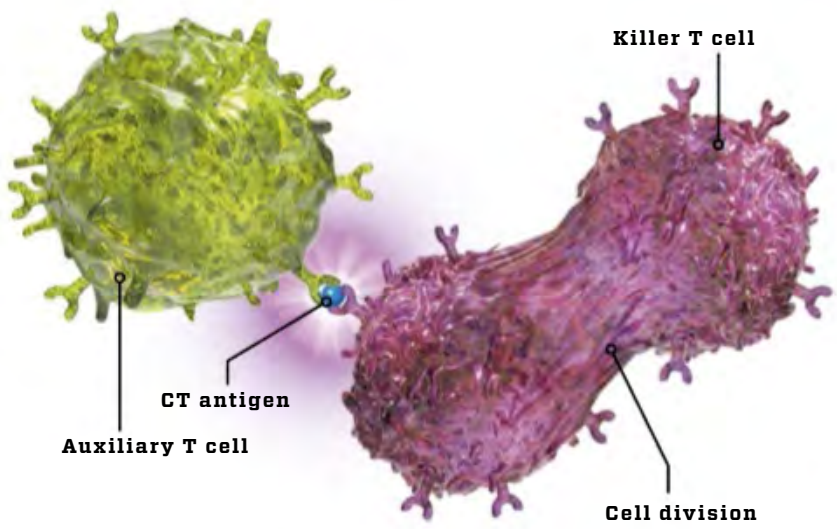
Scientists activate genes

1 Scientists extract T cells from the patient. Like other healthy cells, the auxiliary T cells have blocked out the genes that code for proteins known as CT antigens. The blocking happens via methyl groups on the DNA, but scientists now add 5-aza-CdR, which removes the methyl groups.



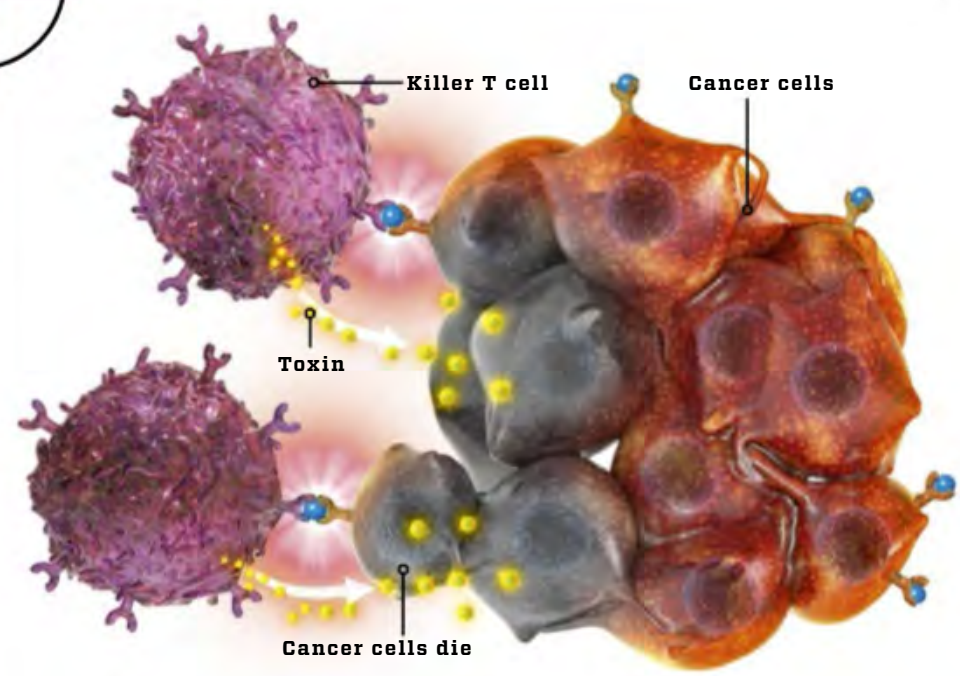
Cells mimic cancer cells

2 The genes for CT antigens have now been unlocked, and the auxiliary T cells begin to produce the antigens. The antigens end up on the cell surface. Other healthy cells do not have these antigens on the surface, but cancer cells do – the auxiliary T cells now resemble cancer cells.



Auxiliary cells train killer cells

3 The scientists add blood from the patient to the auxiliary T cells. Some of the blood's killer T cells are able to bind to the CT antigens, and when that happens, the killer cells begin to divide. Finally, there is a large group of killer cells which can recognise the antigens.



Killer cells attack the tumour

4 The killer T cells are injected into the patient's blood. They circulate with the blood and accumulate near the cancer tumour, because they recognise the antigens on the surface. Once the killer cells have bound to the tumour, they begin to liberate toxins which kill the cancer cells.

Nature's giants go berserk

Huge animals normally keep to themselves and away from other large species. But hunger, rage, or heroism might force them to fight for their lives.

BUFFALO SENT ROUND THE OUTSIDE | Mother elephant hurls the attacker through the air.

By **Andreas Ebbesen Jensen**

FILM MONSTERS GO TO WAR

In the recently-released film "Godzilla: King of the Monsters", the main character fights other huge monsters so intensely that humanity itself is in danger...

An elephant trunk consists of 150,000 muscles and can lift 500kg. In 2016, a female with calves pulled her weight when a buffalo was about to attack. The mother used her tusks to pierce the buffalo, tossing it through the air like a rag doll.

KIM MAURER/CATERS NEWS/RITZAU SCANPIX & WARNER BROS.

Tiger sharks normally hunt alone, but the predators cooperate when large prey must be caught. The sharks attack humpback whales, biting their fins. Eventually the whale is so handicapped that it sinks helplessly to its death.

KOSTA STAMOULIS/NOAA NMFS PERMIT #932-1489-08

SHARKS ATTACK GIANT | Humpback whale in mass brawl with tiger sharks.

SUZI ESZTERHAS/MINDEN PICTURES/GETTY IMAGES

A jaguar's biting strength outcompetes that of tigers and lions, so even though Caimans can grow more than twice as large as jaguars, they are no threat to the powerful feline. After a brief struggle, the jaguar punctures the carotid artery or skull.

NO CHANCE FOR THE CAIMAN | Jaguar bites the skull or carotid artery.

The ice of the Hudson Bay in Canada is now so thin that seal hunting is no easy option. Instead polar bears are choosing much more dangerous prey: walruses. The polar bear surprises the one-tonne animal, sinking in its claws far away from the tusks.

PAUL SOUDERS/GETTY IMAGES

BLUBBER AD LIBITUM | Climate change forces polar bear to take up more hazardous hunting.

VINCENT GRAFHORST/MINDEN PICTURES/GETTY IMAGES

PhotoDoc

ANIMAL KINGDOM GIANTS ATTACK EACH OTHER

A giraffe can kill a lion with one single forceful kick. Still, two hungry lions attacked an adult giraffe in 2017. The giraffe's hooves were deformed, making it relatively unsteady. Once the lions caught it, it was killed.

DEFORMED HOOVES PROVED FATAL | Hungry lions butchered this disabled giraffe.

A crocodile came too close to a hippo baby, and the group of 50 hippos attacked. Hippos have a biting strength of several tonnes and they quickly broke the back of the large reptile, leaving it to flow down the river in its misery.

VACLAV SILHA/BARCROFT/GETTY IMAGES

FEMALE COLLECTIVE CARRIES OUT DEATH SENTENCE | Forceful bite kills crocodile.

When a tiger tried to get to two sloth bear babies, the mother launched a counter-attack with claws spread and teeth bared. The bear fur made it difficult for the tiger to get a grip on its opponent. It gave up after only two minutes,.

ADITYA SINGH/GETTY IMAGES

FUR PROTECTS AGAINST TIGER BITE | Heroic bear mother defends babies.

With a body length of approximately 5cm and 10cm-long legs, our Australian giant orb weaver is a very large spider. Its one-metre-wide web is so strong that it can capture a bird, ensuring food for several weeks.

DEBSCH

AUSTRALIAN SPIDER EATS BIRD FOR DINNER | Finch caught in metre-wide cobweb.

Fast radio bursts are invisible to humans, but the ASKAP telescope can spot the mysterious bursts from space.

OZGRAV, SWINBURNE UNIVERSITY OF TECHNOLOGY

By **Rolf Haugaard Nielsen**

Telescopes search for powerful bursts from space

Extreme radio-wave bursts from remote galaxies involve the same energy as 80 years of solar radiation – and astronomers have no idea why. New telescopes are to search the sky to find the origin of the bursts.

If human eyes could see what a radio telescope sees, the sky would be different. The disc of the Milky Way would be brighter, and we would see smoke rings around exploding stars and gas flows from black holes. And at regular intervals, everything would be outshone by powerful fast radio bursts – for one millionth of a second.

For some 20 years, astronomers have been puzzled by these enigmatic bursts; no familiar astronomical phenomena can explain the massive energy charges. Now, scientists are using two new telescopes, ASKAP here in Australia and CHIME in Canada, in an effort to solve the mystery. In the course of a single year, they have discovered as many bursts as older telescopes found in 20 years. The major harvest confirms that the bursts are due neither to radio noise from Earth, nor Solar System phenomena, nor violent events in the Milky Way – indeed the inexplicable signals have travelled through space for billions of light years, coming from remote galaxies. So, astronomers are beginning to narrow down where the signals might come from: black holes, neutron stars, intelligent life... or something completely different.

Bursts reveal the size of the source

The long distances to the bursts and their brief duration make it incredibly difficult to study the sources directly, even where the bursts come from. On the other hand, the duration of the bursts could reveal the sizes of the sources.

A fast radio burst of 10 microseconds could only come from a source where the surface light can escape within this brief period of time, and the speed of light of 300,000km/s therefore indicates that the source has a maximum diameter of 3,000km – much less than the Sun's 1.4 million kilometres.

The briefest burst ever observed lasted just 0.03 microseconds, indicating a source with a mere 10km diameter. So the bursts must come from extremely compact objects – such as evaporating black holes, or collisions between neutron stars. These small stars have diameters of 10km to 20km, but as their neutrons are just as densely packed as atomic nuclei, the neutron stars achieve twice the Sun's mass.

The theories are challenged by one of the discovered radio sources, which has flashed 20 times since its discovery in 2016. Clearly the repeated bursts cannot come from individual destructive events such as neutron star collisions. They must come from a type of mechanism that does not destroy the radio source, so it can flash over and over again.

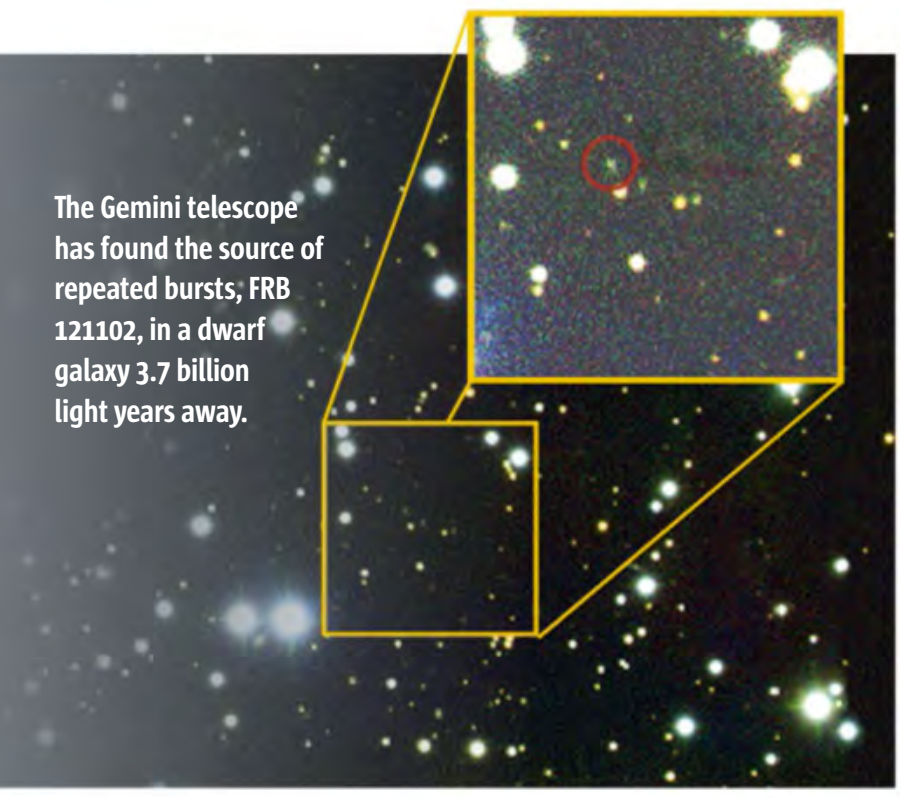
Telescopes finecomb the sky

The mystery of these fast radio bursts can only be solved via more observations, and so radio telescopes throughout the world are being used in an intensive search to solve the mystery. The Australian Square Kilometre Array Pathfinder (ASKAP) telescope in 2017 gave astronomers improved "glasses". Before ASKAP, a total of 34 ▶

Repeated bursts add to mystery

In recent years, one single source of fast radio bursts, FRB 121102, has flashed 20 times. The repetitions cannot be due to a single event, such as a neutron star collapsing into a black hole. Although the source does exclude some possibilities, it has caused more questions than answers. Astronomers don't know if the repetitions are standard, and telescopes have only captured the brightest bursts from most sources. Nor do they know if the fast radio bursts have several types of sources which produce either one or repeated flashes.

The discovery of yet another repeating source has fuelled the search for mechanisms that can release extreme quantities of energy over and over again. One possibility is neutron stars with powerful magnetic fields, magnetars, that strike sparks from repeated short circuits in the encounter with a supermassive black hole's magnetic field.



The Gemini telescope has found the source of repeated bursts, FRB 121102, in a dwarf galaxy 3.7 billion light years away.

GEMINI OBSERVATORY/AURA/NSF/NRC.

fast radio bursts had been spotted, but in the past year alone the telescope has captured 20 new ones. The CSIRO-run facility in the Mid-West region of Western Australia consists of 36 linked parabolic antennas of 12 metres diameter. The efficiency of the network is due to a large field of vision that covers an area of the sky 1,000 times the size of the full moon.

Moreover, the accuracy is impressive. ASKAP can locate the source of a fast radio burst within a thousandth of a degree – corresponding to pointing out the width of a human hair at a distance of 10 metres. The accurate observations mean that optical telescopes stand a good chance of finding the galaxies that emit the bursts. Before ASKAP, only the source that has flashed repeatedly since 2016 had been located, in a dwarf galaxy some 3.7 billion light years away.

Most newly-discovered fast radio bursts came from remote galaxies at least seven billion light years from Earth. The most powerful burst was twice as intense as the previous record holder, emitting what corresponds to 80 years of solar radiation in a few microseconds. The telescope also captured the closest fast radio burst so far, from the ESO 601-GO36 galaxy, located only 120 million light years away.

However, ASKAP will very soon be outdistanced by the new Canadian Hydrogen Intensity Mapping Experiment, CHIME, which over a test period of three weeks found 13 fast radio bursts, bringing the total number to 67. The telescope even found another repeating radio source, with six bursts in three weeks.

Astronomers' present theories suggest that fast radio bursts are triggered somewhere in the universe a few times every minute. When CHIME has been fully introduced later this year, astronomers hope to capture some 12 new fast radio bursts every day.

Early bursts from Parkes' lunches

Fast radio bursts are among astronomy's major unsolved mysteries. Since they were discovered in data from the 64-metre Parkes radio telescope in New South Wales in 2007, they have been shrouded in mystery and scepticism. Back then, most astronomers believed that the fast radio burst was just a measuring error – particularly after 16 signals that resembled the fast radio burst proved to come from scientists opening the microwave oven in the lunch room prematurely. But in 2014, the Arecibo telescope in Puerto Rico, which has a parabolic antenna of 305 metres, spotted a new fast radio burst that sped up the search for the extremely high-energy bursts.

The imaginative explanations point in many directions. Some astronomers talk about neutron stars that pulsate, collide, or cause short circuits due to super-powerful magnetic fields. Others believe in evaporating black holes. Scientists have even proposed that they emanate from sophisticated civilisations... without going into detail as to how the ultra-brief energy discharges that make the Sun seem weak might be produced.

Journey reveals hidden matter

The road to solving the mystery requires more fast radio bursts and careful analyses that can reveal whether the bursts are always caused by a specific mechanism, or by several different types of phenomena.

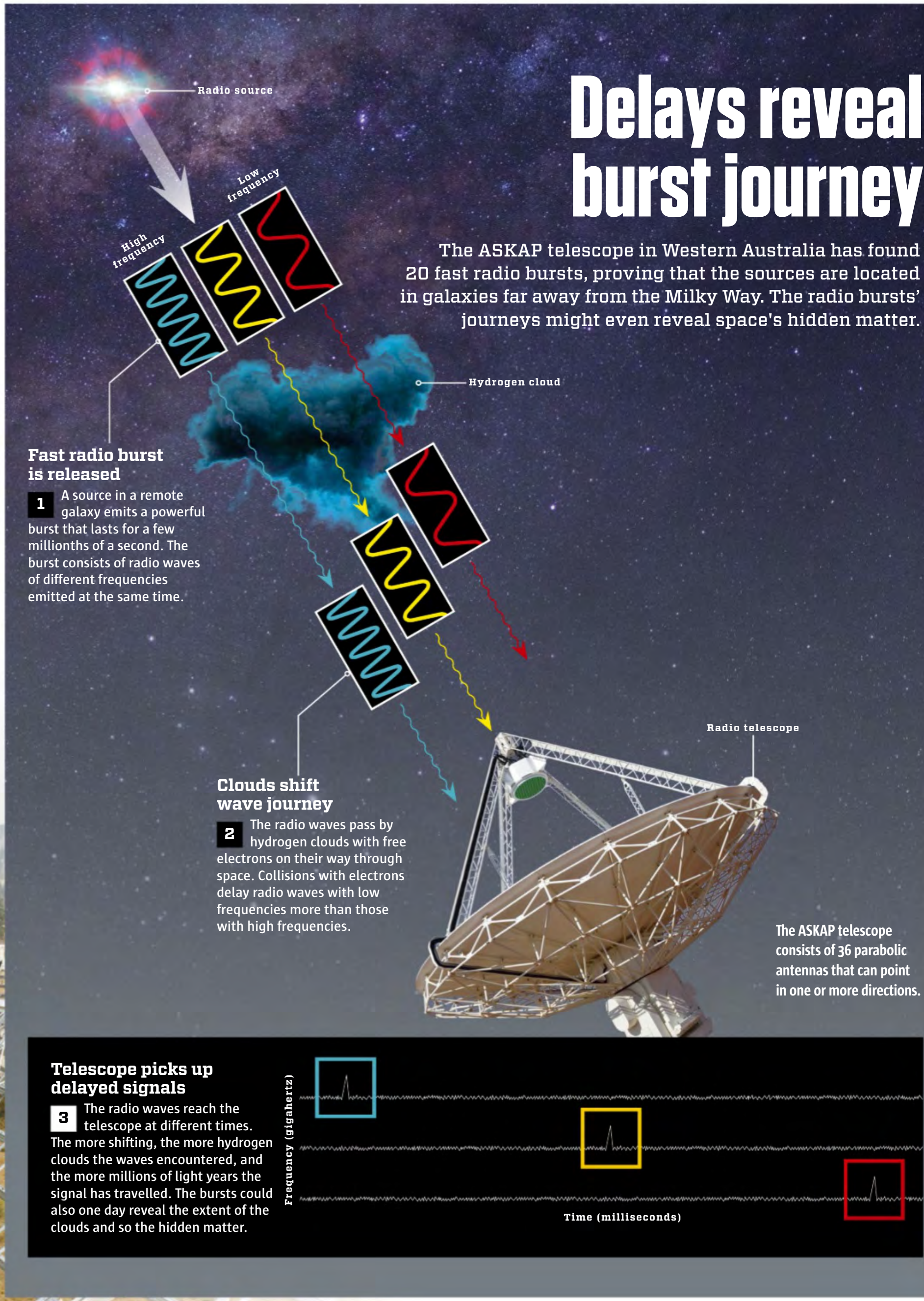
No matter what the sources prove to be, the bursts could form an important piece of the astronomical puzzle. On their way through space, the radio signals' wavelengths are delayed by extremely thin, almost invisible hydrogen clouds between the galaxies. Astronomers can only find 60% of the universe's visible matter, whereas the hidden matter is hiding in the clouds, causing time lag. Fast radio bursts from remote galaxies throughout the universe can be used to determine the extent and volume of the clouds and reveal if they include all that visible matter which astronomers cannot find.

Many mysteries must be solved on the way, but the thousands of bursts that should be captured by the new telescopes could soon determine if black holes, special star types, or alien civilisations are the answer. SCI

The CHIME radio telescope consists of four half-pipes without any moving parts. The innovative design can spot 2–50 fast radio bursts a day.
SHUTTERSTOCK

Delays reveal burst journey

The ASKAP telescope in Western Australia has found 20 fast radio bursts, proving that the sources are located in galaxies far away from the Milky Way. The radio bursts' journeys might even reveal space's hidden matter.



KEN IKEDA MADSEN/CSIRO

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MA/SI68

The ultimate vacuum is a section of space – it could be only $1cm^3$ – with neither matter nor energy. We have still not found this phenomenon in the universe.

By **Jens E. Matthiesen**

CHALLENGE

DOES "NOTHING" EXIST?

Some questions are so substantial that they have been a mystery to scientists for centuries. Even if they never find the answers, the search for an explanation makes us wiser.

Physicists are still searching for nothing

The search for the absolute vacuum, in which no material exists and neither energy nor forces apply, has extended over three millennia. Philosophers and physicists have tried to produce the total vacuum both in practice and in theory – but nature seems to oppose them. If ever the vacuum finally seems to materialise, it gets filled up again with new discoveries and realisations.

Exactly 99.9999426697% – that is how sure CERN physicists were that their measurement was correct. So, on 4 July 2012, they dared to announce that they had discovered what they had been looking for ever since they activated the large LHC accelerator for the first time in 2007: the Higgs boson. The scientists knew from the start that it would be very difficult to find it. Forget about needles and haystacks: in the LHC, only one observable Higgs boson is produced in ten thousand billion collisions between the protons that speed about the accelerator's 27km-long tunnels at a speed close to that of light.

Luckily, the physicists were sufficiently observant to capture it, and it shows that our current understanding of the universe's fundamentals still holds water. The Higgs boson is necessary for other particles to have weight. If it did not exist, other particles would be like photons of light: rapid, but without any mass. And further, the universe would contain only electromagnetic radiation, but no electrons, protons, atoms, molecules, planets, or stars. In other words, it would be empty of matter.

The Higgs boson does not only explain the fact that we exist, it also contributes to answering the question of whether a vacuum exists. The idea of a space that has been drained of all matter and energy has existed in the heads of philosophers and scientists for millennia, and for some time the answer has swung back and forth between no and yes. But the discovery of the Higgs boson gave us a new idea of what exists in an area of space in which nothing else is present.

Nothing is either empty or superfluous.

EMPEDOCLES (490-430 BC) maintained that a vacuum could not exist.

The question "Does nothing exist?" sounds simple, but on reflection it might be among the most complex questions that we can ask. The definition of "nothing" must necessarily be "the absence of everything", so if we are to understand "nothing", we also have to understand "everything". Scientists were forced to take quite a detour before they found the answer.

We are brought up to accept nothing

As children we are introduced to the idea and the concept of nothingness without thinking very much about it. In elementary school, the teacher will say: "There are two oranges on the table. Now, I will remove them both. Then what is left?" Most bright children will answer "nothing" or "zero", and both will satisfy the teacher. In upper secondary school, those answers will not be quite so successful. The maths teacher will ask for a unit, so the correct answer will be "no oranges" or "zero oranges". The physics teacher might go one step further and claim that the correct answer is "air", because the space that the oranges took up has now been replaced by oxygen, nitrogen, and other elements. In university, the question will probably be rephrased: "There are two oranges – not on the table, but in space between the galaxies. Now we will remove them. Then what is left where they were?" Astronomy students will know that even in intergalactic space, there are a few hydrogen and helium atoms, so giving that answer will be correct, but still not exhaustive. The obvious next question would be: "What is in the space that the atoms do not fill?" And this question is difficult not only for students, but also for the brightest minds in physics and cosmology. And that was also the case for the Greek philosophers, who pondered the question some 2,500+ years ago.

The Greeks consider nothingness absurd

The founding father of scientific thinking believed that the idea of "nothing" was meaningless. According to Thales of Miletus, who lived in 635-546 BC, the very fact that someone thought of the existence of "nothing" would mean that "nothing" was "something" all the same – and so, it would no longer be "nothing". In his world, "nothing" could hence only exist if there was not somebody or something that could observe it or imagine it. It sounds a little cryptic, but Thales also tried to make his ideas more concrete by asking himself the question of what would be left if everything was removed from an area. His answer was water. To Thales, water was a very special material, as it could appear in the different states of liquid, gas, or ice. That gave him the idea that water could also appear in other states, concluding it was the original substance of the universe, of which all materials were made up. "Everything is water", he said, and so it was obvious that the closest you could come to "nothing" was water in its "original" state, which was liquid, according to Thales.

Thales' basic idea of an omnipresent, original substance was maintained by generations of Greek philosophers. To Anaximenes (585-525 BC) the substance was not water, but air, and to Heraclitus (535-480 BC), it was fire – in both cases a much more volatile substance than water.

Empedocles (490-430 BC) was more methodical . He set out to study whether air is a substance or if it is the absence of all substance and so "nothing". For this purpose, he used a flask – a bottle with a circular body and a cylindrical neck. Empedocles made small holes in the body of the flask and subsequently carried out several experiments with water. He found out that when he filled the flask with water and blocked the opening with his hand, the water remained inside the flask. Not until he removed the hand did the water begin to escape through the small holes. Empedocles realised that air had to be a substance, and that it took up the space of the flask in the same way water did. And what is more, the water could only leave the remaining space if the air was allowed to enter.

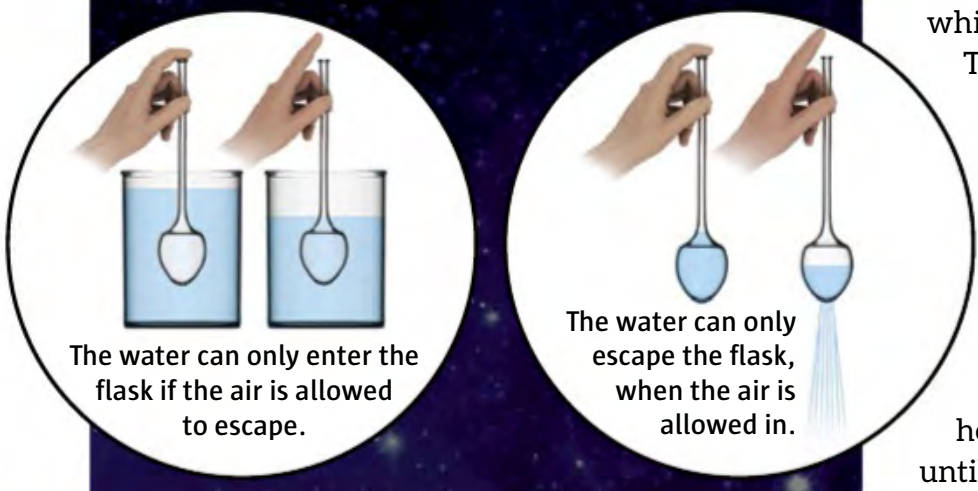
Today, the experiment seems trivial, but the result was very wide-ranging. Empedocles concluded that nature resists the formation of a vacuum, and this conclusion remained for hundreds of years.

Empedocles expanded his predecessors' ideas of one basic substance to four: water, fire, air, and earth. He also developed the first ideas concerning forces, which he

The vacuum was a long time coming

Throughout Antiquity and the Middle Ages, it was believed that a vacuum could not exist. As a minimum, all spaces would be full of air or an unknown substance known as "aether".

450 BC: Nature prohibits a vacuum



The water can only enter the flask if the air is allowed to escape.

The water can only escape the flask, when the air is allowed in.

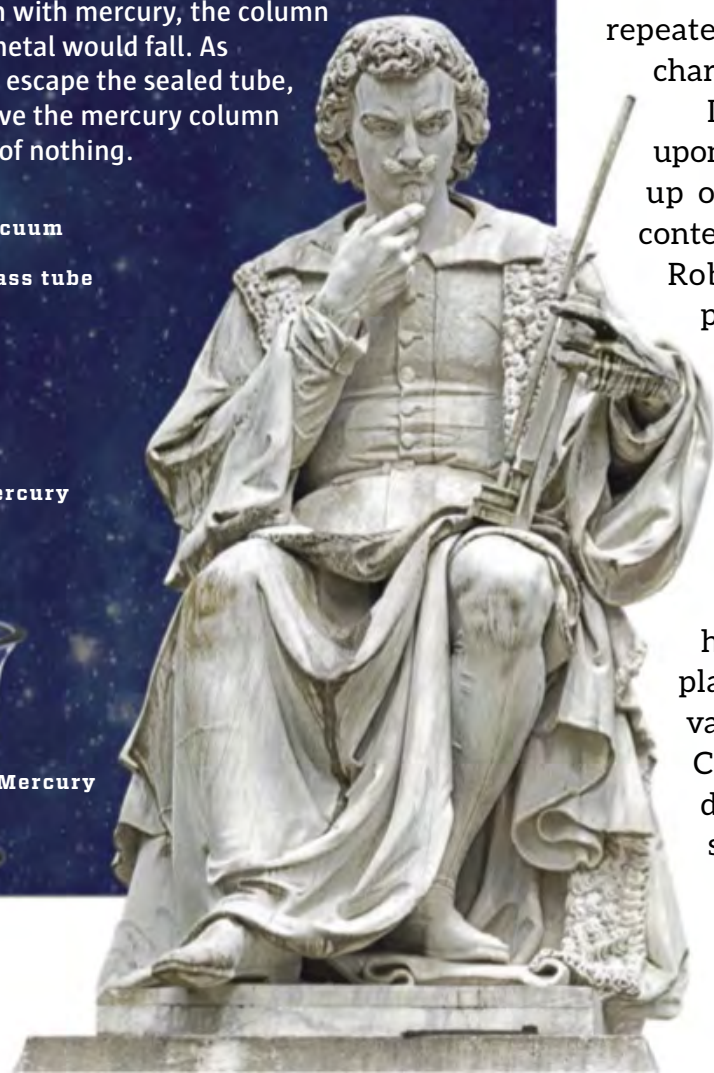
Water and air struggle for space

Empedocles of Greece made simple experiments with a flask with small holes in it. He observed that there would always be either water or air in the flask. He concluded that nature does not allow a vacuum.

1643: People can create a vacuum

Mercury produces a vacuum

Evangelista Torricelli discovered that if he filled a glass tube with mercury and turned it upside down in a dish with mercury, the column of the liquid metal would fall. As nothing could escape the sealed tube, the space above the mercury column had to be full of nothing.



named "love" and "strife", and which influenced everything that was made up of the basic substances. Finally, he introduced "aether" (today more commonly spelled 'ether'), a substance that was even thinner than air, omnipresent, filling the tiniest of spaces. In this way, Empedocles excluded the existence of "nothing", saying: "Nothing of the All is either empty or superfluous."

Not until 2,000 years after Empedocles was nature's intolerance of a void disproved. It was done in a very simple experiment.

Nature defeats the fear of emptiness

Take a glass tube that is 1m long and place a plug at the bottom. Immerse the bottom of the tube into a dish which is also filled with mercury, and remove the plug.

This simple experiment was performed by Evangelista Torricelli in 1643, based on the advice and instructions of his great role model and teacher, Galileo Galilei, who had died the year before. When Torricelli performed the experiment, he observed that the mercury column in the tube began to sink, and it did not stop until it had reached an altitude of 76cm. Torricelli also realised why. The weight of the heavy mercury in the tube makes the column sink until it is balanced with the atmospheric pressure on the surface of the mercury in the dish.

With his experiment, Torricelli achieved two things. He invented the barometer, and he produced a vacuum. When the mercury column sank, it left a void of 24cm at the top of the glass tube, which had to be filled with "nothing". In other words, Torricelli had done what everybody had considered impossible for thousands of years. Nevertheless, his reaction was very modest:

"Many have argued that a vacuum does not exist, others claim it exists only with difficulty in spite of the repugnance of nature; I know of no one who claims it easily exists without any resistance from nature."

Others were rather more thrilled by the result. In the following years, several scientists from other nations repeated his experiment, trying to find out which characteristics are involved in a vacuum.

In France, Torricelli's experiment was elaborated upon by Blaise Pascal, who placed the entire test set-up on scales, demonstrating that the vacuum's contents, if any, did not weigh anything. In England, Robert Hooke developed pumps which could produce a vacuum in larger spaces, and his teacher Robert Boyle carried out experiments in which he placed mice, snakes and birds in the vacuum to watch them suffocate. Whatever was in the vacuum, it was not air.

Boyle also placed a bell in the vacuum and observed it become silent, as its sound could not travel through the vacuum. Light, on the other hand, was apparently not influenced. A lamp placed on one side of a glass container with a vacuum could be observed from the other side. Consequently, Boyle was on the track of the difference between waves in physical substances such as air and water and electromagnetic waves such as light.

Everything consists of the four elements of earth, air, fire, and water – and between them is a fifth substance: aether. So, all spaces are full of something. That is how Greek philosopher Empedocles described the world, and his idea remained until the 1700s.

The discovery of the vacuum in the 1600s challenged the "horror vacui" – the fear of empty space – that had existed in natural scientists' descriptions of the world all the way from Antiquity and up through the Middle Ages. And the breakthrough reached far beyond the world of science.

The magical vacuum fascinates the world

In 1645, a collection of prominent people – including Emperor Ferdinand III and the Imperial Diet – gathered in the German city of Regensburg to experience a mysterious phenomenon. The man behind the spectacular show was German physicist Otto von Guericke, who was also the mayor of Magdeburg. Von Guericke had brought two copper hemispheres of 60cm diameter, which could be united into a hollow ball. With a magician's sense of drama, he asked volunteers from the crowd to pull the hemispheres apart. This was, of course, easy. Then he assembled the ball again and, by means of a pump he had invented himself, he sucked the air out of it via a valve. Once again, the audience was invited to pull at the hemispheres, but this time they were impossible to move. At this point, von Guericke played his trump card, hitching two teams of horses, eight animals to each hemisphere, and urged them to pull. Nothing happened. The two hemispheres remained united.

"We must conclude that there is no stationary ether.

ALBERT MICHELSON
proved in 1887 that there is no such thing as an ether through which Earth travels in its orbit around the Sun.

In this way, von Guericke had shown, how powerful a vacuum is – or rather how strong are the powers that apply around it. The pressure of the air on the outside of the hemispheres and on everything else at the ocean surface is one atmosphere, corresponding to 1kg per cm^2 or 10t per m^2 – much more than the combined force of 16 horses.

Von Guericke repeated his performance many times, in some cases even using 24 or 30 horses, and the result was always the same. It was potent popular science and a celebration of the conclusion at which Torricelli had arrived, that we live "at the bottom of an ocean of air".

Blaise Pascal of France had also established that the ocean of air becomes ever thinner the higher we climb. The conclusion that followed was logical: air is not a substance that fills all of space.

The discovery of the vacuum as space without any air did not mean that the idea of an omnipresent ether was abandoned. The ether could consist of something else altogether, as Empedocles had imagined. The greatest genius of the 1600s, Isaac Newton, had a rather ambivalent relationship with ether. From his publications it appears that he switched between accepting and denying its existence. In 1675, he introduced his theory of light, which involved it travelling through ether. Four years later, he abandoned the idea of ether, only to return to it in 1718 in a new publication about the nature of light.

The fundamental question of what light is was discussed intensely by physicists of Newton's era and in the decades that followed. Was it particles or waves? The dispute continued for 100 years and was not settled until 1804, when British physicist Thomas Young published his ground-breaking experiment in which he made light pass through two narrow slits to produce a striped interference path on a plate behind it. The path proved that light behaved in the same way as waves interacting on the surface of water. Two wave crests combine to a higher intensity, whereas a wave crest and a trough cancel each other out.

The idea of light as waves supported the idea of an ether. When light was able to pass through Torricelli's vacuum, it had to be because the vacuum contained ether through which the light could travel. Similarly, the vacuum between stars and planets had to be filled with the same ether, ensuring that the sunlight could reach us on Earth. Another century was to pass before it became clear that this was entirely wrong. This happened when American physicist Albert Michelson made his ingenious test set-up now known as the interferometer. In short, the principle of the experiment is to split a light beam in two and send the two parts in opposite directions and back again by means of mirrors. Once the beams unite again, they produce an interference pattern. Michelson's idea was to use the test set-up to measure Earth's motion in relation to the ether. If the Earth was sailing through the ether like a boat through water, the paths should change as he rotated the test set-up, since Earth's motion through the ether would then influence the two light beams differently.

With the assistance of his colleague Edward Morley, Michelson in 1887 managed to erect the test set-up so accurately that conclusive measurements could be made. The two scientists initiated the experiment, turning the test set-up, but nothing happened. No matter the position, the interference path was the same. This could only mean one thing, and Michelson immediately realised it: "We must conclude that there is no stationary ether with respect to which the Earth moves while orbiting around the Sun."

Gravity becomes part of space

Without ether, it was suddenly possible to imagine a spatial area filled with "nothing". As an intellectual experiment, we could design a small container, say a cube of $1cm^3$, and suck all atoms out of it, so it would be emptied of substance. If, in addition, we could protect it from light and other electromagnetic radiation, it would also be emptied of energy. What remains then has to be "nothing" – or what?

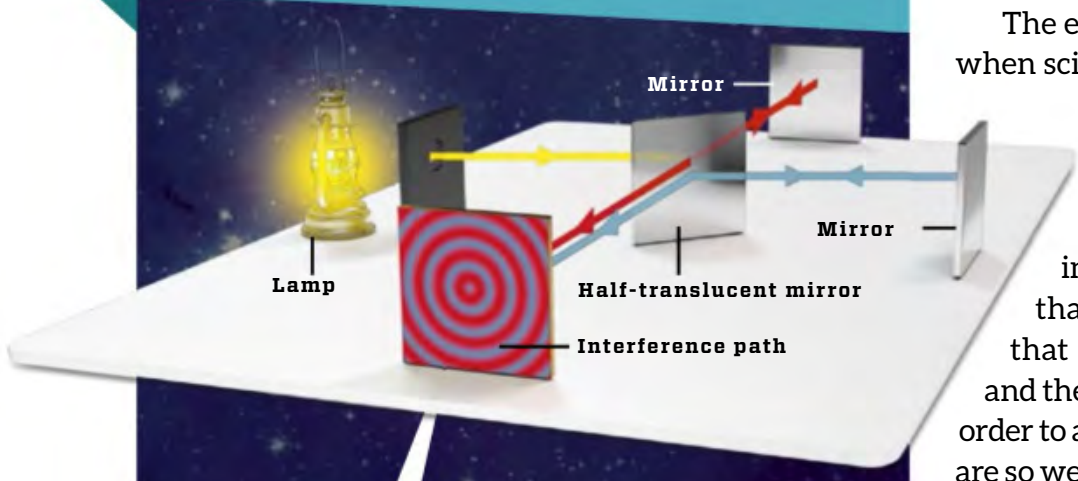
Physicists were not given much time to ponder this question, as already in 1915, only 28 years after the "disproving" of ether, the question was turned upside down when Albert Einstein introduced his general theory of relativity, including a brand new description of the world.

According to Newton's perception, space is something that exists independently of its contents. So at least theoretically, we can remove everything from a spatial area, and the area will still be there. But in the universe

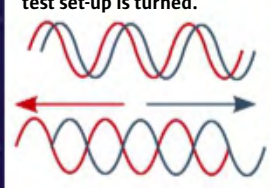
Space emptied of ether and filled with waves

In the 1800s, the idea of an ether filling space between stars and planets prevailed, but a new invention proved the idea wrong. 100 years later, the same invention revealed the gravity waves of the universe.

1887: Ether leaves space



Expected result:
The light waves get displaced when the test set-up is turned.



Measured result:
The light waves do not change, no matter the position of the test set-up.

Disappointing result "killed" ether

Albert Michelson invented his interferometer to measure Earth's motion in proportion to the ether of space. The instrument was to indicate the motion by the two light beams being differently affected, so their interference patterns would change when Michelson turned the test set-up. But nothing happened, because there is no ether.

2015: Gravity waves conquer universe

Invisible waves deform space

In 2015, the huge LIGO interferometer proved the existence of gravitational waves for the first time. They were predicted in Einstein's theory of relativity 100 years earlier. The waves are produced by masses in motion and deform space as they flow through the universe.

THE LIGO DETECTOR uses laser light in very long tunnels to measure the effect of gravity waves.

that Einstein introduced, things are different. First of all it is not 3D like Newton's universe, but rather 4D, the fourth dimension being time. Secondly, space is defined by its own contents. The mass within space determines how space shapes, and the shape of space determines how the mass moves. Mass and space are hence inseparable in Einstein's spacetime; it does not make sense to imagine one without the other. Moreover, relativity theory tells us that masses in motion produce gravity waves which roll through the entire universe, distorting spacetime. So no matter what we do with our small cube of "nothing", gravity waves would flow through it in all directions.

The existence of gravity waves was proven in 2015, when scientists working with the LIGO detectors in the US measured a distortion of spacetime that had been caused by two black holes merging deep inside the universe more than one billion years ago. The LIGO detectors are interferometers that are similar to the test set-up that Michelson used to disprove the ether, except that his lamp has been replaced with a laser gun, and the entire apparatus is thousands of times larger in order to achieve the necessary sensitivity. Gravity waves are so weak that we can only measure the ones produced by the most dramatic events in the universe. But following the discovery in 2015, we know that they must indeed be omnipresent.

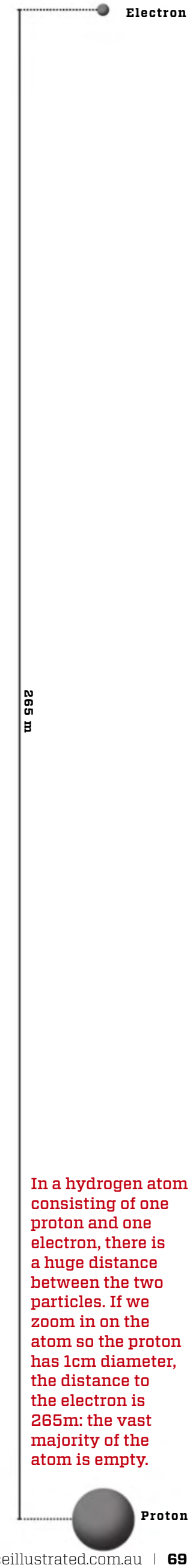
In his work with the general relativity theory, however, Einstein encountered a very different problem. In order to make his equations comply with the universe that we can observe, he had to introduce a constant. He didn't fancy this idea himself and subsequently described it as his "biggest mistake", but later observations show that a cosmological constant is indeed at play in the universe. Astronomers have proved that the universe is expanding, and that the expansion is accelerating. This means that there has to be a force that counteracts gravity. What produces this force remains one of the big mysteries, but it has been named "dark energy". In our small cube, the dark energy would also be present, just as it is in other places of the universe.

With his relativity theory, Einstein described the universe on a large scale. Other physicists of the 1900s took the opposite approach, zooming in on the tiniest of details, exploring the atom. And here were found new conceptions of what is going on in places where no matter is present.

Atom vacuum is full of energy

Look carefully at the full stop at the end of this paragraph. The printing ink of this punctuation mark consists of some 100 billion atoms. If we wanted to see one of them with the naked eye, we would have to enlarge the full stop to a diameter of 100m. And if we wanted to see the atomic nucleus, we would have to enlarge it to a diameter of 10,000km – the distance between the Equator and the North Pole.

In hydrogen, the most simple of atoms, the nucleus consists of a single proton which is orbited by one electron. The distance between the two particles is huge compared with their sizes. If we travel from the centre ▶



In a hydrogen atom consisting of one proton and one electron, there is a huge distance between the two particles. If we zoom in on the atom so the proton has 1cm diameter, the distance to the electron is 265m: the vast majority of the atom is empty.

of the proton to the electron, we will have covered only 1/10,000 of the distance by the time we reach the outer edge of the proton. As the electron is also much smaller than the proton, it is clear that the vast majority of the atom consists of space that is not inhabited by elementary particles. Indeed, this space makes up 99.99999999999999% of the atom's volume. It would, however, be wrong to say that it was entirely empty. The magnetic forces between the electron's negative charge and the proton's positive charge produce an intense electric field which fills the space between them.

The situation is the same if we zoom in even further on the proton. It consists of small elementary particles known as quarks. The quarks make up only a small portion of the proton's total mass, about 9%. The rest is energy generated by the forces at work between the quarks and the gluons and the other massless particles from which the proton is made.

During the first half of the 1900s came a new branch of physics, quantum mechanics, describing what happens at the atomic and subatomic levels. Quantum mechanics involves a series of ideas that immediately conflict with our normal, tangible way of seeing the world. One of them is to describe all particles, including elementary particles, as waves, and this has important consequences. In 1927, German physicist Werner Heisenberg introduced his uncertainty principle which, in short, declares that it is impossible to determine both a particle's location and its motion at the same time. We can consider this principle if we draw a wave on a piece of paper. We can define the wave's location by selecting a specific point on its curve. But based on this alone, we cannot know anything about the wave's size or its direction. Or the other way around: if we instead choose to establish the wave's size and direction, we cannot state an accurate single location at the same time.

It is very nice to be right sometimes.

PETER HIGGS,
after CERN physicists managed to find the particle he predicted and which provides other particles with mass.

The uncertainty principle also has consequences for the hypothesis concerning our small cube of "nothing". We have emptied it of atoms, and consequently of elementary particles, and so we can state their exact location as being not there, or "zero". However, that means that their energy cannot also be "zero", because that would be inconsistent with the uncertainty principle. Indeed, according to quantum mechanics, in our cube there will always be a very little energy present – known as "zero-point energy". A space of zero-point energy is hence also known as a "quantum vacuum". That is as far we can get, energywise. We will never be able to come any closer to "nothing".

Void is buzzing with activity

Particles come from nothing, exist for a brief moment, and return to nothingness. It sounds like magic, but it is also a consequence of quantum mechanics, which allows that two particles with opposite charges can occur spontaneously in a quantum vacuum and then neutralise each other after a brief moment. Physicists talk about fluctuations of "virtual particles". The greater and heavier the particles are, the briefer the time they exist. In this way, an electron and its antiparticle, a positron, can "jump" into reality and disappear again after 10^{-21} seconds – so rapidly that in the same time light would travel only the distance corresponding to 1/1,000 of the diameter of a hydrogen atom.

So on one hand the virtual particles are highly volatile, but on the other, they occur all the time. That is true anywhere in the universe – including within our small cube of "nothing". We can consider the quantum vacuum to be a seething soup of virtual particles with all kinds of wavelengths rolling about in all directions inside the cube.

The existence of the virtual particles was already predicted in the early 1900s, but not until 1996 was the prediction proven, using experiments which Dutch physicist Hendrik Casimir had proposed back in 1948. The idea was to place two metal plates in a quantum vacuum and slowly bring them together. When the distance becomes very narrow, the two plates will begin to attract each other. The reason is that the distance between the plates is now only suitable for the virtual particles, which have such short wavelengths, whereas all kinds of wavelengths will exist in the rest of the vacuum. The result is that the virtual particles exert a higher pressure on the exteriors of the plates than on their interiors, so the plates are forced against each other. The phenonomenon is known as the Casimir effect.

The experimental confirmations of the predictions of quantum mechanics form an important basis for the 'standard model', as we call physicists' description of everything in the universe. It contains both the particles that make up matter, and the particles that carry the forces.

Today, the existence of almost all the particles of the standard model has been proven, but up until 2012 there was still one important hole in the puzzle. The central player of the Higgs boson was missing, and hence also an explanation of why there is mass in the universe.

The ether stages a comeback

It was impossible for Peter Higgs to avoid crying as, from his seat in the third row of the CERN auditorium, he listened to the news from the scientists.. The fact that the particle whose existence he had predicted in 1964 would be discovered within his lifetime was simply too overwhelming for the 83-year-old scientist. And he was not the only one. Throughout the world, physicists shared his surprise and pleasure, because with the proof of the existence of the Higgs boson, the standard model had been saved.

"It is very nice to be right sometimes," Peter Higgs said, when he regained control of his emotions.

The Higgs boson produces a field that exists throughout the universe, and so it is omnipresent in the same way as the ether in which philosophers and scientists had believed for millennia, until it was killed

off in 1887. The Higgs field differs from other fields in the world of physics by not varying in strength, and in not having any direction. It is often described as a syrup that sticks to some particles, but not to others. Elementary particles such as electrons and protons are affected by the Higgs field, which thereby provides them with mass. Photons of light, on the other hand, speed through the field unaffected, and so have no mass.

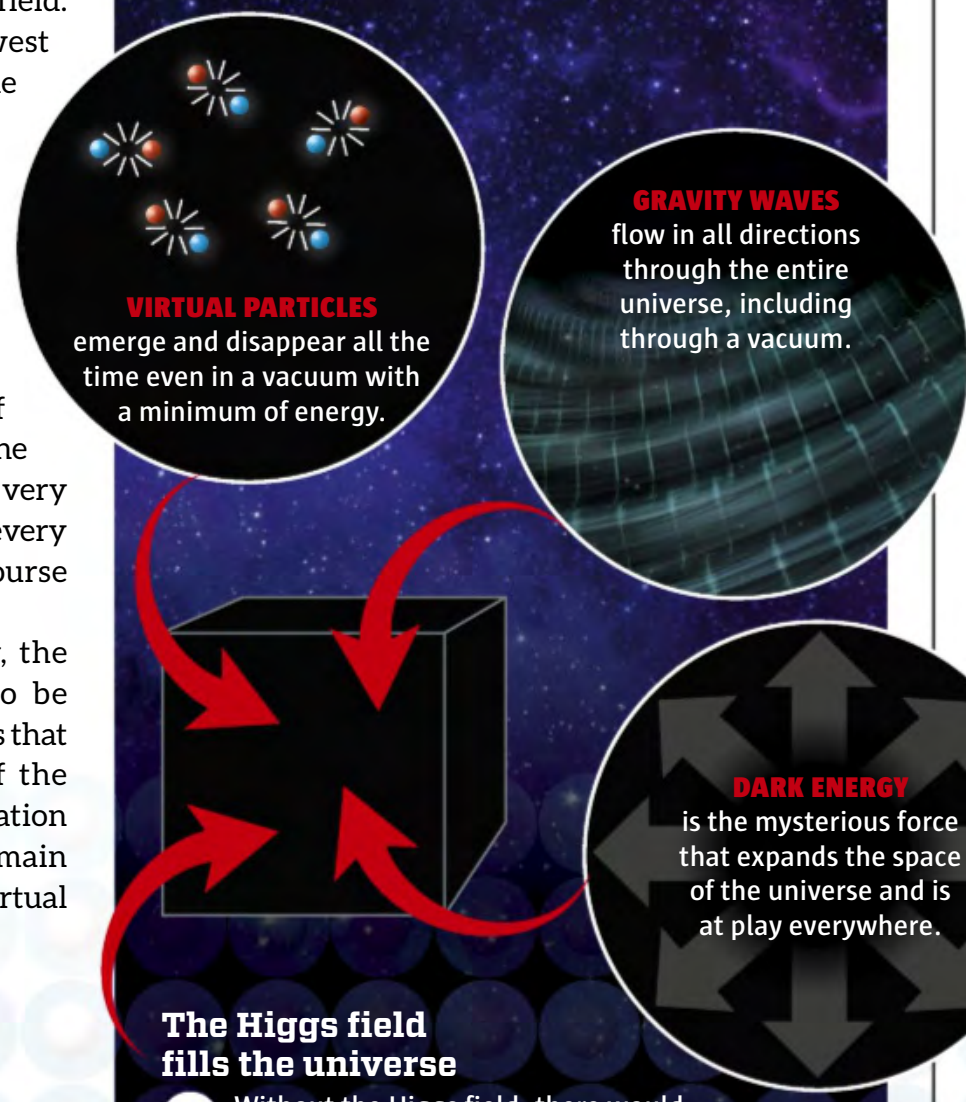
The comparison with syrup allows us to imagine the Higgs field, but Peter Higgs is not a fan himself, as it could lead to the misunderstanding that elementary particles lose energy and speed as they travel through the field. That is not so. The Higgs field represents the lowest energy that can exist in a vacuum, so it is not possible to transfer energy from the field to the particles or vice versa. Peter Higgs would rather compare the field with the way in which light is refracted as it passes through glass or water.

According to the theory of the Higgs field, it exists only at temperatures of less than 10^{17} degrees, and this means that the field has not always existed. In the split second after the birth of time and space in the Big Bang, the temperature of the universe was even higher. But if we disregard this very first billionth of a second, the Higgs field has filled every corner of the universe at all times – and that of course also goes for our small cube of "nothing".

So with the knowledge that we have today, the question "Does nothing exist?" would have to be answered with a "no". Modern physics has taught us that even if we remove all matter from a region of the universe and isolate it from electromagnetic radiation coming from the outside, the Higgs field would remain – in addition to gravity waves, zero-point energy, virtual particles, and probably also dark matter. SCI

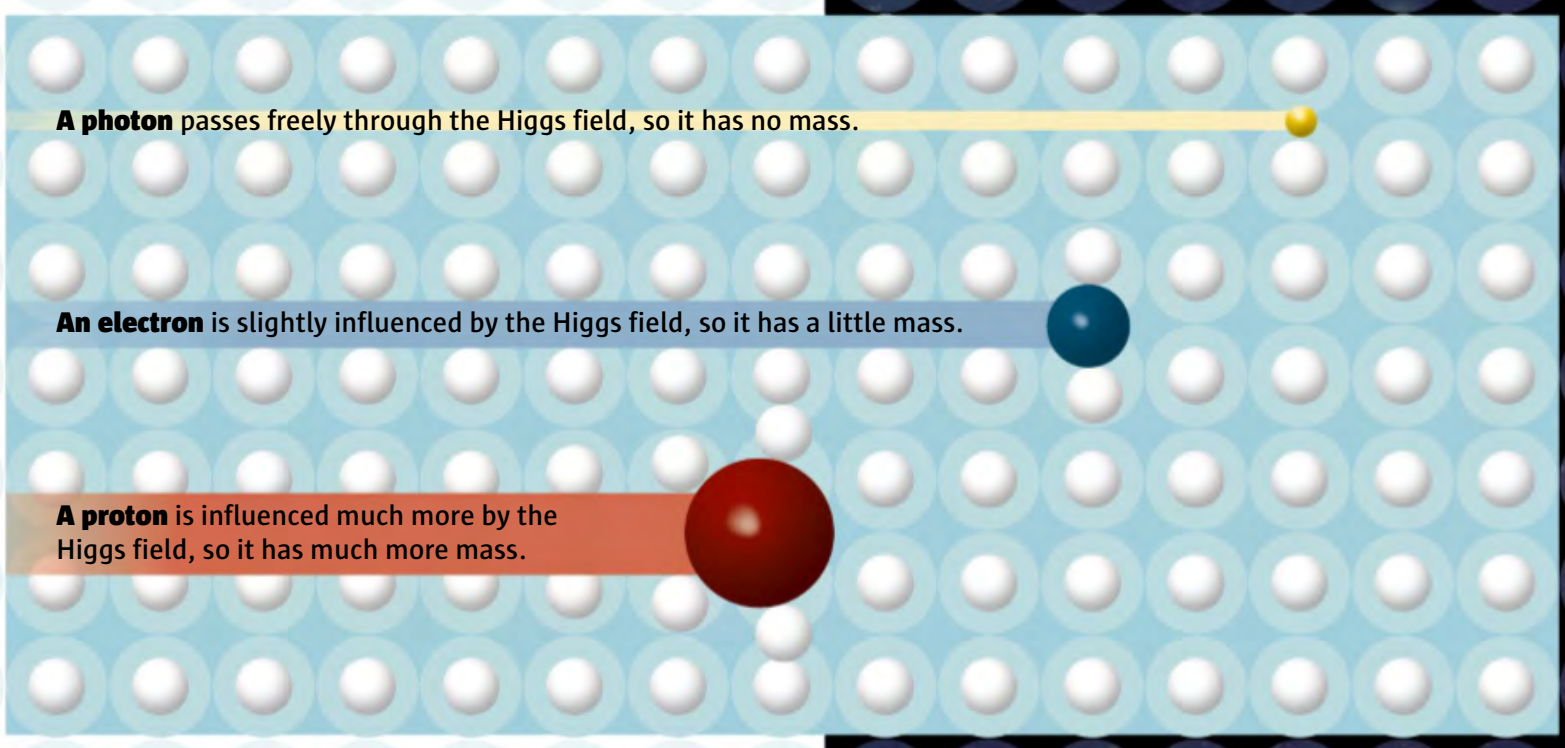
Modern physics fills the void with activity

Both the theory of relativity and quantum mechanics have provided us with new knowledge about what happens in a vacuum. And it is not nothing. The seemingly empty space is pervaded with energy and vibrates with volatile particles – and behind it all is the Higgs field, as the omnipresent ether of space.



The Higgs field fills the universe

Without the Higgs field, there would be no mass in the universe and so no elementary particles, no stars, and no planets. The Higgs field permeates all of space, even regions that have been emptied of matter.



The Higgs boson created the Higgs field one trillionth of a second after the Big Bang. Ever since, the field has filled all corners of the universe, ensuring that elementary particles have mass.

FROM THE SCIENTIFIC ARCHIVES

PRESENT STATUS

GRAPHENE IS THE SUPER MATERIAL OF THE FUTURE

Today, iron and steel remain some of the world's most common materials, but scientists are struggling to control and mass-produce a new material that could change the world: graphene. With a thickness of a single carbon atom, a strength that is 300 times that of steel, and the ability to conduct electricity without any resistance, scientists hope to revolutionise anything from air traffic to batteries.

SHUTTERSTOCK

Made from graphite, graphene is the world's thinnest material.

RITZAU SCANPIX

Mystics help a Spanish miner find one of the iron ore veins that had become more difficult to identify by the 1300s.

By **Pia Konstantin Berg**

Plague and war caused European iron rush

The Hundred Years' War between France and England is raging, and their armies thirst after iron for body armour and weapons. However, the mining industry suffers from the plague, and the difficulties in iron supply see prices skyrocket. Mines must find new methods to meet the iron rush.

The quiet whisper of the autumn wind is suddenly filled with the clatter of metal from heavy armour and weapons. In 1356, thousands of French soldiers and knights march side by side towards yet another one of the Hundred Years' War's bloody clashes – the Battle of Poitiers.

Many tonnes of metal were used to equip this army. Depending on their rank and wealth, the knights either wear an plate armour suit weighing almost 25kg, or chain-mail armour of some 15kg. Head, hands, and feet are also covered in steel. The 500 knights combined are wearing at least eight tonnes of metal, and that's without counting all the steel that was used to equip the 17,000 foot soldiers and 3,000 bowmen.

Nevertheless, the heavy armour is not sufficient protection for the 2,500+ soldiers who will soon be killed at Poitiers – including much of the French knight aristocracy. The king was captured.

Bloody warfare in Europe

Since 1337, France and England had fought for the French Crown. Both nations rearmed as never before to get the upper hand in the long conflict. The rivalry was particularly evident in the metal production of the day, an industry which accelerated tremendously.

The increased exploitation of resources was necessary to obtain the many tonnes of iron required for weapons and armour. English mines were unable to meet their king's demands, so the country had to import thousands of tonnes of iron from the Basque Country and the Austrian province of Styria.

Historians estimate that a well-equipped army required about 500 tonnes of iron to prepare for war, but in ▶

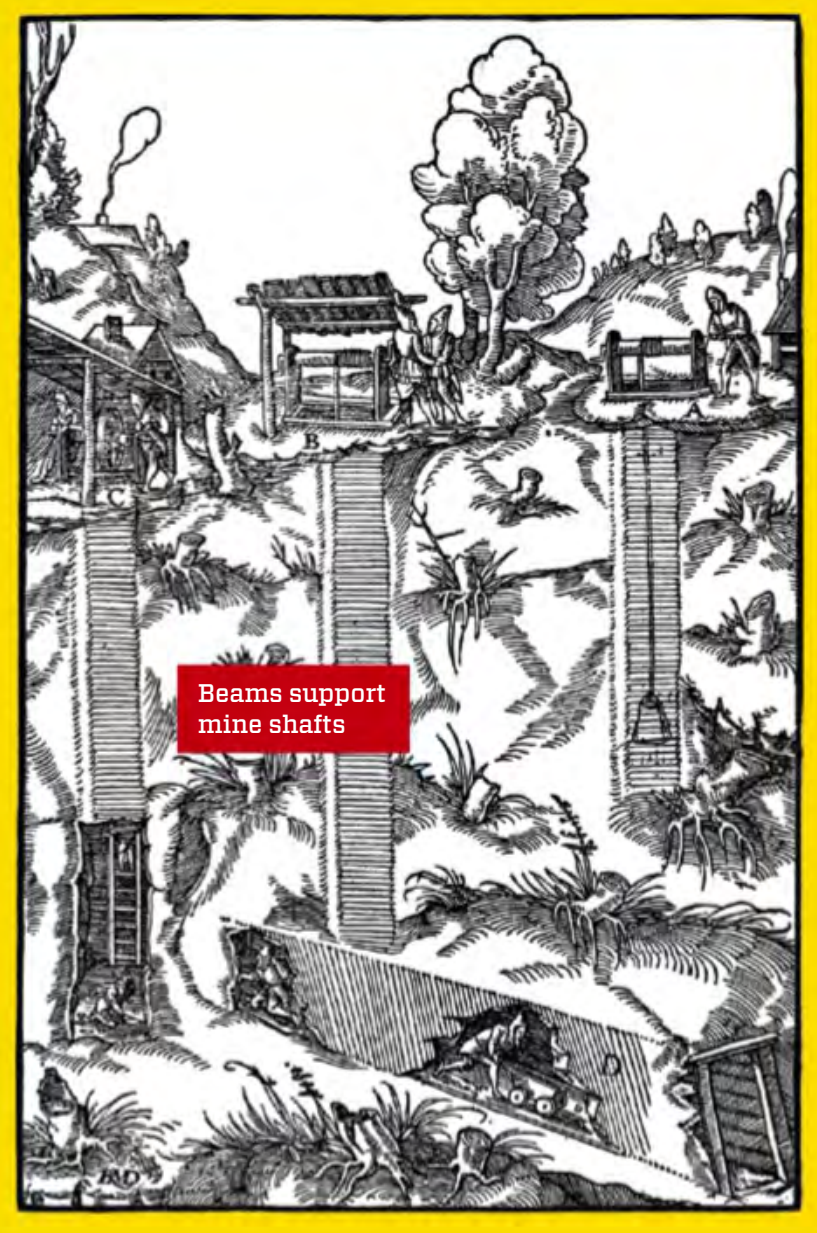
SHUTTERSTOCK

If iron ore is subjected to very high temperatures, the material reacts with carbon to become pig iron.

The mine was powered by water

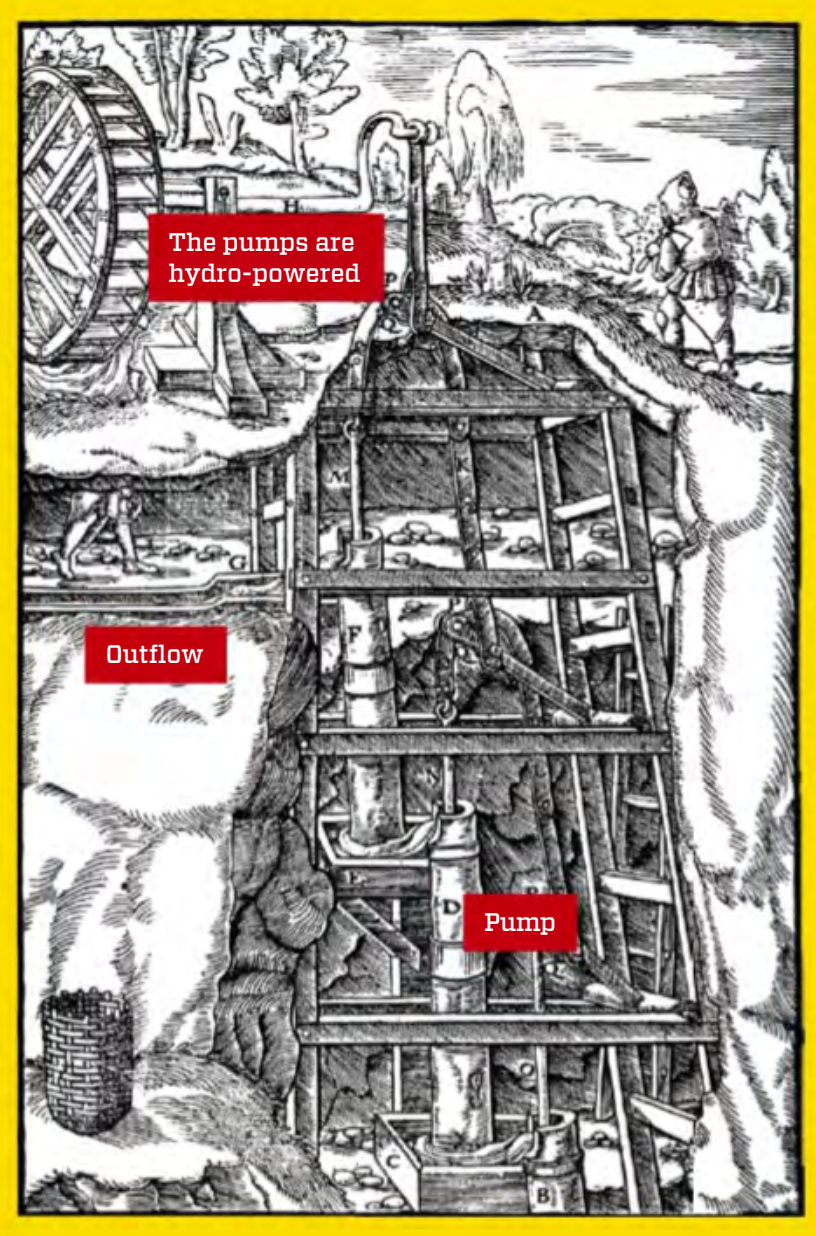
1 MINING REQUIRES KNOWLEDGE

In 1556, German scientist Georg Bauer accumulated all the mining knowledge of the time in a book aimed particularly at mine operators: "De Re Metallica". According to Bauer, ore extraction is not only a question of luck and hard work – it requires a special knowledge of philosophy, arithmetic and architecture. Most deaths in mines are due to carelessness, he claimed.



2 NEW PUMPS DIVERT WATER

For several years, Georg Bauer had been working with mines and miners in the Ore Mountains in South-Eastern Germany, learning all the working processes and the use of the right tools. Like the Romans, Bauer recommended mining hard rock by means of fire. Fast cooling with water makes the rock explode. The book also included designs of pumps which would be able to divert incoming water.



reality twice as much was needed to account for production waste. But the iron extraction was not unproblematic. Where previously it had been possible to mine iron ore relatively close to the surface, by the 1300s the majority of the most easily accessible ore layers had been exhausted, and the iron-seeking rulers could only dream of getting at the deeper ore. Nobody yet knew how to divert incoming ground water from deeper mine shafts to enable deeper iron to be brought to the surface.

Plague makes prices rise

Hundreds of years previously, in Roman times, miners could establish deep shafts leading to the ore-bearing layers. They had solved the problem of incoming water by means of linked water wheels operated by slaves who hoisted the water from the bottom of the mine to keep the galleries dry. Archaeologists have discovered a Roman mine in Spain with evidence of 32 water wheels that combined into a lift of almost 80m.

But after the collapse of the Roman Empire, this mining knowledge was lost,

IRON ORE IS CRUSHED AND WASHED

3

When the ore had been retrieved from the mine, it was to be crushed and washed. Georg Bauer had several suggestions regarding the design of the machinery that was to pulverise the ore by means of hammers.

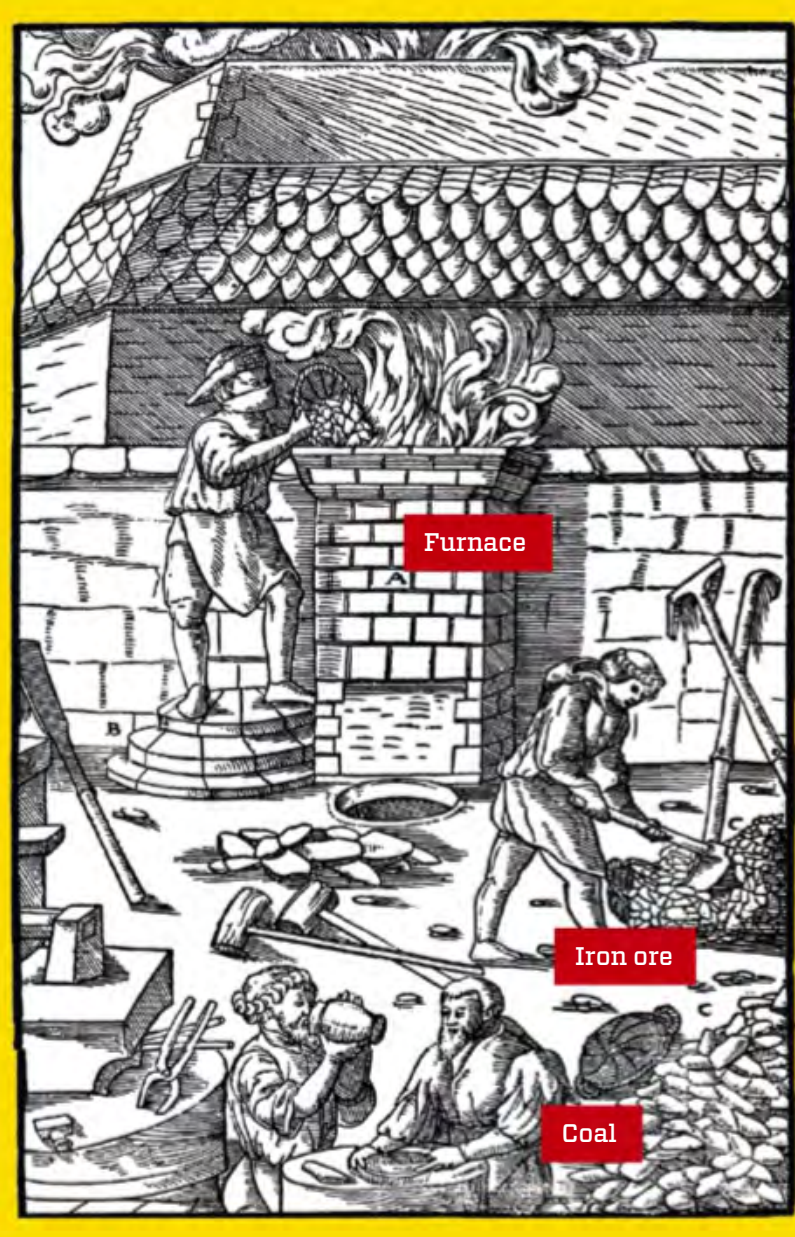
Bauer recommended the use of water to wash out soil and other impurities. In this way the production of slag – a waste product of the smelting process – was reduced.

THE RIGHT FURNACE SMELTS THE ORE

4

The smelting furnace was to be built of bricks or light stones, Bauer explains in his book. By means of detailed woodcut prints, he demonstrated how it is done.

"De Re Metallica" was not published until one year after Bauer's death in 1555, as the woodcut work took a long time. Bauer's work was the standard volume of the mining industry for the next 250 years in ironworks and among metallurgists.



SPL/IMAGESELECT

and in addition the plague raged in the mid-1300s, killing 30-60% of the European population, according to historians. And of course many miners were among these victims of the Black Death.

The combination of war and plague made the price of iron rise drastically throughout Europe; prices more than tripled between 1350 and 1400, Belligerent nations were forced to think outside the box, and in the late 1300s they began to make considerable efforts to improve the technologies behind iron extraction.

Mine shafts become deeper

The most important innovation was water or horse-powered pumps that were to divert water from the mines. Suddenly flooded mines which had been closed since Roman times could be reopened. By the 1400s, English miners had managed to establish new mines at depths up to 50m.

Soon, iron extraction thrived in Europe, but one particular region stood out: the Austrian province of Styria, which produced some 2,000 tonnes of iron a year – twice as much as all England combined. ▶

Modern production, of course, dwarfs such figures – modern Austria produces more than two million tonnes of iron annually. But back then the 2,000 tonnes were enough to make Styria one of the leading iron producers of the time.

This was evident in the forests, where Styria's miners harvested timber to support shafts and galleries. Near the town of Eisenerz, workers removed so much wood in the 1400s that the German Roman Emperor was forced to issue a "Waldordnung" – woodland rules – to regulate logging so that the future of the mining industry would be assured.

Mines are death traps

Iron production required very hard work. The mines were dark, and dust was a constant menace. The particles entered and stuck in the miners' lungs, causing chronic headaches, shortness of breath and eye irritation.

Apart from the dust, the miners also needed to beware of the constant danger literally looming above their heads every day. They risked bone fractures, disablement or death if they were struck by falling rocks or fell from their unsteady ladders. If supports collapsed, or flooding took them by surprise, the miners could be left in desperate situations.

As a consequence it was in the mines of the Middle Ages that the seeds of the first trade unions were sown. It was German workers in particular who contributed to improving safety through the establishment of guilds or "Gewerkschaften". The spokesperson for a gang of workers could negotiate working conditions with the mine owner.

Soldiers attack mines

Working conditions seemed less significant, however, when the miners became directly involved in the ruler's disputes. The wars of the early 1400s were more destructive than ever. The German Roman Emperor's army destroyed the Czech mining towns of Kutná Hora and Havlíckuv Brod during the Hussite Wars (1419-1434). Local miners and blacksmiths were so key to the enemy's ability to wage war that the soldiers killed them – after filling the mine shafts with soil and destroying the smith's shops.

Miners were valued experts who in times of peace could travel freely from country to country to work. Again it was

BRIDGEMAN IMAGES

German workers who took particular advantage of this opportunity, settling in the eastern region of the Alps and elsewhere. Local rulers were happy to receive the newcomers, providing land so that workers and blacksmiths could build workshops and cabins for their families. Indeed the arrival of the miners not only assisted in the extraction of the valuable ore in the ground below their land, it also made for healthier state coffers. The rulers received considerable taxes in payment for the miners being allowed to extract the ore.

The Hundred Years' War ends

Miners and blacksmiths were also responsible for the equipment of the Frenchmen who in 1356 launched one daring attack after another at Poitiers – encouraged by what they believed was an English retreat. But despite being outnumbered by the French, the English stood firm and finally forced the French to take flight. The French king, John the Good, failed to escape the field, and died in captivity several years later.

Not until 1453 were the French able to oust the enemy, causing severe English losses at Castillon. With the Hundred Years' War over, the demand for iron fell. But not for long. As the monk Bartholomeus Anglicus had said much earlier: "In many ways, iron is more valuable than gold." The iron rush would break out again. SCI

In the Battle of Poitiers in 1356, the iron armour of the combined French knights weighed a minimum of 8 tonnes.

BRIDGEMAN IMAGES

Iron was in short supply during Medieval wars.

The Church also demanded iron

European armies were yearning for metal, but peasants, artisans and the Church also needed iron.

Though much of the metal production of the time was used for weapons and armour during the Hundred Years' War, metal was also in demand among civilians for uses such as for peasants' ploughshares, horseshoes and artisans' tools and nails.

Church building also required iron for lifting systems and large, heavy church bells. In 1341, when the Newland Church in England was modified, the Bishop of Llandaff was keen to get his hands on some of the Forest of Dean's profitable iron mines. He demanded that King Edward III give one tenth of the neighbourhood's extracted iron to the Church.

Moreover, archaeological excavations in English cemeteries have revealed that the bells were often cast during the construction work. Bell casters frequently went from church to church to offer their services.

Instant Expert: thunder & lightning

Red-hot explosions produce shock waves of sound

Thunder and lightning cause both surprise and fascination, but scientists still do completely understand the weather phenomenon in every detail. At any given time there are some 1,800 thunderstorms taking place, with our planet struck by up to 6,000 lightning bolts every minute, causing damage to nature, structures, and people.

Lightning is assumed to have been an important element in the origin of life, and early humans probably got fire from lightning strikes. They must have considered lightning a blessing from the gods, but now we know that behind thunder and lightning there are natural processes that scientists still do not yet completely understand.

Thunderstorms have to do with the formation of major shower clouds in unstable air. The instability typically involves heating from Earth's surface in a situation where there is cold air at higher altitudes of the atmosphere. Bubbles of air that become warmer than the surrounding air will rise to form clouds, intensifying upward flow even more. The process is known as convection and is very common – particularly near the Equator and above very large land masses.

Convection is first observed as white, dome-shaped cumulus clouds. As the process intensifies, the cloud grows upwards, At some point, the cumulus cloud turns into a shower cloud, which could develop into a thundercloud with a characteristic fan of ice crystals at the top – a cumulonimbus or Cb. But whether a cumulonimbus will cause a thunderstorm or not is difficult to say. Only a few hundred metres of growth at the top of the cloud might make the difference. Lightning bolts are brief, very violent electric discharges in and between clouds and the surroundings. Lightning bolts can be sparked in the cloud, travel from cloud to cloud, from cloud to air, or end up as lightning strikes between clouds and Earth's surface. The voltage difference can be hundreds of millions of volts and the amperage some 200,000 amps.

The total energy transmitted in the microseconds during which lightning strikes differs, but the energy corresponds to about five 100W light bulbs turned on for a month. Only a slight fraction of the energy is left where lightning strikes, depending on the electrical resistance of the object struck. The majority of the energy is left in the lightning channel between the cloud and the ground. The temperature of the lightning is 15,000-30,000°C – up to around five times hotter than the Sun's surface.

The immediate and intense heating of the air around a lightning bolt causes shock waves of sound: thunderclaps. The rumbling is due to the time gap between shock waves from different places in the lightning channel, and to sound waves reflected between clouds and ground.

LIGHTNING BETWEEN CLOUDS

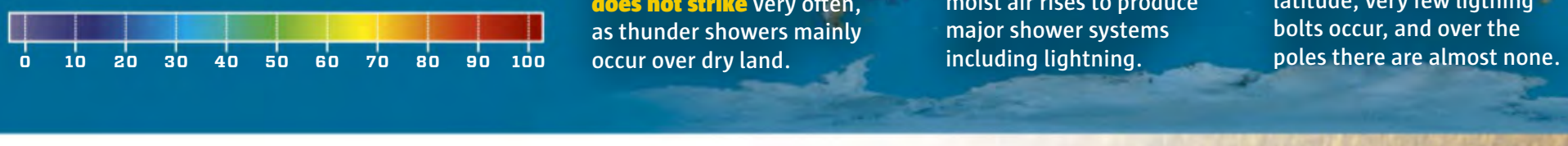
How lightning originates

Lightning originates in cumulonimbus clouds that include large quantities of ice crystals and water drops. Negatively and positively charged particles are produced in countless collisions and friction between the ice crystals and water drops, so voltage differences develop. When the voltage difference becomes too great, lightning bolts will be produced in order to neutralise the electric charge.

DOUGLAS E WALKER/GETTY IMAGES

// AFRICA EXPERIENCES THE MOST LIGHTNING BOLTS

Via satellites used to measure lightning discharges, meteorologists have learned a lot about the global distribution of lightning strokes. Scientists estimate that every day, some 40,000 thunder showers are produced throughout the world, most of them close to the Equator, where the heating caused by the Sun is very intense, so that heat and moist air rise to produce major shower systems.



LIGHTNING IN THE CLOUD

Positively charged particles at the top of the cloud

Negatively charged particles at the bottom of the cloud.

1 **When the insulating ability** between the areas that separate electric charges collapse due to the major voltage difference, the electric charge will be neutralised.

2 **Lightning strokes** most frequently begin from the top by a series of predischarges of intensely charged air molecules taking leaps of about 50m towards the ground, forming a lightning channel.

LIGHTNING FROM CLOUD TO GROUND

3 **Close to the ground,** the electric field between the tip of the lightning channel and conductive objects on the ground will trigger upward discharges: “streamers”.

4 **The system short-circuits** when the upward and downward discharges meet, causing discharge in the shape of lightning.

// BALL LIGHTNING AND JETS

The myths and reports about ball lightning are numerous – by far outnumbering the number of scientific dissertations. As it is a rapid and rare phenomenon, only a few images exist, and there is no accepted explanation of it. One of the most widely held theories involves ball lightning consisting of glowing plasma held together by a magnetic field produced in charged air. The reports almost all involve ball-shaped bright objects the size of anything from tennis balls to soccer balls, which move around and then finally disappear – sometimes with a bang.

Another relatively newly discovered type of lightning is atmospheric or elevated lightning known as sprites, blue jets, and elves. Sprites are a carrot-shaped network of red discharges from the top of the clouds and up to an altitude of 90km. Blue jets are conical discharges which rapidly (up to 100km/s = 360,000km/h) dart upwards from thunderclouds to an altitude of some 40km. Elves are bright rings that spread outwards for millionths of a second from the top of sprites at altitudes of 90km.

Lightning in the atmosphere

Sprites, blue jets, and elves are three types of electric discharges at high altitudes in the atmosphere.

MIKKEL JUUL JENSEN

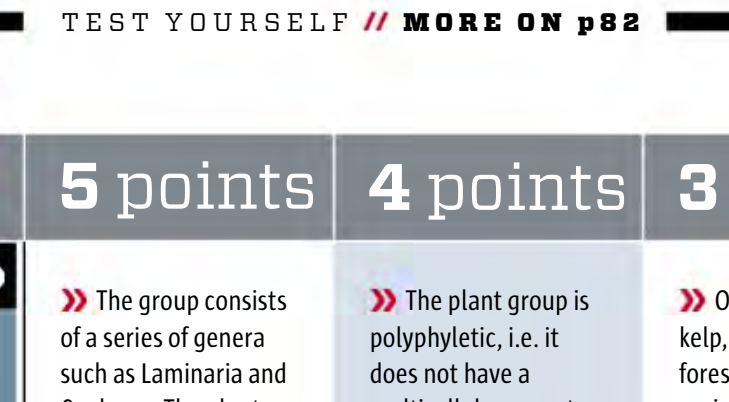
TRIVIA COUNTDOWN

Earn more points using fewer clues to answer the questions. Answers below – don't peek!

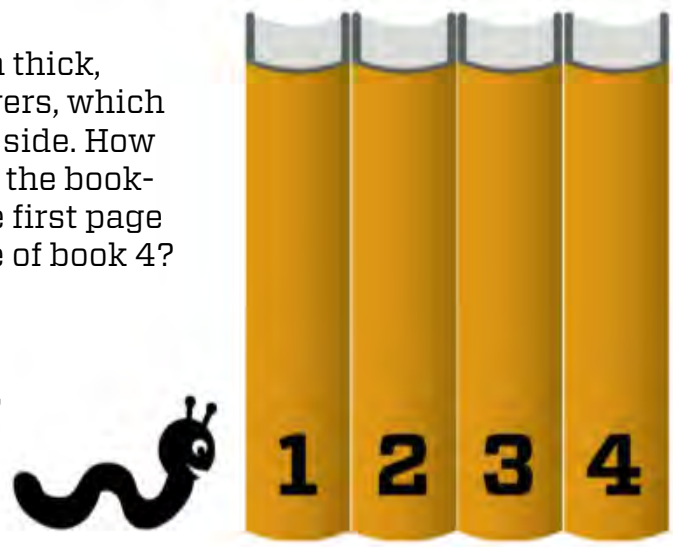
	5 points	4 points	3 points	2 points	1 point
BIOLOGY **1. Name this group of plants**	The group consists of a series of genera such as Laminaria and Caulerpa. The plants grow all over the world.	The plant group is polyphyletic, i.e. it does not have a multicellular ancestor. They are also known as macroalgae.	One of the species, kelp, can form large forests in temperate regions including 50-60m-long plants.	The plants play an important role in many of the world's kitchens. The nori variant is often used for sushi.	Many species can be observed on beaches, where they often wash up, but the sea is their real habitat.
ASTRONOMY **2. Name this heavenly body**	This heavenly body has two small moons, Nix and Hydra, which were spotted by the Hubble telescope in 2005.	The biggest moon, Charon, has a diameter of 1,200km, so big that the object is almost a double planet.	Until 2006, it was considered the outermost and smallest Solar System planet located in the Kuiper Belt.	The International Astronomical Union now categorises the heavenly body as a new type of object: a dwarf planet.	The dwarf planet shares its name with a cartoon dog from 1930 – the same year in which the body was discovered.
PHYSICS **3. Name this colour**	Light of this colour has wavelengths in the spectrum between 625 and 740 nanometres.	Huge stars such as Antares and Betelgeuze are this colour due to a relatively cold surface temperature.	Pigments of this colour have been extracted from small cochineals. The modern version is E 120.	The Russian name of the colour, krasny, is closely related with the word for beautiful and describes a central Russian square.	In additive colour mixing (as used in TV displays), it is one of the three primary colours. The others are green and blue.
GEOLOGY **4. Name this mountain**	The 1,281m-high mountain is located at. 40° N and 14° E near the country's third biggest city.	The sinking of the African continental plate under the Eurasian plate produced the mountain.	It is part of the Campanian vulcanic arc close to Naples and is considered one of Earth's most hazardous volcanoes.	In 79 AD, the stratovolcano had an explosive eruption that covered the city of Pompeii 10km away in ash.	In Roman times, the volcano was called Vesaevus and Vesbius. The mountain often lends its name to pizzerias.

LOGIC

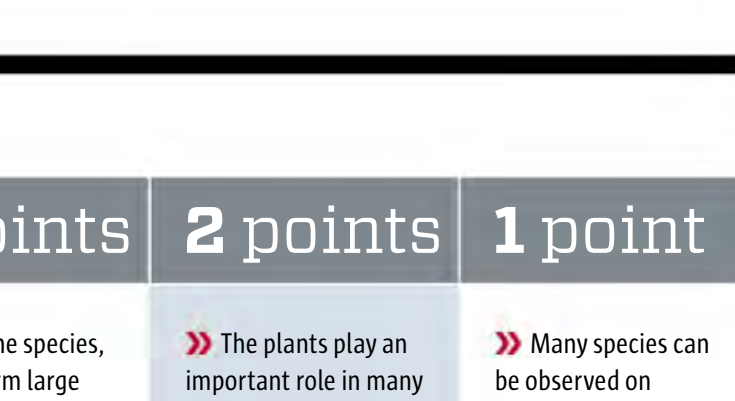
9 What does the last domino piece look like?



10 Each book is 5cm thick, including the covers, which are 0.5cm thick on each side. How many centimetres must the book-worm consume from the first page of book 1 to the last page of book 4?



More questions on p82, and answers on p11...



11 Which of the possible answers is the correct fourth clock in sequence?

12 All three pairs of scales are balanced. How many rabbits must there be on the bottom right scale?

TRIVIA COUNTDOWN ANSWERS

1: Seaweeds **2:** Pluto **3:** Red **4:** Mount Vesuvius

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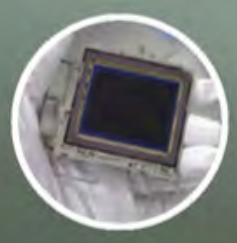

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ALSO IN THIS ISSUE...

Test Yourself

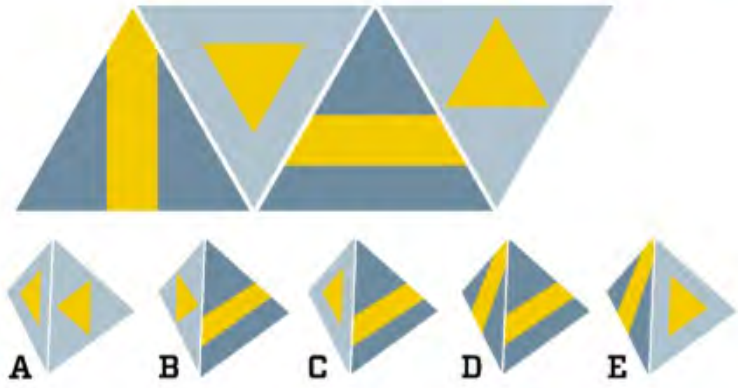
SEE THE ANSWERS ON PAGE 11

MIND-BOMBS!

Solve problems designed for different types of intelligence and find out in which you excel.

Editor: **Malene Breusch Hansen** //
Text & Art: **Anker Tiedemann**

VISUAL INTELLIGENCE



1 How many of these tetrahedrons (three-sided pyramids) can be created when the pattern at the top is folded?

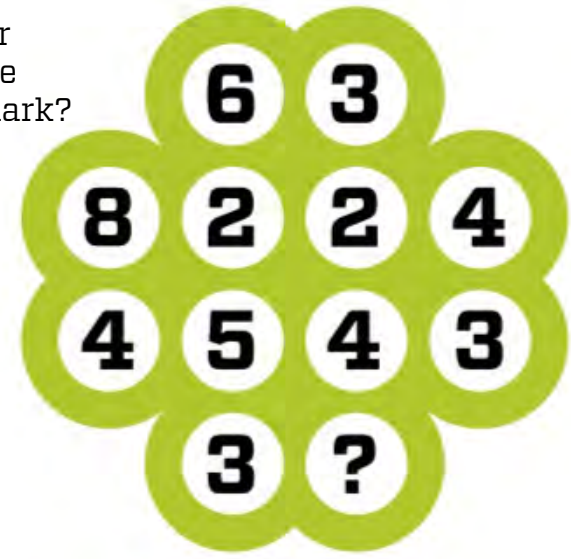
2 Which number has been cut in four pieces?

3 Spot three errors in the reflected image below.

4 In how many different ways can you use a straight line to divide the figure into two parts of the same size?

NUMERACY

5 Which number replaces the question mark?



6 Place the numbers 1-10 so the total of the numbers surrounding each black circle is 20. There is more than one answer.

7 Insert the missing numbers so that the sum of all horizontal and vertical rows and of the two diagonals is 65.

17	24			15	=65
23	5		14		=65
4		13		22	=65
		19	21	3	=65
	18	25	2		=65
=65	=65	=65	=65	=65	=65

8 How many times does the number 5 occur in the numbers 1-100?

More questions on p80, and answers on p11...

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